University of Central Florida

Department of Electrical & Computer Engineering

EEL4915

SENIOR DESIGN II

FriendlyEyes

Authors:

Joseph Brown - BSCpE Candidate

Michelle Dubon – BSEE Candidate

Victor Lopez – BSEE Candidate

Manuel Parilli Nunez – BSEE Candidate

Advisor:

Dr. Lei Wei

April 20th, 2022

UNIVERSITY OF CENTRAL FLORIDA

CONTENTS

Table of Figures

List of Tables

1 EXECUTIVE SUMMARY

In today's era, technological progression is constant, and they're very few ideas that have not already been developed and brought to the marketplace. Projects are built on the pillars of innovations, accessibility, and usability and we want to use those pillars to make a project that will be innovative, make a product that is assessable to all users, and then level up prototypes to marketable products. Further, being able to replicate or make these changes to existing products, while reducing production costs is the main goal in any industry. Our team considered several different already existing technologies and chose to innovate and while cheapening products that already existed.

Finalizing an idea for our senior design project was no easy task since we all had different focuses and expectations. Ultimately, the idea that was decided on was a vest that can help blind individuals detect objects around them. A variety of sensors would be attached to a vest that would detect nearby objects. The vest would have vibrational motors distributed around it that would vibrate at combinations of different frequencies and intensities when approaching obstacles or when moving objects are headed its way and would help blind individuals navigate space by letting the user know where not to go.

This project aims to accomplish a walking guidance system for blind people to commute easily and avoid obstacles and people in the process. Further, there are some stretch goals planned such as using a sensor that will be able to detect when the person is approaching stairs, and we want to add an emergency system so if a person falls, a message will be sent to their emergency contact. This system will initially be located on a vest that the person will use as a part of their clothing. After we finalized out design, including the size of the PCB and how many components we would have in the project, we finally implemented and created a better and more comfortable way to carry all the necessary parts. This document contains the extensive research and design choices that led to the construction of the Friendly Eyes vest.

To begin this document, specifications and requirement constraints are described. The specifications needed to be reasonable and realistic so that the group can keep following and meeting them until the end of the building of a prototype. Following this, extensive research was conducted into each subsystem of the project. Once the research was finalized, the component selection was explained, and the final components were highlighted. Due to the rapidly changing nature of technologies like sensors and microcontrollers, there may always be the possibility that the project might have last-minute changes in the components for the project to be as fresh and innovative as possible. Lastly, the design process for hardware and software will be explained thoroughly. With any design process, there should be a corresponding testing procedure to validate that the components work together in the Friendly Eyes prototype.

2 DESCRIPTION

FriendlyEyes is a vest in appearance, however, it offers a variety of sensors to help the visually impaired move around their environment without the need of a cane or the use of their hands to navigate their surrounding environment. Friendly eyes has three different sensors located on the vest around the user's abdomen area. These three sensors tell the microcontroller or the brain of the system when objects are either coming towards the user or if the user is going to collide with an object. In response, the microcontroller will tell the motors to vibrate to inform the user that they must stop in order to avoid a collision. The vest will be lightweight, will be usable for a long period of time, and will be safe to use. The goal of this vest is to ultimately help those who are visually impaired live a more fulfilled life by giving them a larger range of navigability.

2.1 Background & Motivation

According to the World Health Organization, roughly 39 million people are considered blind and another 246 million have a vision that classifies them as legally blind. Additionally, although the walking stick for the blind was invented almost 100 years ago, there has been little to no improvement even though there have been major improvements to nearly almost every aid. Further, improvement in technologies like sensors, cameras, and prosthetics should have aided in the further development of a more advanced walking stick but hasn't. One of the teammates in the project met a blind lawyer who said that the biggest difficulty of using a walking stick is that they must use their dominant hand to navigate, leaving their weaker hand to other important things like answering the phone or holding on to handrails. Also, the fact that a person's hand is always occupied is lessening the quality of life of the individuals who must always rely on the walking stick to navigate. To improve the visually impaired's quality of life, the team has designed and built Friendly Eyes, a wearable that would allow those with visual impairments to detect the world around them hands-free so that they can keep both their hands free for daily life.

Further, from our exploration of other products that are like our intended prototype, it was understood that many project were either still in the prototyping stages and had get to hit the market. Companies and projects that promised to have a product that was accessible, affordable, and readily available, seem to not continue with their promise and the product never goes into production due to the high cost and other factors. The beyond the main motivation of making a product for those who are visually impaired, the group wanted to be able to complete this project with the skills and knowledge that has been accumulated at the University of Central. Ultimately, the goal was to make a vest was equal or better to already existing devices that would help the blind or partially navigate the world around them.

2.2 Objectives

The main objective that we are trying to accomplish as a team in this project is to create an intelligent vest for any person who has visual problems and needs help doing routine activities such as commuting from their home to the local groceries store. In order to complete the project, we implemented a variety of components such as batteries, sensors, microcontrollers, digital signal processing, filter and integrate circuits. Other components that we could integrate into future versions of Friendly Eyes are Bluetooth, a global position system (GPS), and a GSM module, a mobile telephone technology that provides data to a remote network.

From previous background and some investigation, we set the objectives of this project to be:

- Provide a walking guidance system that is affordable for users.
- Design and build a PCB that will be used as the main controller.
- Create an interface where we can use a sensor to detect obstacles, people and stairs.
- The system will provide feedback to the user by making the wearable vibrate.
- The system should be small and have a light weight because it will be on a vest and later a vest and a hat with wireless communication.
- The system should be able to fall to the ground, detect the fall to send an alert, and keep working after.
- The system is built with materials that are easy to find for mass production.
- The system should be able to detect the distance between its user and any obstacle within its range.

2.3 Proposed Working Mechanism

In order to accomplish these objectives, we plan on leveraging sensor technology to create an image that a microcontroller can use to devise what the best direction to follow will be. Our system will do so by performing calculations on input of 3 different sensor mechanisms oriented to accomplish a different task each.

Our focus in the project is to give a clear image of the close proximity to the user. For that purpose, we integrated hardware, software, and the physics of wireless transmission to feed vibrating motors an output, indicating an obstacle-free path to follow. We devised a sensor which we could program to take periodic sweeps of its area of coverage, to then time-average the results, perform a Fast Fourier Transform (FFT) from which to compute a Power Spectral Distribution (PSD). In principle and practice, we were able to extract information on the location of objects from this PSD by setting up an acceptable threshold because it contains the frequency at which its pulse returned with the most power, thus giving perspective on the distance and even its angle.

Afterwards, we did cover the possibility of people or objects moving in the user's direction, for which a simpler sensor may be used to detect when a threat enters a predefined perimeter.

Finally, we did also account for the possibility of having a flight of stairs or a ledge, we did include a sensor that will allow us to keep track on changes in the level of the ground.

From here and through the rest of the development stages of our proposed implementation for the idea was finalized, and we talk about its advances by breaking them up in 4 different subsystems, which in themselves will scale to manage more subsystems and peripheral functions. These will all interact with each other in one way or another, which is why a system-level description will help us make easier descriptions, references, and callbacks, while making it easier for readers to follow along our design process.

Figure 1 below is an effort to illustrate graphically the main relationships that will be discussed in the text.

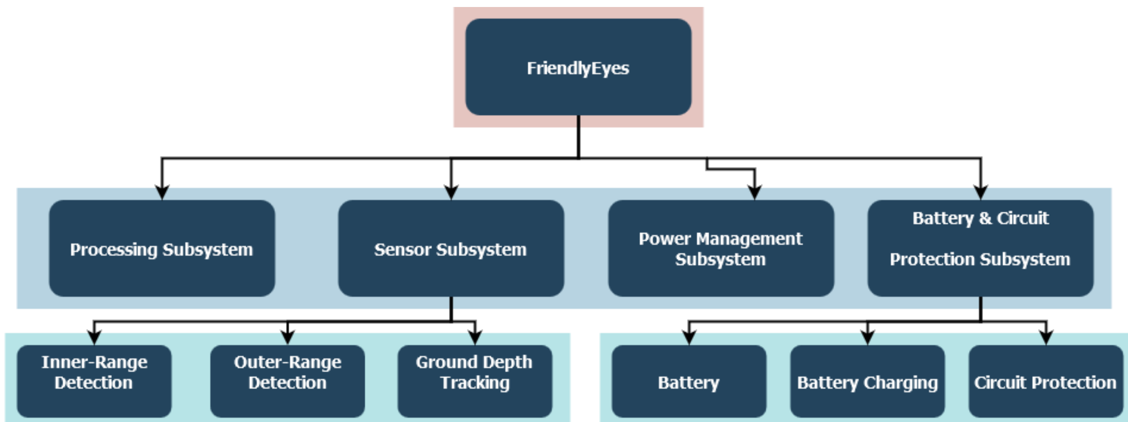


Figure 1: Friendly Eyes Relationship Tree

2.4 Requirement Specifications

The requirement specifications that we took into consideration are shown in the tables below. Key specifications, extended hardware specifications, and extended software specifications were extensively thought of and summarized in the tables below. All requirements in each of the tables were picked to further the goals of keeping this project budget friendly, environmentally friendly, and user friendly. There has been a major attempt to incorporate as many fresh and innovative technologies out in the market today but also incorporate technologies that have a long history of successful functionality. Like any rapidly changing nature of a project in the research and prototype phases, some of the specifications many change as more research is conducted and the project naturally progresses. That being said, it is imperative that we select reasonable expectations now so that they do not change to drastically in the future.

2.4.1 Summary of Key Specifications

Below (Table 1) is a summary of the key specifications that should be met at the end of the prototyping phase.

1.1	Friendly Eyes will be able to measure its range from objects located between 30 cm and 7 m.
1.2	Friendly Eyes will use this data to output a localized vibration in less than 2 seconds.
1.3	Friendly Eyes will be powered by a rechargeable battery, with a battery life of at least 8 hours.
1.4	Friendly Eyes’ software will occupy less than 128 KB in the memory.
1.5	Friendly Eyes’ software will classify contemplated objects approaching the system at speeds higher than 2 m/s as high threat.
1.6	Friendly Eyes will process sensor inputs and determine an object’s distance within ⅛ seconds.
1.7	Friendly Eyes’ vibrational cells will be activated within ⅛ seconds of sensing.

Table 1 Key specifications

2.4.1 Extended Hardware Specifications

Below is a list of extended hardware requirement specifications that should be met at the end of the prototyping phases.

2.1	System will operate on less than 30 V.
2.2	PCB will not exceed 16 sq. inches in size.
2.3	System will be powered by a rechargeable battery and will remain turned on until battery power runs out. Battery is expected to last for at least 8 hours.
2.4	System will be able to accurately measure how far an object is from the user in a range between .3 and 7 meters.
2.5	System will be able to detect objects or individuals moving towards the user between 1 and 5 m/s at a range between 6 and 10 m.
2.6	System will produce an output vibration in less than 2 seconds to leave a buffer for the user's reaction time.
2.7	System will be able to accurately assess materials such as glass and still produce an appropriate output.
2.8	System will be able to reference level of ground to detect stairs or ledges.
2.9	System will withstand the impact from a fall of less than 2 meters.
2.10	System will be able to detect when a fall or crash occurs and offer the possibility to reach for help.
2.11	System will contain vibrating components working with variable intensity to alert users of dangers in the current path.

Table 2: hardware specifications

2.4.1 Extended Software Specifications

Below is a list of extended software requirement specifications that should be met at the end of the prototyping and troubleshooting phases.

3.1	Software will take up less than 128 KBs of space
3.2	Software will accurately classify objects approaching the user at speeds over 2m/s as high threat.
3.3	Software will be capable of deciphering sensor inputs to determine an object's distance within ⅛ seconds.
3.4	Software will be capable of controlling vibration motors to warn a user of dangerous objects within ⅛ of a second of deciphering the input.
3.5	Software will be able to detect sudden changes in movement indicative of a possible accident within a second.
2.6	Software will communicate falls or accidents to the user's emergency contact within 30 seconds of an incident.

Table 3: Software specifications

2.5 Marketability Requirements

Our House of Quality represents the relationship between our requirements and the requirements of the consumers of our product.

On the left side of the diagram, our five marketing requirements are listed. These represent the wants and needs of the customer that would be using our system. Specifically, we believe that they will find important price, size, durability, operational time, and weight. These are the specifications that we believe will make the customer decide whether they will purchase the product. The positive and negative symbols represent whether those specific specifications are desirable or undesirable for the party.

The top of the diagram contains those requirements we believe most important in engineering the device. These are the 'engineering requirements' that represent our wants and needs. These technical requirements are power consumption, range, efficiency, size, and cost. These also have positive and negative symbols to represent our opinion of those respective specifications.

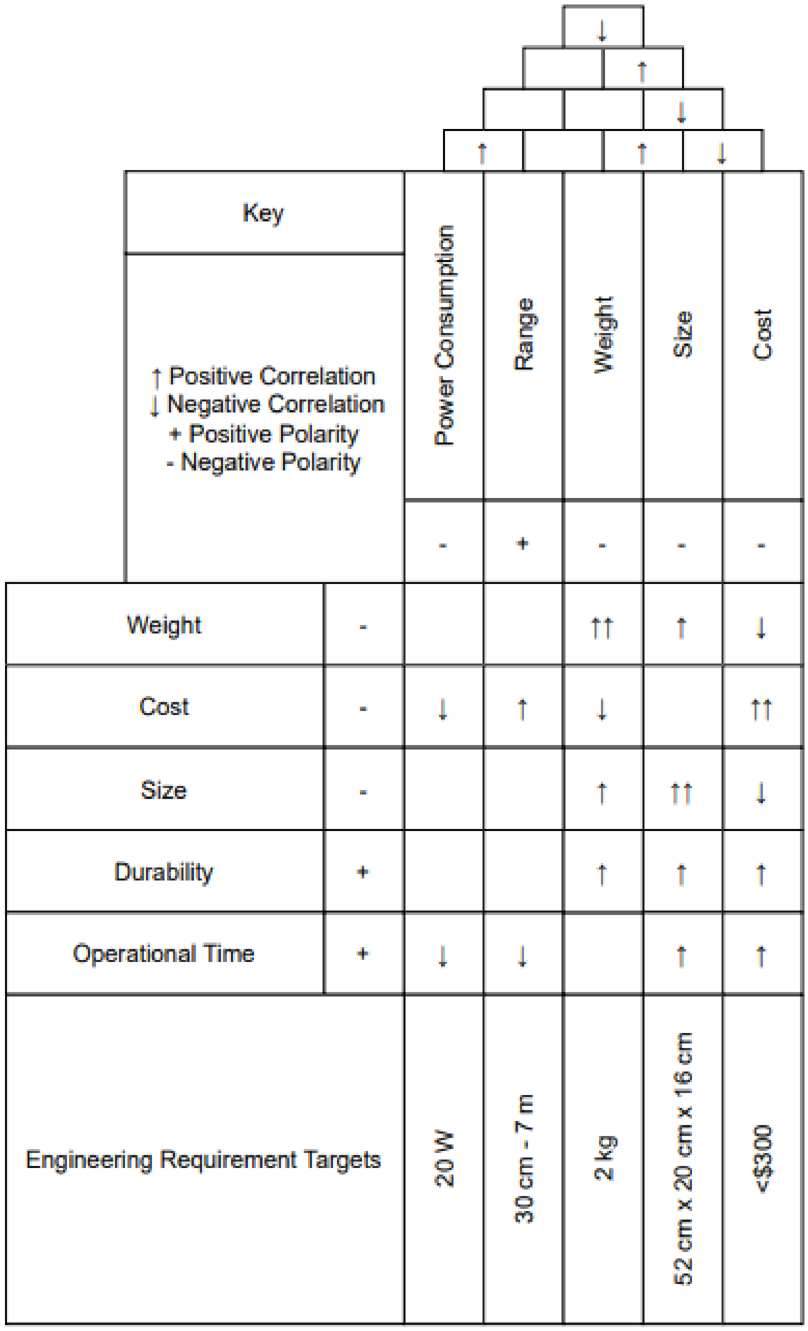


Figure 2 House of Quality

At the end of Senior Design II, the system was defined as presented in the figures below:

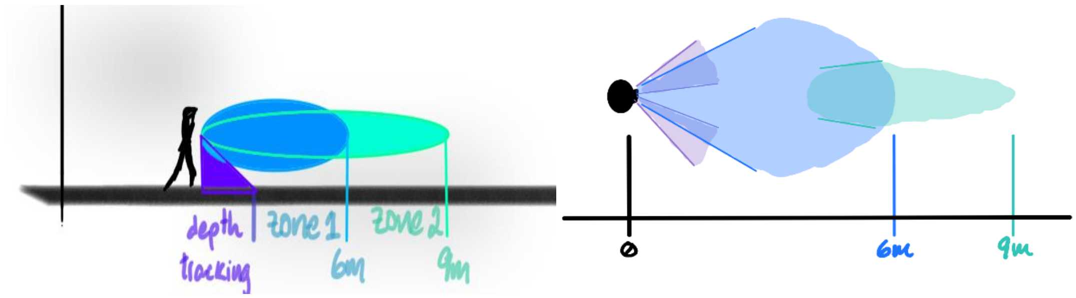


Figure 3: Definition of areas of coverage for FriendlyEyes sensors

In writing, the system aimed to achieve the following requirements:

FriendlyEyes must be able to scan user's field of view up to 7 m away and produce a mechanical output.
FriendlyEyes must issue and prioritize alerts prompted by objects coming into 10 m from the user and doing so with speeds faster than 2 m/s relative to the Earth.
FriendlyEyes must keep track of its distance from the ground and alert the user of sudden changes in the level of the terrain ahead of an incident.
FriendlyEyes must produce all alerts within 1/8 seconds of sensing.
FriendlyEyes must be powered by a rechargeable battery, and the system must run for ≥8 hours on a single charge.
FriendlyEyes must be safe for anyone who wears it; therefore, it must: .be able to assess known and common dangerous materials. .keep its temperature low, .handle the risk for ESD,

Table 4: Final Requirement Specifications

3 TECHNOLOGY INVESTIGATION

The design of the wearable was ultimately due to extensive investigation of many different modern and relevant technologies. When researching technologies that would go into each subsystem of the project, many different technologies were analyzed and compared, so that the best fitting technology would go into the system. Since technology availability is changing rapidly, there may be technologies that may come out over the course of building a prototype for the wearable that may be wanted to be integrated so that the wearable remains innovative. Although one of the goals was to keep the system budget friendly, sacrificing quality over cost was not an option. These following sections will showcase all the research and thought that occurred that helped the group come to final decisions on components that would best fit the project.

There are present numerous comparable products and projects out in the market and in research facilities that will permit us to contrast and get ideas on how to build and demonstrate our wearable. The range of models that we observed permitted us to analyze what worked best for our wearable and obviously what doesn't work best regarding genuine utilization. With our research of other existing similar projects, we began to limit what parts and other technologies would be necessary for our wearable while taking regards of what prices are most reasonable and having our completed vest hit an ideal price tag for our potential intended consumers if the project were to be produced. Additionally, although our wearable is intended for those who are partially or fully visually impaired, we would like this product to be useful for those who are not visually impaired but that would use our wearable either for safety or active activity.

Smart Assist for Blind People (SASB)

In Hebron, Palestine, students attending the Polytechnic University created a vest that uses voice commands and motor vibrations that would allow the partially and fully visually impaired persons to walk with any aid. Their project called the Smart Assist for Blind People (SASB) was designed in a way that would allow the visually impaired to go about their daily lives without a cane. Their design implemented a ground sensor, the system would direct the people by voice commands and vibration commands, and their system also provided the user with a sound alert signaling its battery capacity before switching immediately to energy-saving mode before it runs out. [a] The vest wearer would also be able to follow voice commands through the headphone connected to the system. The vest is currently not in production. The students at the time were seeking sponsors to help them make the vest into a product that could reach the market for the intended users. Unfortunately, the vest seems to have remained a product not in the market but gained a lot of attraction due to its helpful nature. Due to there not being a product on the market, there was no good approximation of what this product costs and how others could budget their prototype.

Eyeronman

Eyeronman is a product intended to assist the partially and fully blind and was co-design by engineers at the Tactile Navigation Tools, Visuomotor Integration Laboratory, and the Technology Translation in Medicine Lab at New York University's Langone Department of Physical Medicine and Rehabilitation. [b] The product was conceived after the founder of Tactile Navigation Tools, Dr. J.R. Rizzo, while they were in medical school studying multisensory integration and due to their own life because they developed degenerative vision loss at an early age. The Eyeronman has two wearable items, one part being an external vest that has embedded into its sensor that interpret the user's environment, the second part being an internal belt that is fitted with vibrating motors that will translate the data to tactile information. Based on where the vibrations are felt and their speed, a user will be able to figure out the direction of an obstacle and the speed with which it is approaching. Further, the system would detect an obstacle on the user's upper right and convert that into vibrations in the upper right portion of a T-shirt or vest made of electroactive polymers. For some stretch goals in their design, they are looking to build a functional prototype wearable that can sense 120 degrees of the vertical with a ten to 18-foot range. Additionally, Dr. Rizzo envisions that the Eyeronman can be taken to a level where the wearable can be fully connected to a 4G, Wi-Fi with a headset or form of auditory communication. At the time the Eyeronman vest was gaining traction, the company was a start-up looking for more investment without a product that was to be put in the assembly line. Unfortunately, when you visit the Tactile Navigation Tools website, the Eyeronman vest does not have a dedicated page to it and the product does not seem to have furthered its development nor have made a place in the market. Due to its helpful nature, it has remained an attractive prototype for inspiration for other engineers. Additionally, due to there not being a product on the market, there was no good approximation of what this product costs and how others could budget their prototype.

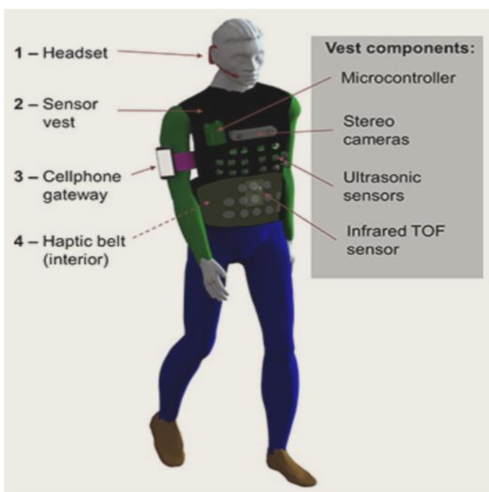


Figure 4: Eyeronman

MIT's Computer Science and Artificial Intelligence

Researchers from the Massachusetts Institute of Technology's Computer Science and Artificial Intelligence Laboratory (CSAIL) developed a system that used a 3-D camera, a belt with separately controllable vibrational motors distributed around it, and an electronically configurable Braille interface to give visually impaired users more information about their surrounding environments. [c] The 3-D camera is worn in a pouch around the neck. A processing unit that runs the team's proprietary algorithms quickly identifies surfaces and their orientations from the 3-D camera data. The sensor belt, which had five vibrating motors evenly spaced around its forward half, could vary the frequency, intensity, and duration of the vibrations, as well as the intervals between them, to send different types of tactile signals to the user. Then, there was a reconfigurable Braille Interface, which is worn at the user's side, and consisted of two rows of five reconfigurable Braille pads.

Symbols displayed on the pads would describe the objects in the user's environment. The symbol's position in the row would indicate the direction an object would be found in. A user that is adept at Braille would find that the signal from the Braille interface and the belt-mounted motors would coincide. Their system, in tests, the chain-finding system reduced test users' contact with objects other than the chairs they sought 80 percent of the time. Further, because the scientist's prototype was able to be used in conjunction with a cane, the navigation system reduced the number of cane collisions with people loitering around an experimental hallway set up by 86 percent of the time. The researchers at the time hoped that their design would someday be commercially viable. Unfortunately, the system seems to have remained a product not in the market. Further, due to there not being a product on the market, there was no good approximation of what this product costs and how others could budget their prototype. Additionally, unlike the last two existing prototypes, this one is not a vest but a series of systems.

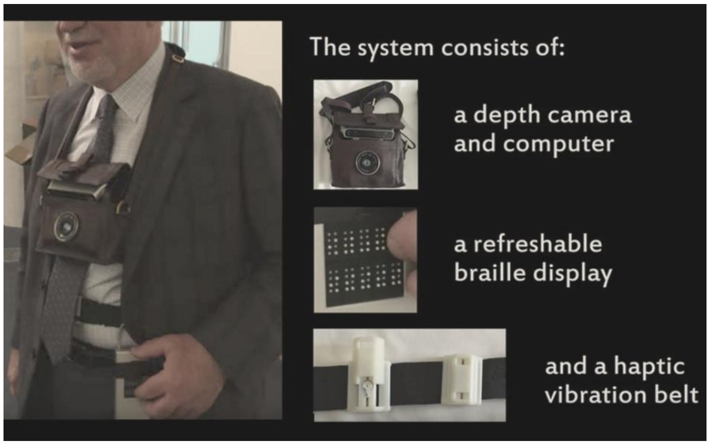


Figure 5: MIT's project

Honda's "Ashirase"

A Japanese startup that was incubated at Honda Motor Company has a prototype that will help the partially visually impaired. [d] The prototype is an in-shoe navigation system for low-vision walkers that allows them to feel which way to walk through in-shoe vibrations connected to a navigation app on a smartphone. The device is which is attached to the show, vibrates to provide navigation based on the route set within the app, and motors sensors which consist of an accelerometer, gyro, and orientations sensors, enable the system to understand how the user is walking. While the person is en route outside, the system localizes the user based on global navigation satellite positioning information and data based on the user's foot movement. The vibrators are aligned with the foot's nerve layer, so the users can feel the pulse. Vibrators on the left, right, and front of the shoe indicate the user should turn left, right, or go straight ahead. Unlike the other products that warn the user when to stop when either being approached or approaching an object or obstacle, the device helps navigate the person which left the user to walk in a freer state of mind. Further, the system does not work well indoors due to GPS not reaching the user but there are plans to use Wi-Fi or Bluetooth-based positioning. In terms of stretch goals, the startup wants to develop the function to generate a map itself from the outdoor environment and the startup also wants to integrate the system with the public transit system. The subscription to use the app of the product to enable GPS will be between $18 to $27 and the actual price of the product is not yet disclosed but production is set to begin in 2023.

Having reviewed these previous implementations of systems with similar purpose and characteristics, we set out to look for technologies relevant to our vision and available to us. We defined the following list in the form of design blocks we would need to include in our design, to narrow our search from early stages:

- The system will have at least three different sensor modules to capture data.
- A microcontroller will control all the information from the sensors, manage the charging of the battery, and control the vibrators.
- Digital signal processors would help analyze all the information from the sensors to the microcontroller. The vest has three sensors, and they did receive the same data at a standard range. For that reason, the DSP needed to eliminate or filter the data that was not needed from the sensors, which was ultimately accomplished.
- Analog filters are an essential part of any electronic circuit to eliminate any voltage noise or frequencies that are not desired. They will be part of the battery because all power supplies generate some noise at the output or peaks of voltage at some point, and they can be dangerous for the components and create errors in the system, such as a false value.
- Integrated circuits are an essential part of any design nowadays, and Friendly Eyes is not the exception. All the charging systems that form MOSFETs with Op-Amps are designed in silicon die. That is the integrated

circuit or a chip when ready to use. They control the input and output voltage and stabilize the voltage, so it does not have any peak.

- The battery is the main element of the project because it will provide power to all the components in the circuit. Also, the battery will last a minimum of 8 hours so, the user can use the vets during the day without worrying about charging it.
- This element is an upgrade that we did consider adding in a future version of the vest. If the user falls, a sensor will detect the motion and notify the microcontroller to send a message to the user's emergency contact. In order to do that, the GPS will calculate the user's position and send it to the microcontroller to send that information in a text message, for example.
- The last component that will work along the GPS is the GSM with a sim card inside. This device can make calls and send text messages to other persons, such as the user's emergency contact, with the location of the person with disabilities that is using the vets.

With these guidelines we went on to address each of the mentioned categories under its respective subsystem.

3.1 Sensor Subsystems

The main feature of the project relies on the utilization of different kinds of sensors to collect the data that all other subsystems will be working for. While navigating our day-to-day lives we run into a lot of different kinds of obstacles made of different materials, with different shapes and posing completely different scenarios from one to the other. Humans have the ability of devising and discerning things from other things, along with a series of characteristics such as their angling, height, and the danger it would represent as well. Since we are designing instrumentation to figure out this issue for the portion of the population that cannot do it by themselves, we implemented a combination of sensors to gather the necessary information for the integrated processing unit to make the decisions on how to best assist the user in his/her next steps.

The system we choose and would be moving forward with consisted of three different kinds of sensors, all oriented at accomplishing a different goal. Friendly Eyes must account for threats moving in its direction at a speed, stationary objects to which the user moves towards, and finally a feature that will alert the user of changes in the ground level, i.e., a flight of stairs in the path or a ledge. The range of detection will be divided in three sections with some overlap between them: an outer half ring will detect moving objects or individuals, the inside of that ring will work to detect objects in the near-field, and the final set of sensors will work on the same section but pointing downwards at an angle.

Although each of the selected modules to work particular zones have different requirements regarding our application, there are some global measures we looked to adhere to while investigating the technologies available. Low power consumption provided degrees of freedom, and ease of integration are some of the qualities that all three of our choices are based on. Other than that, requirements regarding the sensors refresh rate, reliability of data delivered, detection across different materials and more are specific to each of the 3 zones covered by the system. These are discussed further in their corresponding sections.

3.1.1 Technologies Available

After having defined our project, we proceeded to investigate what technologies could fulfill the duties of each zone. We looked at an array of modules and devices covering most of the unlicensed wireless spectrum, making note of the mechanism used along with their advantages and disadvantages.

As marked with yellow in the figure below (Figure 6), our search was confined within the first 4 categories of the wireless spectrum. This is because at the level we are working the project and the resources we count with, using smaller wavelengths would immediately introduce constraints that would prevent overall success of the design. They are summarized later on in the document under Section 4.1 Wireless Spectrum.

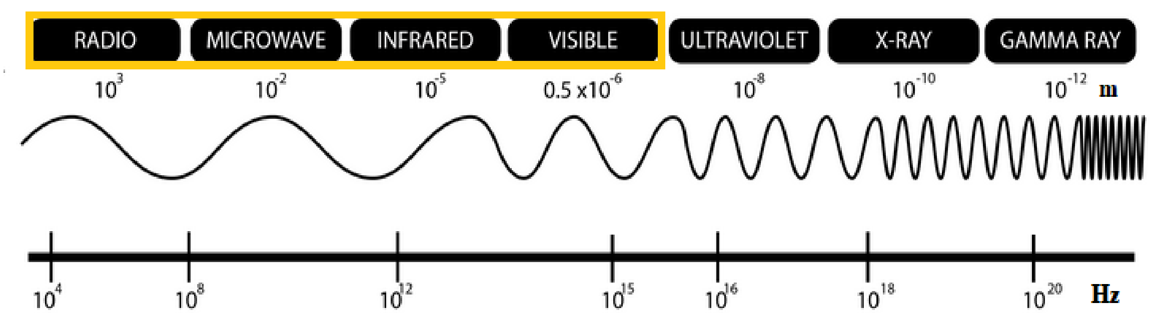


Figure 6: Wireless Spectrum

Even though we made it a requirement to not go over a certain frequency of operation for our sensing technology and it is not pictured in the above figure, we did include the implications of cost in our vision for the system, which in turn led us to include under consideration lower-cost but higher energy-consuming technologies in within the sound domain of the frequency spectra as well.

3.1.1.1 Acoustic Spectrum

Starting with the technologies available using longer wavelengths we found ultrasonic sensors. Well-known to electrical engineers, these type of sensor does not provide accurate-enough results for our purpose, aside from the fact that because of the physics these are based in their range is quite limited. Nonetheless, ultrasonic sensors are relatively inexpensive and have a very low processing cost.

3.1.1.2 Radio Spectrum

Further into the spectrum, we got into systems using radio waves in their implementation. This is where restrictions regarding the electromagnetic spectrum start to impose constraints on the selection for our components, but also where most options within the means of our project were found.

Navigation and instrumentation radar modules provide high accuracy due to their use of shorter wavelengths within the radio band and attention to detail in design, but their implementation is not practical since they require many additional components to form subsystems, yielding costs that would take away from the accessibility to the public a product like ours is chasing after.

Continuous-wave (CW) radar modules offered a wide range of options in the market, but it was quickly noted that these work based on the Doppler effect, so they can only detect objects in motion and their output is not reliable when there is more than one moving object in their range. The use of a continuous wave also implies a higher power consumption than other contenders in the list, and a good resolution will force an ADC to use high sampling frequencies adding more unnecessary constraints to our design.

Also relying on the Doppler effect but with a slightly different implementation we found Doppler radar modules. These further developed CW radar sub-types use information from the phase difference received from the emitted wave to the received wave to make measurements, so aside from the velocity of an object it can detect if there are any changes in the objects present in its range.

Pulsed radars are again using the Doppler effect as their principle, but this time it delivers measurements obtained by comparing a single transmitted pulse against its own reflection. One big advantage over those using CW technologies is that the transmitter is actually turned off between pulses, so results obtained should have higher accuracy in principle as well, all the while consuming much less power.

3.1.1.3 Optical Spectrum

Heading into the micrometer wavelength realm, we found newer ideas and a growing market for sensor applications requiring this type of technology. Sensors laying in this portion of the spectrum are known to be at the forefront of self-driving vehicle systems and navigation for robotic systems as well, but it being a relatively new technology still struggles to fill the gap between what is available and what is accessible.

The most widely available sensors in the optical spectrum us Infrared (IR) and LiDAR technologies, with different materials used for their construction and working at different wavelengths as well. IR sensors are the cheaper option amongst the two, but since their use is limited to presence detection, the cost for an IR module with a suitable range for our application is out of bounds. With LiDAR in turn, it is easier to find a module with the appropriate range, but they will be at least in principle and in current times, more expensive than IR. Both types are affected by weather, and none are good at detecting the presence of clear materials like glass, so there seem to be no advantages for our system digging into the optical spectrum.

3.1.2 Technology Selection

The following table (Table 5) contains a summary of our findings with relation to the constraints and specifications of our system. It was attached to further justify reasoning behind our choices. In no way does this table represent facts about the technologies therein.

	Acoustic	Radio				Optical	
Parameter	Ultrasonic	Instrumentation	Continuous-wave	Doppler	Pulsed	Infrared	LiDAR
Best for	Distance	Navigation	Motion	Motion, Presence	Distance, Position	Motion, Presence	Motion, Presence, Distance, Position
Range	[green]	[red]	[green]	[green]	[green]	[yellow]	[green]
Weather	[green]	[green]	[green]	[green]	[green]	[yellow]	[yellow]
Cost	[green]	[red]	[red]	[yellow]	[green]	[yellow]	[yellow]

Table 5: Comparison of sensor type related to our application

Since we had already defined subsystems for different operations, we were better positioned to look for sensors that meet more accurate criteria within their assigned duty. But even then, it proved complicated to find much variety within confines of our application parameters and its budget.

3.1.2.1 Inner-Range (.3-7m)

Independent of the performance of the previous segment, the bulk of the project will rely on the proper operation of the system within the range comprehended between .3 and 7 meters. To work this area, we looked at different characteristics such as sensors' ability to yield an accurate response in the presence of different materials, sensors that will deliver data in a way that would allow us to develop algorithms for our particular application, and particularly one that produced a reliable response while working on a different frequency band than the INS-3330 to lower the probability of errors induced by receiving cross-signals from one module to the other.

It was difficult to find variety within the bounds of our application, so we narrowed down our search using all previously studied parameters to obtain a limited but comprehensive array of options to be the core of our project. Looking mainly into radar modules because of availability, price, and price as it relates to what is useful, we summarized key features of our top two contenders (Table 6).

Review of the qualifications of each of these modules determined that Texas Instrument's chip far outweighs the needs of our application, and even though price is not a defining factor, in this case a good price does not equal a better product. This is due to the fact that integrating a chip such as one from the IWR6843 family would present further complications, with all concerning power management, the actual physical handling and soldering of the component, the complexity of a printed circuit board that needs to accommodate 180 contacts from only one component, and more.

Added to that is the fact that using a system such as this one takes the difficulty and effort necessary for a project of this magnitude and just shifts it to the wrong place. That is to say that the integration of mixed signals in a PCB, the development of power systems and writing code to implement digital signal processing on a microcontroller are the weight of this project and using TI's product would take away much of the opportunity to do this work.

Other than these two options, most sensors lacked the power necessary to fulfill the needs of our application, while few surpassed them but showing 3 and 4 figure price tags. There were not many options that worked for the interest of our project within reasonable price ranges using either radar or other wireless bands. The A111 is valued at $12 per unit online, and its capabilities far outweigh the need to go for more expensive LiDAR modules.

Owing to all the exposed reasons we singled out Acconeer's A111 Pulse-Coherent Radar module. The A111 works in the 60 GHz band, has a built-in antenna (Antenna-in-Package), and can take measurements with frequencies up to 1.5 kHz while using low-power consumption technology similar to that of regular pulsed coherent radars. These characteristics made for a radar module that is easy to integrate to a PCB layout and with high immunity to disturbances by either one of the other subsystems in the garment, or external factors like weather and lighting conditions.

The A111 has two built-in storage units in it. One is used to hold the program uploaded by an external processor via SPI, and the second unit stores the information coming from the mmWave Radio module through the ADC. This digital output from the sensor is then again transmitted through SPI to an external unit for handling the data and performing the task it has been programmed to accomplish. The company provides directions on specific processing units that are better fitted to interface with the A111 sorted according to the estimated load of the application.

Table 5 summarizes the characteristics of the two main options to fulfill our system's requirements.

Acconeer A111 (Radar Sensor)	TI IWR6843AOP (RF SoC)
Absolute range up to 7 m with mm accuracy	Specifications on the ranging capabilities of this chip and those in its family vary a lot with distance and object size. The datasheet created a scale based on experimentation. The following are examples provided by TI as concerns to our application: • Coin (US Quarter) at 1 m • Wooden chair at 20 m • Human at 40 m
Pulsed-Coherent Radar (PCR)	Frequency-Modulated Continuous-Wave Radar (FMCW)
60 GHz	60-64 GHz
This chip involves more levels of understanding with regards to its integration. • Processing unit is independent of the sensor. Similarly, ARM Cortex M4 or M7 are recommended • 1 antenna in package • No hardware DSP • 50 pins	The idea at the conception of this device was to include all commonly implemented external features into the chip. • Built in ARM Cortex R4F • 4 antennas in package • Built in C674x DSP • 180 pins • Hardware accelerator
The A111 will use less power, but it is not fair to judge it in this way since more active components will need to be added to attain similar characteristics to its counterpart. This sensor was designed with low-power applications in mind. Having developed PCR technology allowed them to make sure they could advertise low numbers in this field. • 10Hz sweep rate – 3 mW • 100Hz sweep rate – 20 mW	The power consumption of this system will be notably higher than that of its counterpart, but it carries a much heavier load in comparison. It was previously noted that CW systems will in theory require relatively high power to function. The following are average power consumption values published by TI with ADC 6.4 Msps, 64 chirps, 256 samples/chirp, DSP and hardware accelerator powered on: • 1TX, 4RX – 1.19 W • 2TX, 4RX – 1.25 W

Table 6 Acconeer's Radar Sensor vs Texas Instruments System-on-Chip (SoC)

Figure7 and Figure 8 show the characteristics of coverage of its beam for both elevation and horizontal planes. With this images we can perform calculations to give ourselves perspective on the range of capture of our technology selection, and start devising ways to take advantage of the conditions.

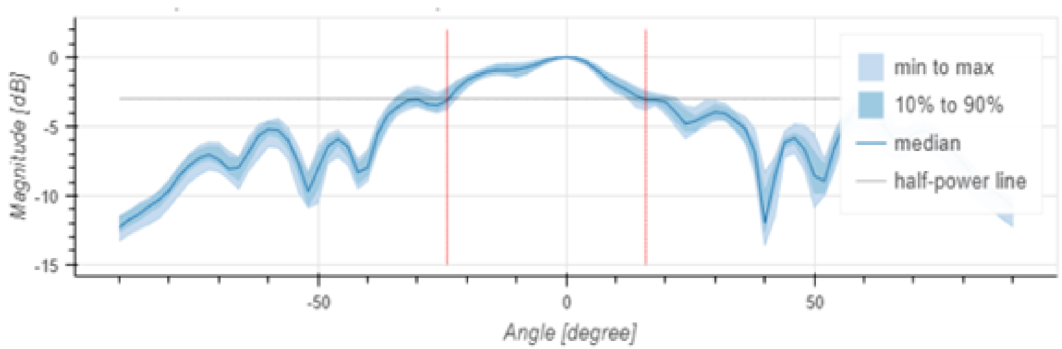


Figure 7: Acconeer's A111 radiation pattern at elevation plane

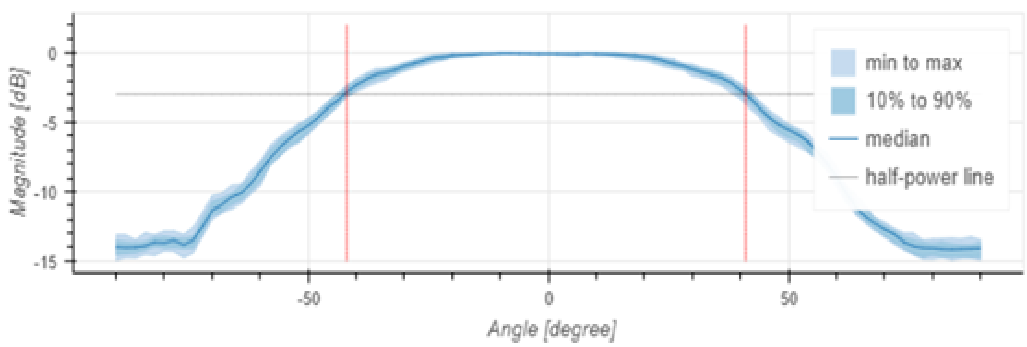


Figure 8: Acconeer's A111 radiation pattern at horizontal plane

3.1.2.2 Outer-Range (6-9m)

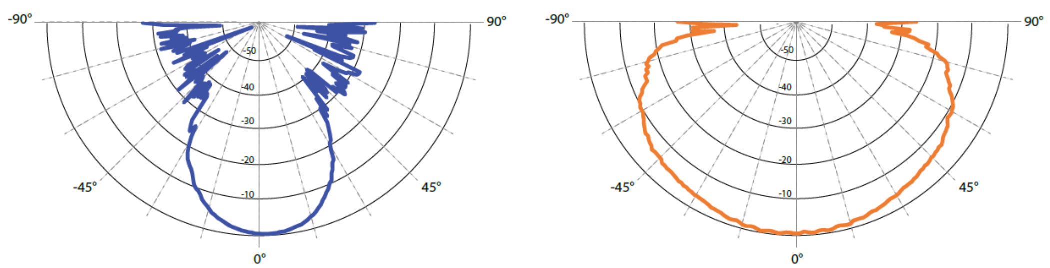
For the outer portion of our range, we are going to use a Doppler motion sensor module tuned to work a radius from 6 to 10 meters from the user. Furthermore, since we are guiding the person wearing the system while walking, we filtered out information that is not useful to us by providing a lower bound for the speed of the incoming threat at which the sensor starts capturing data around the 1 m/s mark, which is still higher than average values found in studies regarding the walking speed of the visually impaired.

Because of the nature of the application of this stage, this sensor will provide a digital output directly linked to the processing unit, as to produce the intended vibrational feedback with time left to spare for the user to react to a person walking or jogging in his direction. We chose Innosent' INS-3330 Doppler Motion Sensor to cover this range.

Manufacturer	PN	Technology	Cost	Range
InnoSent	INS-3330	Doppler motion radar sensor	$43.00	10m
GARMIN		LIDAR SENSOR	$59.95	10m
DFRobot	SEN0413	IR ToF	$19.90	12m

Table 7 Comparison of available modules for outer range

The INS-3330 module was not the cheapest option available with characteristics falling close to the specifications for our system, but it offered the best relationship to the price accounting for its ease of integration and data delivery mechanism, offering comprehensive figures encompassing the recognition of movement together that enables the possibility to calculate direction, speed, and intensity of the signal. It delivers this data using a built in UART interface that can be connected directly to the main processing unit for a short reaction time.



system pattern (-10dB)	azimuth	system_az		43		°
	elevation	system_el		116		°

Figure 9: Doppler Radar Areas of Coverage

This is also a module that’s fabricated with ease of integration in mind, providing UART output, an analog option as well, and even an onboard digital signal processor.

These all represent advantages because the main challenge in our project relies on the inner-range of detection, but we still want to integrate all the features we envisioned to have. This module provides the opportunity to do so, with guides on best practices for hardware integration and housing, software provided directly by company developers and an intuitive graphic user interface that will facilitate means for us to understand how our code should be structured to obtain the measurements we wish to get from it.

3.1.3.3 Depth Tracking

The final sensor subsystem will most likely consist of an ultrasonic pointed at an angle of about -30 degrees with respect to the x-axis. This sensor will be calibrated with the user's height during the first use, and the processing unit will use that information in conjunction with a constant stream of data to determine if the level of the ground is about to change and an alert to the user is imminent.

To cover this range, we selected a module designed by DFRobot, which offered the advantage of having a built-in i/o multiplexer. This was beneficial for us because even though at the moment we have open GPIO in our processing unit we did add features that require control. Ultimately, it was in our best interest to keep our options open

Shall our implementation for this range work fine with our selection for the part, there is room to study the possibility of integrating more ultrasonic modules around the garment, always accounting for the possibility of introducing further complications before moving forward, but this just one of the advantages that having a module that uses just 1 physical pin poses.

3.2 Processing Subsystem

Processing will handle the main load in the whole system, in charge of controlling peripherals and a variety of functionalities, selecting a microcontroller unit, along with its IDE and all other implications will be of utmost importance for the success of FriendlyEyes.

3.2.1 Technologies Available

The main control of this project is the microcontroller, so its was imperative that extensive research and a selection process occurred to in this section. The microcontroller chosen would need to communicate to the system and extract data from three different sensors. It was important that the microcontroller be from a selection of innovative but also frequently utilized selections so that the there was confidence that the microcontroller would be overall workable. Below is extensive research and selection of the microcontroller.

3.2.1.1 Microcontroller Unit (MCU)

The microcontroller selected for this project needs to be capable of taking in multiple streams of sensor data and deciphering all of it so that it can be relayed to the user in a useful manner. In deciphering the data, calculations must be performed to judge distance of the user from various obstacles in the environment, and a threat level must be determined from this calculation. After calculation, this information is to be relayed to the user via motors that are placed around their torso. The direction of the obstacle should correspond to the motor that is vibrated, and the vibration level should be proportional to the perceived threat of the obstacle.

Because of the sensitivity of the user, it is imperative that we minimize any risk of using the product. Our microcontroller must be consuming as little power as possible to prevent our user from potentially being stranded. Thus, we should be looking for a microcontroller with a low operating voltage so that power draw can be minimized. Processing speed is also important, because our user needs to have time to react to any vibration before they are struck by an obstacle (or strike one themselves). We should look at trying to choose a microprocessor with a high clock speed, giving us some leeway in the efficiency of our code and making sure that the delay between obtaining a signal from a sensor and communicating with our user is miniscule.

With three motors representing directions and two main sensors detecting obstacles, we had at least ten general purpose input/output (GPIO) pins available just for the sensors and vibration motors. However, depending on our sensor choices, we may end up using as many as ten sensors, meaning that there would be a requirement of eighteen GPIO pins for our sensing/vibrating system.

It is important that the microcontroller selected has a good development environment. That is, it is easy to write source code and transfer it to our MCU for debugging. The microcontroller should also have strong documentation, or a large support community to search for help should issues arise. Some units that fit our requirements:

Texas Instruments MSP430

The MSP430 line offers plenty of MCUs that satisfy the requirements we have laid out. The first considerations would be MCUs that we have experience with, specifically the MSP430FR6989. This MCU certainly has enough non-volatile memory for our software - at 128kBs of storage there would be no issue storing the program that would calculate the data from our sensors. It also offers two I2C connections, should we need to interface this way (which will be the case if we are able to implement a gyroscope into our design), in addition to having 83 GPIO pins for interfacing. The greatest pitfall of the MCU is that it has a measly 2 kilobytes of RAM. This may not be an issue if we choose to use ultrasonic sensors to detect objects, but it will likely prove an obstacle in using radar detection, due to the intense calculations required and large amounts of sensor data that would need to be stored in memory (the radar would need to sweep an area multiple times and store this data as a matrix in memory).

A similar microcontroller is the MSP430FR5964. This MCU loses some features of the FR6989 that we had no use for while gaining extra non-volatile memory, RAM, and I2Cs. The device has 256kBs of storage, 8kB of RAM and 68

GPIO pins, as well as four I2Cs and four UART connections. The clock speed remains the same as the FR6989 at 16MHz.

It costs less than the FR6989, with its price coming in at $2.68 for a single unit. It uses the same development environment as the FR6989 – that is, Texas Instruments' Code Composer Studio (CCS), easing use for us since we are comfortable with this environment due to its prevalence in our coursework. The additional 6kb of memory make this the MSP430 that will be considered for this project.

ATmega328P

The ATmega328P is a cheap Atmel microcontroller that is predominantly known for being the core of the Arduino Uno. This MCU is primarily being considered due to the ease of programming for it, as testing with an Arduino Uno would be trivial and cheap, as we are already using the Arduino Uno in testing other parts of this project. The ATmega328P has 32 kilobytes of storage, 2 kilobytes of SRAM, and runs at 16MHz. It has twenty-three available GPIO pins, in addition to one I2C, two SPIs, and 1 USART interface.

This microcontroller does contain all necessary connections but may not be considered due to the lack of hardware power in comparison to other options (the same reason the MSPFR6989 is out of consideration). However, should we end up requiring less memory, this MCU would be a strong contender vs the others that are under consideration.

The ATmega328P can be purchased in single quantities at as little as $2.60.

STMicroelectronics STM32

The STM32 family are Arm Cortex based 32-bit microcontrollers that offer a huge range of specifications for different applications. A promising STM32 MCU we've been looking at is the STM32F048C6. This MCU contains a 32-bit ARM Cortex M0 CPU, that can operate at up to 48MHz, as well as 32 kilobytes of non-volatile flash memory and 6 kilobytes of SRAM. It also contains 37 general purpose input/output pins, as well as one I2C interface, two USARTS, two SPIs and a USB2.0 full-speed interface.

Its price comes in extremely cheap at $2.02 for a single MCU, meaning that it is very affordable even without having to buy in bulk, and its development board is also available from STMicroelectronics for $10.99

NPX Semiconductors K32 L2B

The NPX Semiconductors K32 L2B is an ultra-low-power 32-bit ARM microcontroller. Like the STM32F048C6, it contains a 32-bit ARM Cortex M0 CPU. This CPU can run at up to 48MHz. It can contain as much as 256 kilobytes of non-volatile flash storage, and 32 kilobytes of RAM. It has two I2C modules and up to fifty GPIO pins, as well as one UART module.

Depending on the storage, this MCU can cost as little as $3.42 for the 64 kilobyte storage version, to $5.14 for the 256 kilobyte storage version in single quantities, and its development kit costs $25.

Maxim Integrated Darwin MAX32625

The Max 32625 is another Arm Cortex based 32-bit microcontroller pertaining to Mamixm's DARWIN line. However, unlike the other two Arm Cortex based MCUs, the CPU featured on this device is the Arm Cortex M4. This processor can operate at up to 96 MHz when running intensive applications, but also has a low power clock option of 4 MHz for systems that would require us to maximize battery life.

The DARWIN microcontrollers developed by Maxim Integrated are designed to be power efficient while still having hefty amounts of power for running any applications that a developer may request of them. Maxim Integrated claims that these DARWIN MCUs contain the "lowest active mode and SRAM retention power available" meaning that they should be extremely optimized for low power systems like our wearable.

The MAX32625 contains up to 512 kilobytes of non-volatile flash memory that can be used to store software, and up to 160 kilobytes of SRAM. The lower-cost variant contains 256 kilobytes of flash memory, as well as 128 kilobytes of SRAM.

The device grants us access to 37 general purpose input/output pins, three SPI masters, one SPI slave, three UARTS, two I2C masters, and one I2C slave. The I2Cs are compliant with I2C standards for both standard-mode and fast-mode, meaning that they support transfer rates of 1—kilobytes per second in standard mode and 400 kilobytes per second in fast mode. The three UART interfaces have a maximum baud rate of 1943.2KB, and each individually programable interface supports full-duplex asynchronous communication.

This device has a single built in ADC converter. This converter is capable of measuring internal supplies while also providing 4 external inputs. The device also has a built-in feature allowing the ADC to trigger interrupts automatically when programmed high and low limits are met, and this is even performable when the CPU is in low-power modes.

The unit price for the 256-kilobyte storage variant of this device is $10.52 when buying in single quantities. The associated evaluation board is available for slightly more at $13.02 per unit when purchasing in single quantities.

Issues with the Maxim Integrated Darwin MAX32625

The microcontroller we chose for this project is Maxim Integrated's MAX32625. For development we used the MAX32625PICO development board. We knew that we wanted to use an Arm MCU early on into the project, since we wanted to gain experience with the platform that is growing in popularity. We were also constrained to Arm Cortex MCUs due to the A111 radar sensor that we had chosen for the project.

Acconeer provided APIs for interfacing with their radar sensor, as well as doing many of the calculations required for using the data recieved. However, their provided libraries were closed-source, meaning that they were pre-compiled and only able to be used with the processors that they were compiled for. They provided libraries for the Cortex M0, M4, and M7 processors, limiting us to those specific options for microcontroller selection.

The MAX32625 was a Cortex M4 MCU that met all of the interfacing requirements that we had. It had the SPI interface required for the A111, plenty of GPIO pins for our ultrasonic and INS sensors, and UART interfaces allowing us to connect USB modules for ease of debugging.

We also believed that it would be much easier to program for, since it took advantage of Arm's Mbed OS platform. The platform applies a powerful hardware abstraction layer - allowing one to write readable code quickly without needing to create complicated functions to allow repeating of relatively simple tasks. Writing code bare-metal in Keil or Maxim's own tool chain takes a lot of time, it requires minimum four lines of code just to define how a GPIO pin is being used, while the same is done in exactly one line using Mbed.

Mbed's hardware abstraction layer is used across all compatible devices, meaning that if someone has created code for one device - it can likely be used with another (as long as they are on the same version of Mbed), and many users have posted public repositories of code on their website for use in others' projects. Mbed also has you programming in C++, making it much easier to keep track of memory. In C any dynamic memory created would have to be freed when it is no longer in use to prevent leaks, but C++ allows you to create objects that automatically destroy themselves when they leave scope.

3.2.1.2 Operating System (OS)

A real-time operating system such as Free-RTOS or TI-RTOS could be helpful in polling sensors and scheduling events, however there aren’t multiple hard deadlines that have to be met in this system. With the only hard deadlines coming from polling the sensors, a real-time operating system is likely unnecessary, and would probably just result in us taking up more space on our MCU.

However, should the need to use a real-time operating system arise later in development, the best choice would definitely be Free-RTOS, due to its open-source nature, our group’s familiarity with the operating system, and its compatibility with all of the MCU architectures that are being considered for the project. Our most likely MCU, the NXP K32 L2B, will have us using the MCUXpresso IDE. This IDE also has built in support for FreeRTOS aware debugging, which it doesn’t for TI-RTOS.

3.2.1.3 Integrated Development Environment & Resources

We want software development to be as easy as possible, ideally without having to use third-party tools. A robust community is another boon, as having a lot of community support for the system will make development hang-ups resolve more quickly. Creating and following programming standards will assist in keeping clean code and having access to version control to help in backtracking in case of grievous errors is imperative.

The integrated development environment (IDE) that we choose will be how we debug our software and write code that will be pushed to our MCU. Different MCU developers provide their own IDEs that they support and thus recommend you use when developing for their products. By choosing the IDE that the MCU developer recommends, you can most easily communicate with their boards.

Depending on which microcontroller we choose, there are a handful of different IDEs that we could potentially have to use. Assuming we choose the MSP430 MCU, we would be using Texas Instruments' Code Composer Studio (CCS). With the NXP MCU we could be pushed into using NXP's MCUXpresso software. STMicroelectronics recommends their STM32CubeIDE. All three of these IDEs are based off of the Eclipse IDE, allowing integration with Eclipse plugins. All three developers also include sample code that can be used to learn how to program basic functions of their MCU.

NXP's IDE offers syntax coloring to facilitate ease of reading code, and they also claim that this IDE is highly extensible with most Eclipse plugins. MCUXpresso also supports energy, power, and current measurement on MCUs that support it, and offers MCU-specific debugging views as well as profiling and code trace. You can also view detailed information on memory usage on the device. These features should make it much easier to debug software that is running on the microcontroller, improving the speed that we can go through development. It is compatible with all major operating systems, that is Ubuntu Linux, macOS 10.14, 10.15, and 11.x, and 64-bit Microsoft Windows 10. This means that we should have no issues running this environment on any of our machines.

3.2.1.4 Programming Language

Whatever microcontroller and IDE we end up using, we need to be able to write our code in either assembly or C. There are benefits to using either and it's important to choose the one that will fit best on our project.

By using assembly, we gain maximum control over the hardware that we are using and can squeeze out a lot of speed by optimizing every line of code. Compilers aren't always perfect, and there are quirks that can exist that make your C code not perfectly optimized. Assembly lets you write code at effectively the lowest level, leaving no room for a compiler to mess up the optimization of your program.

However, despite the potential speed improvements of writing our code in assembly, in practice C will likely end up being much more useful for our project. C code will be automatically converted into instructions that the MCU will run, and although it may not be quite as optimal as writing in assembly – it will likely be very close (or faster, since we may not be able to perfectly optimize our assembly code). C will also require us to write many fewer lines of code. Depending on the instruction set, sometimes simple multiplication can take multiple lines of code, where within C it can be done with just a few keystrokes. This means that we can vastly save on actual time spent writing our software by using C.

By using C instead of assembly, we also gain portability. This means that if we have difficulties and need to port our code to another system (potentially for debugging purposes) we can likely port the code to the new device with minimal headaches. Assembly code is written specifically for whatever system it is coded for, and there is no guarantee that multiple systems will have the same instructions implemented or even if the instructions are there, the syntax/implementation may be different on a case-to-case basis. With C, the compiler will figure out what instructions need to be given to the CPU, so no work is needed to be done on the coder’s part (besides potential changes in pin layout, etc.).

Most importantly, C gives us much greater readability. Since multiple members of our project may be working without code, its important that any of them may be able to quickly understand what the code is doing at a quick glance. While comments do help to a degree in assembly, complex functions can still look foreign if you didn’t write them yourself.

3.2.1.5 Version Control

With multiple people working on the project (potentially at the same time) it’s important to be able to easily collaborate on code and have a way of rolling back should software be broken. Git is a popular system for version control that is widely used for collaborative projects. By using Git, we were able to keep plenty of backups and work together on a repository.

A Git repository (or repo) is the place that all code and related documents can be stored. Users that have access to the repository are able to clone documents and code from the repository into a local directory where they can make changes and push them back into the repo. When a change is pushed into the repo, users are required to write a short explanation of the changes that were made, and the commit is saved in the repository. If code breaks, it is easy to look at the commit history and figure out what change may have brought about the issue. This commit/push system effectively automates code documentation since the history is easily available to view.

The most popular way to use Git is through GitHub, which is an online place to publish Git repositories so that they can be easily accessed by others to collaborate on projects together. GitHub is offered completely for free, and as university students we can also get a free GitHub pro subscription, which in the past was required in order to host online private repositories. However, since 2019 GitHub has offered unlimited free private repositories to all accounts, so it is unnecessary to use this subscription just to keep our repositories from being public. Having our code available online at all times will be incredibly useful as a backup system in case of hardware failures and will be useful in transferring data between systems when moving around.

There are other alternatives to GitHub, but GitHub's popularity has lead to many tools being available for it, with GitHub Desktop being a major one that can make creating commits and merging code extremely easy for people who don't feel comfortable using the command line. Since the majority of the group does not have experience using the terminal, having a nice graphical interface to use will be much easier.

3.2.1.6 User Interface

Our product is intended for blind people, and because of this it is important to have an interface that is appropriate for our target audience. As such, we want there to be minimal strain when it comes to starting up our vest and using it. Because of this, there is only one button that is used on the entire device, and it just to toggle the device on and off.

Turning the vest on will be as simple as flipping a switch that grants it power. Once startup has begun, there are no other buttons that need to be pressed before the consumer can begin using the vest. All information that the device needs to construe to the user is done tactilely. Vibrational motors are used to let the user know the direction and distance of obstacles in reference to the user, without them needing to see or listen to any other feedback. If an object is close, or approaching rapidly, the motor corresponding to its direction will vibrate more powerfully than the motor corresponding to a less threatening object (one that is further away).

To shut the vest off, all the user must do is turn off the switch they used to power the device on.

3.2.2 Technology Selection

Between our microcontrollers, we want to choose the microcontroller that satisfies most of the needs of the product we are developing. That is, it needs to be capable of running off little power, since the device is a wearable, and our user may not have access to an external power source throughout a day. It also needs to have ample storage and memory available, so that no issues are had when trying to load our program onto the device or hold sensor data in memory when doing calculations. The clock speed of the device should be looked at, to help determine the performance of the device when making time-sensitive calculations. The available interfaces are also important, since we may need I2C, GPIO, and UART to provide connections to the different sensors we may be using (I2C for gyroscope, GPIO for motors and ultrasonic/radar sensors, and UART for potential GSM/LTE support). Analog-to-digital conversion will be needed when reading data from sensors, so having a high-quality translation will be imperative to have the most accurate data we can get. Also, it is important that price is kept down where possible. Even though this product won't be mass produced and put on the market, it is a good exercise to try and keep prices low anyways.

Power Consumption:

Our vest is expected to be used by the wearer for a full day-cycle, so the power being consumed by the MCU is a major concern. With the user being blind, it is a major concern that they don't end up stranded due to a dead battery, as their ability to find their way around their environment will be limited without the vest supplementing their senses. It is imperative that we choose a MCU that is capable of running on low power, so that we can extend the use time of our product for as long as possible.

The voltage requirements of all of our microcontrollers are fairly similar. The MSP430FR5964 supports a voltage range from 1.8 to 3.6v. The MAX32625 lists its operating voltage as 1.14 to 3.6v. The NXP K32 L2B's operating characteristics list the voltage range as 1.71 to 3.6v. The STMicroelectronics STM32F048C6 runs on a low supply voltage, operating between 1.65 and 1.95v.

The MSP430FR5964, MAX32625, and the NXP K32 L2B each provide their low power mode current draw. The MAX32625 lists its low power mode as consuming 27 micro amps per megahertz. The MSP430FR5964's optimized ultra-low-power mode is listed at drawing 118 microamps per megahertz. The K32 L2B lists its low power mode at drawing 54 microamps per megahertz. The most efficient of these three is the MAX32625, managing to draw half as much current per megahertz when compared to the runner up.

Price:

We only plan on using a single MCU to complete all of our calculations and send information to the vibration motors, so for our prototype price will likely not be a massive concern. We do still want to keep cost down where possible however and would like to avoid purchasing expensive development kits or development tools that some MCUs may require.

The Texas Instruments MSP430FR5964 has the second cheapest price for the actual unit, at $2.68. However, the development kit is the cheapest of all options, as it can be purchased directly from Texas Instruments for $16.99.

The STMicroelectronics STM32F048C6 is the cheapest MCU at $2.02, and has the cheapest development kit at $10.99.

The most expensive MCU under consideration is the MAX32625, coming in at $10.52, much more expensive than even the next most expensive option of the NXP K32 L2B at $3.42. The development board is not the most expensive though. At $13.02 this is nearly half the price of the K32 L2B evaluation kit that is priced at $25. The clear winner from a pricing perspective is the STMicroelectronics

STM32F048C6, having both the cheapest MCU and the cheapest development kit. While the price of the MCU specifically may be less relevant when creating our single prototype, it is still a factor that should be considered if the project were intended to be mass produced.

Memory and Storage:

There are two types of relevant memory that we are looking at when choosing a microcontroller for this product. That is, the non-volatile flash memory that is used for storage on the device, and the volatile RAM that holds our temporary data. This temporary data could be values from the sensors, or calculations that need to be stored in memory from the program.

Our three microcontrollers vary most when it comes to memory. The Texas Instruments MSP430FR5964 contains 256 kilobytes of non-volatile flash storage, in addition to 8 kilobytes of RAM. The STM32F048C6 contains 32 kilobytes of non-volatile flash storage and contains 6 kilobytes of SRAM. The NPX Semiconductors K32 L2B can match the MSP430 at 256 kilobytes of non-volatile flash storage and 32 kilobytes of RAM. The MAX32625 can contain up to 512 kilobytes of storage and 160 kilobytes of SRAM.

Looking at memory and storage among our MCU choices, the Maxim Integrated MAX32625 far surpasses the others in all memory and storage considerations. The 512 kilobytes of potential storage is double that of the MSP430 and K32 L2B, and 160 kilobytes of SRAM is five times that available in the K32 L2B and STIM32F048C6. When considering these, the MAX32625 is the obvious choice.

Clock Speed:

The clock speed of the MCU correlates with the speed at which it can execute instructions. While not a perfect indicator of performance (especially when comparing across architectures), it gives a good idea of the relative speed a MCU may have compared to another. In our project, speed will be an important consideration. We have to be able to decipher signals from our sensors and make calculations in real-time to prevent our user from colliding with obstacles in the environment. Because of this, it is imperative that our MCU can perform instructions as quickly as possible, as to prevent any potential injuries of our consumers.

The two Arm Cortex M0 microcontrollers, the K32 L2B and STM32F048C6, both run at 48 MHz, the Arm Cortex M4 featured in the MAX32625 runs at up to 96 MHz, and the MSP430’s processor runs at up to 16 MHz.

Clearly the ARM based processors run at a much higher clock speed when compared to the Texas Instruments microcontroller, and among the three ARM microcontrollers the MAX32625 has by far the highest maximum clock speed. When choosing amongst those ARM microcontrollers, the MAX32625 can be easily chosen as the winner in performance, however compared to the Texas Instruments MSP430, it is harder to say. Texas Instruments claims that their MCU delivers “40x the performance” of ARM processors in spite of the lower clock rate. Thus, in comparison it is harder to determine a clear winner across architectures without more proper benchmarking.

Interfacing:

The general-purpose input/output pins are used for transferring data or power to or from the MCU. In our vest, we had the GPIO pins work as both inputs and outputs. For our vest, we had minimum need to have three GPIO pins just to send signals to our vibration motors, since we plan on having three directions that our user can be notified of incoming obstacles from.

In addition to those three GPIO pins, we would need connections to the sensors that are used to detect objects. In the case of ultrasonic sensors, we could get away with simply another two pins for a total of five. In case of additional features being added later in development, it would be good to have twenty GPIO pins as a minimum. This is generally a threshold that we must reach, so having significantly more doesn’t necessarily mean that microcontroller has a huge leg up over others, but if we are left with two similarly performing microcontrollers, the one that gives us extra space will likely win out (extra pins give us room to implement potential stretch goals, given enough time).

All our microcontroller options satisfy this specific condition (twenty GPIOs). The MSP430FR5964 has 68 pins available for interfacing. In addition to those pins, it contains four I2Cs. The STM32F048C6 has 37 GPIOs as well as one I2C. In addition, it has a USB2.0 interface. The K32 L2B has up to 50 GPIOs and two I2Cs. The MAX32625 has 40 GPIOs, three UARTS, and two I2C masters.

Since all microcontrollers chosen satisfy the GPIO condition, and having more pins doesn’t improve the performance of an MCU (twenty is simply a threshold that has to be met by the microcontroller), there is no clear victor in this comparison. Any microcontroller amongst these will have the connections required to interface with any sensors that we choose, as well as potentially a GSM/LTE module. However, if a comparison between MCUs is close, having extra pins could be important if the scope of the project happens to increase.

Analog-To-Digital Conversion (ADC)

All of the potential microcontrollers support analog-to-digital conversion, however each does it at different levels. We were most interested in the resolution of the converter. Higher resolution means that we were going get higher accuracy from whatever sensor we are converting the signal from. We also need to look at the number of input channels allowed, as we may need to be making multiple conversions at once (no more than 10).

The MSP430FR5964 has a 12-bit analog-to-digital converter, with up to twenty external input channels. The NXP K32 L2B has a 16-bit analog-to-digital converter, and also supports up to sixteen channels. The STM32F048C6 has a 12-bit ADC and has ten external channels for performing conversions. The MAX32625 contains a 10-bit ADC and has 4 external channels in addition to internal voltage measuring. Finally, the ATmega328P has a 10-bit ADC with eight external channels.

Comparing the four, for our purposes it appears that the NXP K32 L2B beats the others. The 16-bit analog-to-digital converter is substantially more accurate than the two runner ups (STM32 and MSP430) at 12-bit (65536 different numbers vs 4096). In last place the ATmega328P and MAX32625 have only a 10-bit ADC, making them by far the least accurate. The K32 L2B, MSP430, and STM32 microcontrollers all have as many channels as we anticipate potentially needing, while the ATmega328P does not, so this may disqualify it from being used in the project.

	MSP430 FR5964	NXP K32L2B	STM32 F048C6	ATmega 328P	MAX 32625
Storage (kilobytes)	256	256	32	32	256 or 512
Random Access Memory (KB)	8	32	6	2	128 or 160
ADC Resolution	12-bit	16-bit	12-bit	10-bit	10-bit
CPU Speed	16 MHz	48 MHz	48 MHz	16 MHz	96 MHz
GPIO Count	68	50	37	23	40
Communication Peripherals	4 I2C, 4 UART	2 I2C, 1 UART, 2 SPI	1 I2C, 2 USART, 2 SPI, 1 USB 2.0	1 I2C, 2 SPI, 1 USART	2 I2C, 3 UART, 3 SPI, 1 USB 2.0
Voltage Range	1.8v – 3.6v	1.71v – 3.6v	1.65v – 1.95v		1.14v - 3.6v
Price (USD)	$2.68	$3.42 - $5.14	$2.02	$2.60	$10.52

Table 8 Microcontroller Comparison

Among the microcontroller contenders, many of them meet the requirements that we have for our project. We have decided to use the Maxim Integrated Darwin MAX32625 for our project. It may be the most expensive, but it has the greatest number of communication peripherals and has the strongest processing capabilities of the group.

With as much as 160 kilobytes of memory, it has five times as much random-access-memory as the next strongest options, the K32 L2B. We undoubtedly were needing to store as much data into memory as we could possibly need without having to worry about running out of space. The amount of non-volatile flash storage is also huge compared to the other contenders, having access to as much as 512 kilobytes of storage for our application. This is twice as much as the runner up, and even the weakest model of the MAX32625 meets it at 256 kilobytes.

Its power consumption may be slightly more than the others. Although the microcontroller runs more efficient in low power modes - drawing only 27 microamps per megahertz – it runs at multiple times the clock speed, mitigating power savings. However, the huge increase in performance has been deemed worth the increase in power consumption.

This device is also able to interface with everything that we may need in our project. It has access to 40 GPIOs, two I2Cs, and three UARTs, which our sensors and motors are all compatible with.

Calculations should be performed very quickly on the 32-bit ARM Cortex M4 processor running at 96 MHz, and the speed that we can relay information to the user is paramount in this project. The more processing power that we have available, the faster that we can give that information to the user.

The MAX32625 also has the benefit of being of ARM architecture. Since ARM is growing in popularity, experience with the platform is much sought after from companies in the industry. By completing our project on an ARM Cortex based microcontroller, we can grow our resumes and potentially become more valuable potential employees to companies.

Since we are using the MAX32625 MCU as our microcontroller, we should have and were incentivized into using the MAX-IDE for development. However, it appears that this IDE is likely defunct, with the last supported operating system being Windows XP (which is no longer receiving security updates and is a very vulnerable OS to be running nowadays).

Maxim seems to recommend using a third-party IDE from Mbed to use with the MAX32625, however this IDE lacks more complex features that may be required during development.

Because of this, we still be used the MCUXpresso, since they allow other MCUs to be used with the IDE (although we were not be able to get all of the features that are granted to MCUs that fall under NXP’s brand).

Maxim Integrated has put together a good evaluation kit for the MAX32625 called the MAX32625PICO, which is a small board that can easily be interfaced with via USB connection allowing software to easily be ‘drag-and-dropped’ to the MCU.

Despite being more expensive than the competition, the price difference is miniscule on the small scale that we are working with, since at the moment we plan on only using one MCU on our project. When adding the development board’s price into consideration however, the overall cost to us is actually lower than what would be our second choice (the NXP K32L2B has a $25 development board).

One of our group members already has access to the development board for this microcontroller and may have previous experience that could also expedite development.

3.3 Power Management Subsystem

The hardware design for the prototype includes a power section that will consist of a battery, three different sensors, three vibrating motors, and a microcontroller. For all these components, five different DC-DC converters will be used to provide power to the different components of the prototype at 5.5V, 1.89V, 1.2V, 1.8V, and 3.3V. Power will be drawn from a 22.2Wh rechargeable battery. The voltage from the battery will be regulated and stepped up to 5.5V and regulated to power the long-range and inner perimeter sensor via a DC-DC converter. Further, the voltage from the battery will be regulated and stepped down to 1.59V, 1.2V, 1.8V, and 3.3V to power the short-range sensors and the MCU, respectfully, via DC-DC converters. The three vibrating motors will be powered via the microcontroller.

Managing the power constraints is an important aspect of any electrical design for any prototype. A good estimate of how much power is going to be required by each of the hardware blocks is going to be needed to ensure the 22.2Wh power scheme is viable. In order to track this, two tools will be used, a power diagram and a power budget spreadsheet. Once there is more information about the specific components (part numbers) being used in the design, the will be a final power diagram and power budget that will be filled in with the most up-to-date voltage and current requirements. Our current estimate is that a 22.2Wh battery will be required for the design to function. This is a very rough estimate based on the component options.

In Figure 17, it is evident how all of the components in the system will be laid out. The three different sensors are going to receive data and will send it to the MCU. Although the three sensors have been decided on, the exact sensors that will be used in the final prototype will be decided in the next few months, but in the meantime, research about different sensors has been conducted and three different sensors have been picked. For the current prototype, the long-range sensor and the inner perimeter ultrasonic sensor both use 5.5V but draw different currents at 65A and 20A, respectfully. The short-range sensor will use 1.89V but draw 300A. It is assumed that the user will use this system for a maximum of ten hours per day. This is also assuming that the system will use around 2.5W in one full hour. Additionally, we plan to use a microcontroller to process all the data. This microcontroller uses less than 1A at three different voltages, which is not a significant power consumer for the system. The motors that are planned for use are around 80mA at 3.5V but will be powered via the microcontroller. Finally, the sensors, motors, and MCU will connect via their respective DC-DC converters to the battery. It is assumed that those DC-DC convertors have an efficiency of 80%

because it should be assumed that the converters will drop some power. For that reason, it is estimated that the total use of the system in ten hours is 22.2Wh.

3.3.1 Technologies Available

To power the wearable, multiple DC-DC converters will be used to step up or step-down DC electrical power to a certain voltage. A DC-DC converter is a type of electrical device that converts a certain DC input voltage and outputs a different DC voltage. Most electronic appliances and portable devices use DC-DC conversion instead of AC-DC conversion because DC-DC conversion is mainly used to increase the voltage from the battery's lower voltage. This can, in the long run, save space inside of a device, because there would not be a need for multiple batteries or multiple power circuits. [1] Additionally, many electrical devices have subcircuits that require a voltage that may be different than the voltage supplied by the battery or an external power supply. [2]

There are three different types of non-isolating DC-DC converters that were considered for the wearable, and these are buck converters, boost converters, and buck-boost converters. Non-isolating types of DC-DC converters are used where the voltage needs to be stepped up or stepped down by a relatively small ratio, and there is no issue with the input and output having no dielectric isolation. [3] These three different types of DC-DC converters are a type of switch-mode power supply circuits that use semiconductor switching techniques to get the required output voltage, which is different from standard linear methods that can only provide stepped-down voltage regulation. [4] The buck converter is used to take a DC input voltage and step it down to a reduced DC output voltage. The boost converter is used to take a DC input voltage and step it up to an increased DC output voltage. The final type of DC-DC converter in consideration is a boost-buck converter that can take a DC input voltage and either step-up or step-down voltage to a particular DC output voltage. For the wearable, it will most likely be needed to use both buck and boost converters. There will most likely not be a use for a boost-buck converter for the wearable since there are no components in the wearable that will have or need a varied voltage.

3.3.1.1 Buck Converters

For the wearable, we needed and did have five buck converters. The first buck converter will be used to step down the DC input voltage from the battery at 4.2V to a DC output voltage needed by the Acconeer A111 sensor at 1.89V. The second buck processor will be used to step down 4.2V from the battery to 1.2V needed by the microprocessor. The third buck converter will be used to step down 4.2V from the battery to 1.8V needed by the microprocessor. The fourth buck converter will be used to step down 4.2V from the battery to 3.3V needed by the microprocessor. The three sensors will be powered via the MCU GPIO pins, with three buffers for each motor. The fifth buck converter will be used to step down the 12V from the wall through a wall adapter to charge the battery at 4.2V.

The four buck converters that will be used, will be stepping down the input voltage, and will also be stepping up the input current so that the circuit has a power output that is not too low and will be able to properly power each component of the wearable. There is a basic and common circuit configuration for a buck convertor that uses a series transistor switch, a diode, an inductor, and a capacitor. When the transistor is continuously switched on or off, the average output voltage value will be related to the duty cycle of the circuit or D, which is the conduction time of the transistor of one full switching cycle and D = $t_{on}/(t_{on}+t_{off})$. [4] The buck converter's steady-state output voltage is given by the following equation, Vout = D*Vin. [4] The duty cycle must always be less than one and because the duty cycle multiplies with the input voltage, this makes sure that the output voltage will be less than the input voltage. Additionally, since the output voltage will always be low, the buck converter does not have to keep a low output current, and it can handle a high output current.

3.3.1.2 Boost Converters

For the wearable, there will be a single boost converter. The boost converter will be used to step up the DC input voltage from the battery at 4.2V to a DC output voltage needed by InnoSent sensor at 5.5V. The boost converter will be used to step up the input voltage and will also be stepping down the input current so that the power output is not too high and will not burn the components but will instead be able to properly power each component of the wearable. The boost converters share a very similar circuit composition with a buck converter having a transistor switch, a diode, an inductor, and a capacitor. Like the buck converter circuit, the boost converter’s transistor switch turns on and off, making changes to the duty cycle of the circuit. The boost converter's steady state is given by the following equation, Vout = Vin(1/(1-D), where D = $t_{on}/(t_{on}+t_{off})$ and is the duty cycle of the circuit. [4] The output voltage can be regulated by controlling the duty cycle and must be more than one or much higher than one so that when it multiplies with the input voltage, the output voltage will be high. If the output voltage is high, the output current must be low so that the output power does not burn the components of the wearable. With the steady-state equation in mind, the output voltage will always be greater than the input voltage, making the converter a boost converter.

3.3.1.4 Buck-Boost Converters

The third type of DC-DC converter is the buck-boost converter. This is an adjustable regulator which can both step-down and step-up a voltage functionality. What this kind of DC-DC converter can do is either take the input voltage and reduce the voltage to a lower value to a fixed output voltage or increase the voltage to a higher voltage, all while allowing for a continuous input current. As talked about before, this is essentially a combination of a buck and boost converter. The disadvantage of the boost-buck converter is that the polarity at the load terminal is opposite to that of the source end and therefore application of this type of converter may be limited. [5] The advantage of having a combination of a boost-buck converter is that it can use a minimal number of components while also offering a lower operating duty cycle and higher efficiency across a wide range of input and output voltages. [5]

3.3.2 Technology Selection

Due to the rapidly changing nature of the prototype's design, the components in the schematic may not match the components discussed in this section. For the prototype, there will be five DC-DC converters throughout the power circuit and these five DC-DC converters will be split into six schematics. Using TI WEBENCH, two schematics were reviewed per subsystem of the power circuits. Ultimately, what is being sought after in every DC-DC converter is for it to have a low cost, high efficiency, and low BOM count and small footprint so that the converters do not take up a large space on the PCB and so that the PCB does not end up being too costly. It should also be noted that all Iout values were nominal. That being noted, Iout values on WEBENCH are Iout maximum

3.3.2.1 Buck Converter (12V to 4.2V)

The first subsystem of the power circuit will be used to charge the battery. This DC-DC converter is taking is 12V DC power and stepping it down to 4.2V for the battery to charge. The 12V being stepped down was power stepped down originally by wall power adapter that stepped down 120V AC to 12V DC. It was difficult to narrow down the options for possible candidates since there were over one hundred possible selections for a Vin of 12V and Vout of 4.2V. But, the highest efficiency, low BOM cost, low BOM count, and small footprint were the most important factors for selections of the 12V to 4.2 Buck converter.

The first candidate for the first subsystem has a buck converter topology and is a 4.5V to 17V, 5A, synchronous step-down voltage regulator in SOT23 based around the TPS565201 chip and is shown in Figure 10. The efficiency of this buck converter is 95.8 percent, the BOM cost is $1.72, the BOM count is 10 components, the footprint is 167 mm^2. This is a great candidate because of its high efficiency, low cost, low BOM count, and small footprint.

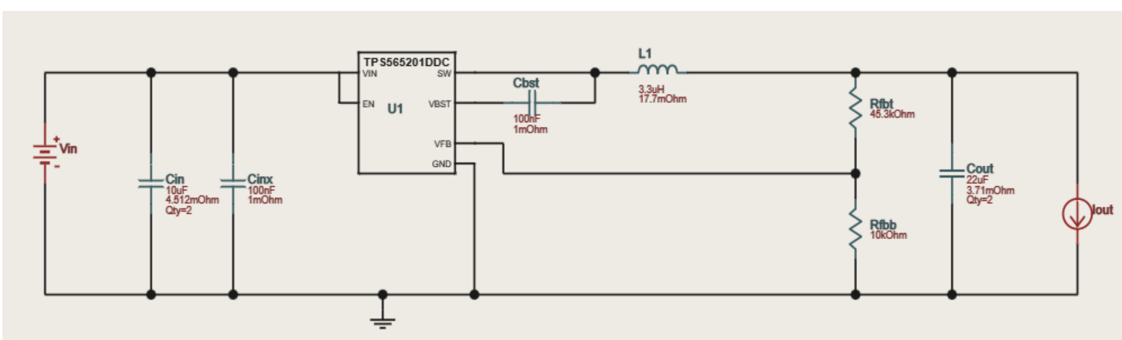


Figure 10: Candidate 1 for the first subsystem of the power circuit

The second candidate for the first subsystem has a buck converter topology and is a 4.5V to 17V input, 4A output, synchronous step-down converter in eco-mode based around the TPS564201 chip and is shown in Figure 11. The efficiency of this step-down converter is 93.9 percent, the BOM cost is $1.52, the BOM count is 9 components, and the footprint is 163 mm^2. This converter is slightly less efficient but less more expensive, has a smaller BOM count, and has a smaller footprint than the first candidate.

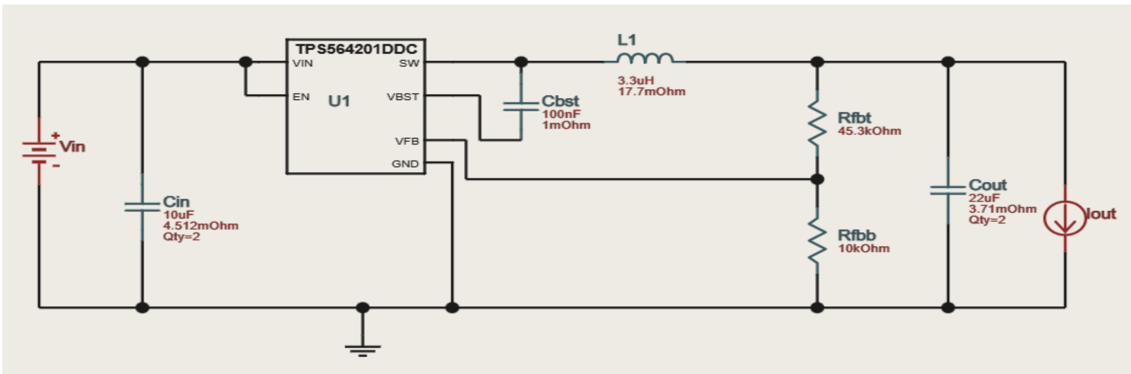


Figure 11: Candidate 2 for the first subsystem of the power circuit

The first and second candidates were the most probable selections for the 12V to 4.2V DC-DC buck converter. Two other candidates were looked at, the third candidate is a buck converter topology and is a 4.5V to 17V input, 3A output, synchronous step-down converter in FCCM mode based around the TPS563208 chip. The efficiency of this buck converter is 92.4 percent, the BOM cost is $1.00, the BOM count is 9 components, and the footprint is 165 mm^2. This converter has a slightly lower footprint than the first candidate but a slightly higher footprint than the second candidate. Further, the third candidate has around the same BOM count and a smaller BOM cost than the first and second candidates. The third candidate also has a lower efficiency than both the first and second candidates.

The fourth candidate for the first subsystem has a buck converter topology and is a 17V input, 3A synchronous step-down regulator in SOT-23 with advanced eco-mode based around the TPS563200 chip. The efficiency of this buck converter is 93.9 percent, the BOM cost is $1.03, the BOM count is 9 components, and the footprint is 165 mm^2. This converter has a slightly higher footprint than all other candidates except the first candidate. Further, the fourth candidate has around the same BOM count but a smaller BOM cost than all other candidates except for the third candidate. The fourth candidate also has a lower efficiency than the first candidate but a comparable efficiency to all other candidates. Below is Table 8, comparing the two preferred candidates, along with the two other possible candidates.

Ultimately, the best candidate for the first subsystem that would provide power to the battery for our prototype would be the first candidate based on the TPS565201 chip. It has high efficiency, low BOM count, low BOM cost, and a small footprint.

12V – 4.2V	Candidate 1	Candidate 2	Candidate 3	Candidate 4
Chip	TPS565201	TPS564201	TPS563208	TPS563200
Efficiency	95.8%	93.9%	92.4%	$1.03
Footprint	167 mm^2	163 mm^2	165 mm^2	165 mm^2
BOM count	10	9	9	9
BOM cost	$1.72	$1.52	$1.00	$1.03

Table 9: Candidates for 1st subsystem of the power circuit

3.3.2.2 Boost Converter (4.2 to 5.5V)

The second subsystem of the power circuit design will used to power the long-range InnoSent sensor and the perimeter ultrasonic DFRobot sensor. The design that was chosen was a DC-DC converter with a minimum Vin of 3V and a maximum Vin of 4.2V as this is the voltage range of our battery as it discharges. This design will output 5.5V which is required for the operation of the long-range sensor and perimeter sensor. Additionally, the buffers that are being used for the 3.3V DC signal are made with op-amps. Op-amps have a high voltage rail and a low voltage rail that they are powered by. These are their plus and minus supplies. There is going to be a use of ground for the low and then something else for the high. In the theory, if they're a minus three rail and a plus three-rail, the op-amp will be able to make minus three-volts to minus three-volt sine wave perfectly. In practice, the op-amps will not quite be able to reach their poles, so if they are powered from plus three-volts to minus three-volts, then maybe it will be able to produce a sine wave that may be plus 2.8 volts and minus 2.8 volts since plus-minus three-volts are the extreme of what it should be capable of but it won't quite get there. Thus, because a 3.3-volt signal is going to be sent to the motors, the system will need something higher than 3.3 volts to power the op-amps. That is where the 5.5-volt line comes in. With this in mind, it was difficult to narrow down the options for possible candidates since there were again, over one hundred possible selections for a Vin of 4.2V and Vout of 5.5V. But, the highest efficiency, low BOM cost, low BOM count, and small footprint were the most important factors for selections of the 4.2V to 3.3 Boost converter.

The first candidate for the first subsystem has a boost converter topology and is a 20V, 10A fully integrated sync boost with load disconnect based around the TPS61178 chip and is shown in Figure 12. The efficiency of this buck converter is 95.3 percent, the BOM cost is $5.44, the BOM count is 21 components, the footprint is 269 mm^2. This is a great candidate because of its high efficiency but has a high cost, large BOM count, and big footprint.

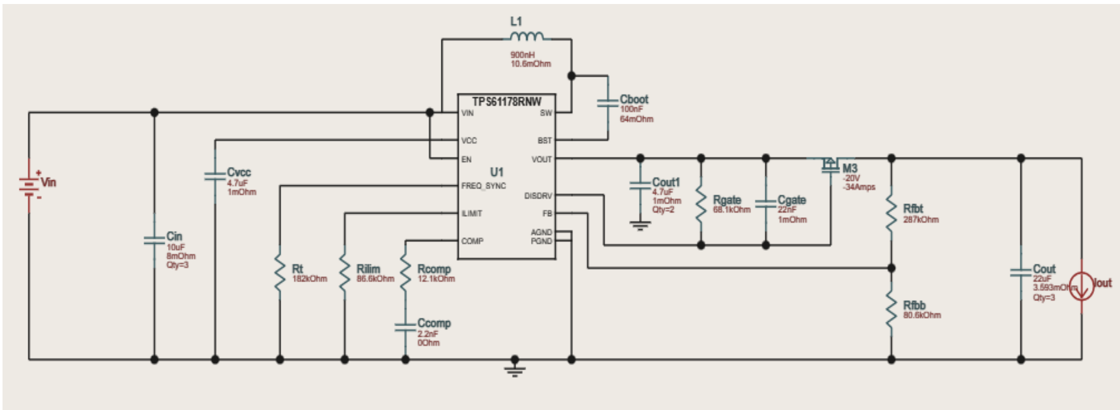


Figure 12: Candidate 1 for the second subsystem of the power circuit

The second candidate for the second subsystem has a boost converter topology and is an 8-A boost converter with a 0.5V ultra-low input voltage converter based around the TPS61022 chip and is shown in Figure 13. The efficiency of this boost converter is 94.9 percent, the BOM cost is $1.33, the BOM count is 7 components, the footprint is 159 mm^2. This boost converter is a good candidate because it has high efficiency but has a lower cost, smaller BOM count, and smaller footprint than most of the other DC-DC converters.

The first and second candidates were the most probable selections for the 4.2V to 5.5V DC-DC boost converter. Two other candidates were looked at, the third candidate for the second subsystem has a boost converter topology and is a 10A fully integrated synchronous boost converter based around the TPS61088 chip. The efficiency of this boost converter is 93.9 percent, the BOM cost is $2.53, the BOM count is 18 components, the footprint is 220 mm^2. This boost converter could be a great candidate because it has high efficiency but has a lower cost, smaller BOM count, and smaller footprint than the first candidate.

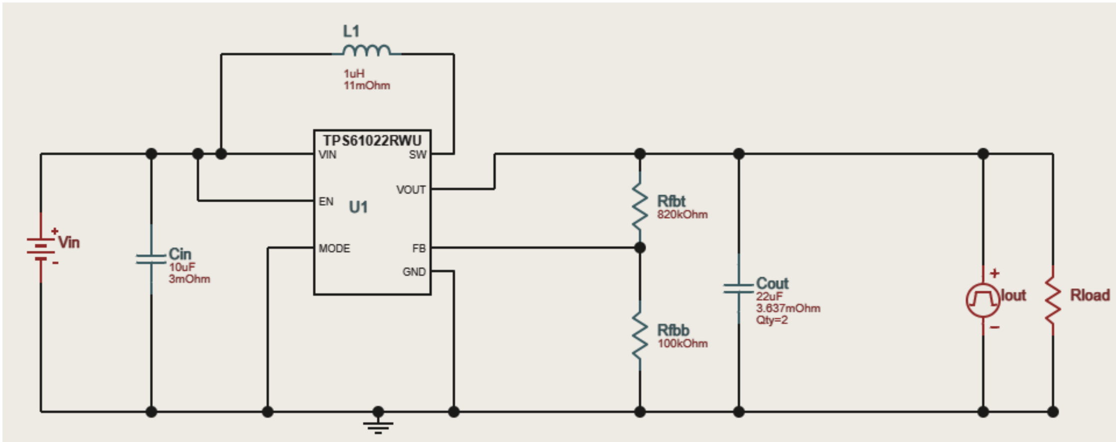


Figure 13: Candidate 2 for the second subsystem of the power circuit

The fourth and last candidate for the second subsystem has a boost converter topology and is an 8-A valley current, adjustable output voltage synchronous boost converter based around the TPS61236P chip. The efficiency of this boost converter is 95.9 percent, the BOM cost is $1.56, the BOM count is 11 components, the footprint is 158 mm^2. This boost converter could be an even better candidate because it has high efficiency but has a lower cost, smaller BOM count, and smaller footprint than the other candidates. Below is Table 9, comparing the two preferred candidates, along with the two other possible candidates.

4.2V – 5.5V	Candidate 1	Candidate 2	Candidate 3	Candidate 4
Chip	TPS61178	TPS61022	TPS563208	TPS61236P
Efficiency	95.3%	94.9%	93.9%	95.9%
Footprint	269 mm^2	159 mm^2	220 mm^2	158 mm^2
BOM count	21	7	18	11
BOM cost	$5.44	$1.33	$2.53	$1.56

Table 10: Candidates for 2nd subsystem of the power circuit

Ultimately, the best candidate for the second subsystem that would provide power to the long-range sensor and the perimeter ultrasonic sensor that is on the prototype would be the second candidate based on the TPS61022 chip.

3.3.2.3 Buck Converter (4.2 to 1.89V)

The third subsystem of the power circuit design will be used to power Acconeer A111 short-range sensor. Again, the design that was chosen was a DC-DC converter with a minimum Vin of 3V and a maximum Vin of 4.2V. This design will output 1.89V and 0.3A which is required for the operation of the short-range sensor. Once again, the team needed to narrow down the options for possible candidates since there were again there were too many selections. But, the highest efficiency, low BOM cost, low BOM count, and small footprint were the most important factors for selections of the 4.2V to 1.89 Buck converter.

The first candidate of the third subsystem has a buck converter topology and is a 2.4V to 5.5V input, 4A synchronous step-down converter based around the TPS62865 chip and is shown in Figure 14. The efficiency of this buck converter is 94.5 percent, the BOM cost is $1.48, the BOM count is 8 components, the footprint is 55 mm^2. This boost converter is a good candidate because it has high efficiency, lower cost, small BOM count, and a small footprint.

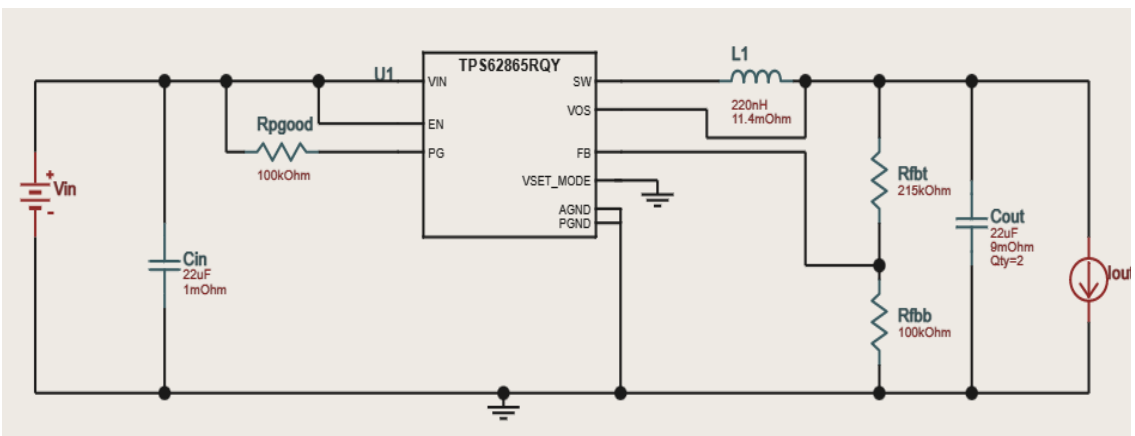


Figure 14: Candidate 1 for the third subsystem of the power circuit

The second candidate of the third subsystem has a buck converter topology and is a 5.5V 4A synchronous step-down converter with an IC interface converter based around the TPS628682A chip and is shown in Figure 15. The efficiency of this buck converter is 93.1 percent, the BOM cost is $1.48, the BOM count is 6 components, the footprint is 48 mm^2. This buck converter is a good candidate because it has a lower BOM count and footprint than the first and third candidates, has slightly lower efficiency, but has a comparable price.

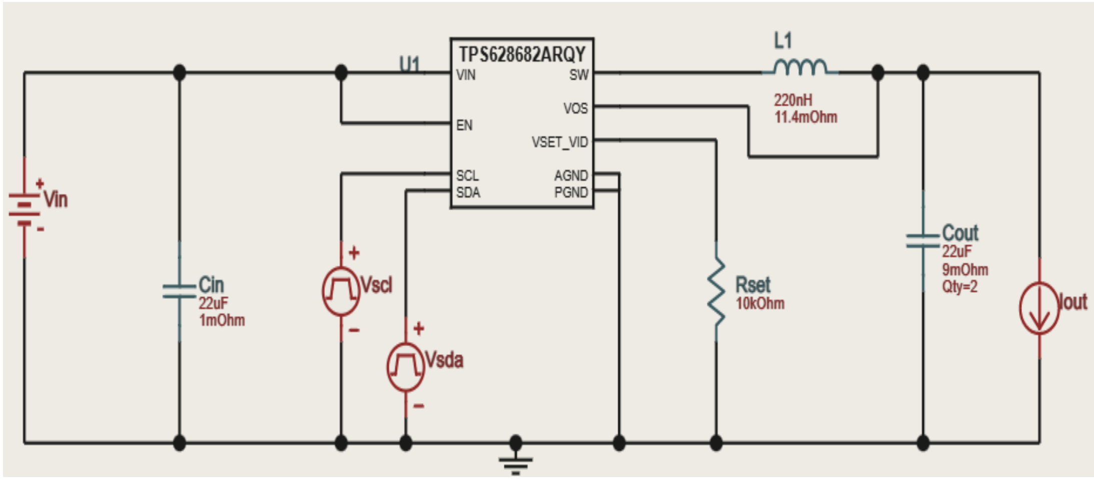


Figure 15: Candidate 2 for the third subsystem of the power circuit

The first and second candidates were the most probable selections for the 4.2V to 1.89V DC-DC boost converter. Two other candidates were looked at, the third candidate of the third subsystem has a buck converter topology and is a 3A high-efficiency step-down converter based around the TLV62090 chip. The efficiency of this buck converter is 91.4 percent, the BOM cost is $1.32, the BOM count is 9 components, the footprint is 64 mm^2. This buck converter is a good candidate because it has a lower cost than the first candidate, but has slightly lower efficiency, a bigger BOM count, and a larger footprint.

The fourth and last candidate of the third subsystem has a buck converter topology and is a 2.95V to 6V input, 2A synchronous step-down SWIFT converter based around the TPS54218 chip. The efficiency of this buck converter is 92.5 percent, the BOM cost is $1.27, the BOM count is 17 components, the footprint is 146 mm^2. This buck converter is a good candidate because it has high efficiency and low cost, comparable to the other converters, but has a high BOM count and a larger footprint. Below is Table 10, comparing the two preferred candidates, along with the two other possible candidates.

4.2V – 5.5V	Candidate 1	Candidate 2	Candidate 3	Candidate 4
Chip	TPS62865	TPS628682A	TLV62090	TPS54218
Efficiency	94.5%	93.1%	91.4%	92.5%
Footprint	55 mm^2	48 mm^2	64 mm^2	146 mm^2
BOM count	8	6	9	17
BOM cost	$1.48	$1.48	$1.32	$1.27

Table 10: Candidates for 3rd subsystem of the power circuit

Ultimately, the best candidate for the third subsystem that would provide power to the Acconeer A111 short-range sensor for the prototype would be the first candidate based on the TPS62865 chip. This is due to it having a low BOM count, low BOM cost, high efficiency, and a small footprint.

3.3.2.5 Buck Converters (4.2 to 1.2, 1.8 & 3.3V)

The fourth, fifth, and sixth subsystems of the power circuit design will be used to power the microcontroller and therefore also the three vibrating motors. The design that was chosen for the fourth, fifth, and sixth DC-DC converters all had a minimum Vin of 3V and a maximum Vin of 4.2V. This design will output 1.2V for the first VDD. The next design will out 1.8V for the second VDD. The design will output 3.3V for the VDDIO. All these outputs are required for the operation of the microcontroller. For the final time, the team needed to narrow down the options for possible candidates since there were again there many selections. But, the highest efficiency, low BOM cost, low BOM count, and small footprint were the most important factors for selections of the 4.2V to 1.2V, 1.8V, and 3.3V converters.

The first candidate of the fourth subsystem has a buck converter topology and is a 2.4V to 5.5V input, 4A synchronous step-down converter based around the TPS62865 chip and is shown in Figure 16. The efficiency of this buck converter is 91.9 percent, the BOM cost is $1.47, the BOM count is 7 components, the footprint is 52 mm^2. This buck converter is a good candidate because it has low cost, high efficiency, a small BOM count, and a small footprint.

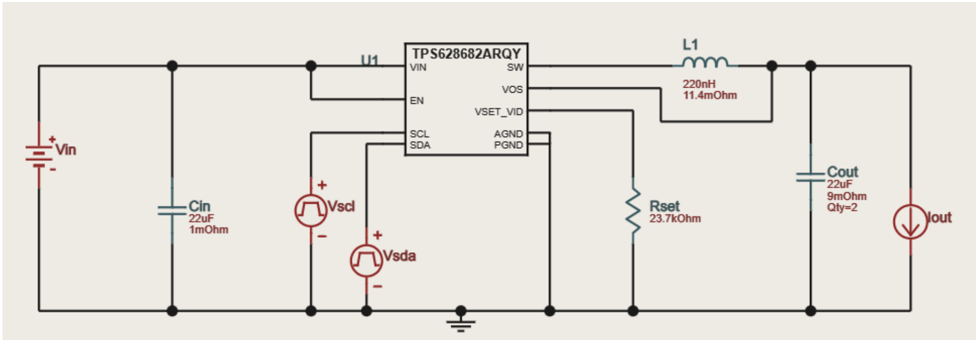


Figure 16: Candidate 1 for the 4th subsystem of the power circuit

The second candidate of the fourth subsystem has a buck converter topology and is a 5.5V, 6A synchronous step-down converter with I2C interface converter based around the TPS628640B chip and is shown in Figure 17. The efficiency of this buck converter is 91.9 percent, the BOM cost is $1.48, the BOM count is 6 components, the footprint is 45 mm^2. This buck converter is a good candidate because it has lower cost, higher efficiency, a smaller BOM count, and a smaller footprint than the first candidate.

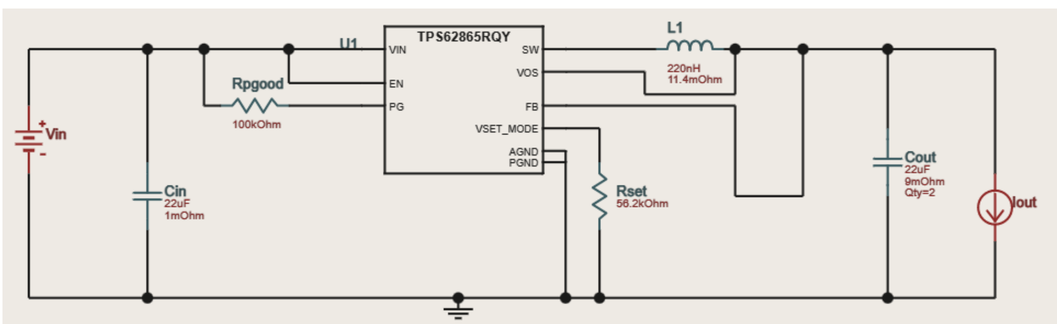


Figure 17: Candidate 2 for the 4th subsystem of the power circuit

The first candidate of the fifth subsystem has a buck converter topology and is a 5.5V 4A synchronous step-down converter with an IC interface converter based around the TPS628682A chip and is shown in Figure 18. The efficiency of this buck converter is 92.8 percent, the BOM cost is $1.46, the BOM count is 6 components, the footprint is 49 mm^2. This buck converter is a good candidate because it has low cost, high efficiency, a small BOM count, and a small footprint.

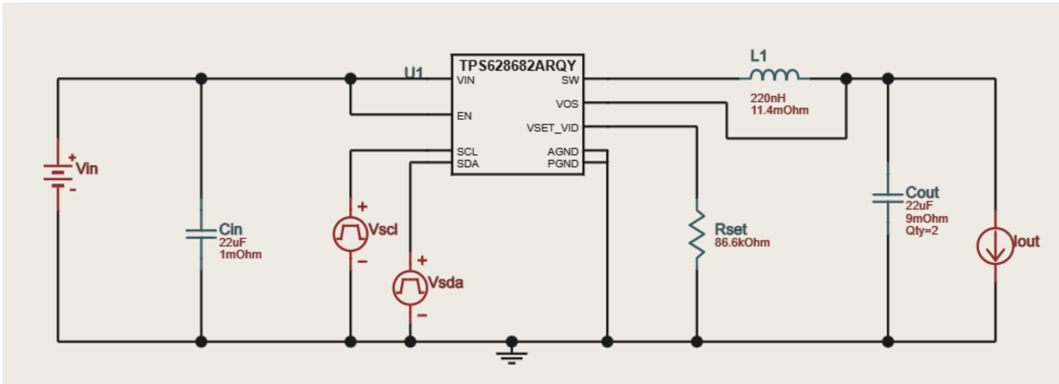


Figure 18: Candidate 1 for the 5th subsystem of the power circuit

The second candidate of the fifth subsystem has a buck converter topology and is a 2.4V to 5.5V input, 4A synchronous step-down converter based around the TPS62865 chip and is shown in Figure 19. The efficiency of this buck converter is 94.3 percent, the BOM cost is $1.47, the BOM count is 7 components, the footprint is 52 mm^2. This buck converter is a good candidate because it has higher efficiency than the first candidate but has a larger BOM count and larger footprint than the first candidate.

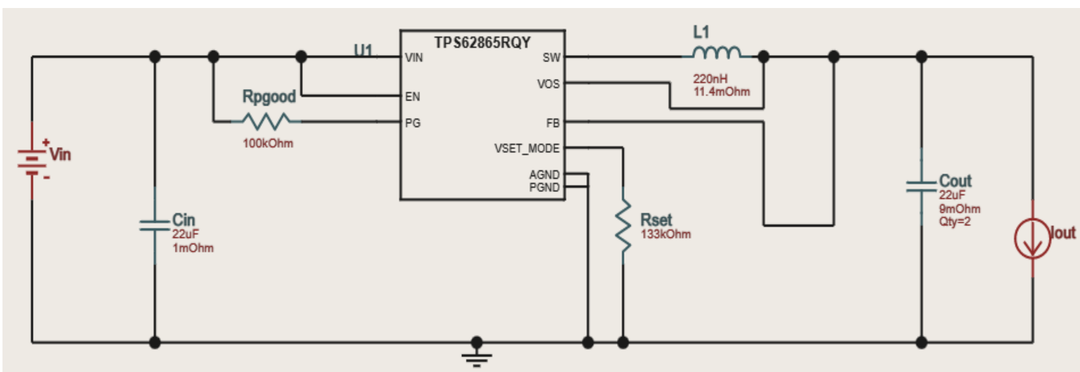


Figure 19: Candidate 2 for the 5th subsystem of the power circuit

The first candidate of the sixth subsystem has a buck-boost converter topology and is a high-efficiency 1.5A single inductor buck-boost converter based around the TPS630242 chip and is shown in Figure 20. The efficiency of this buck-boost converter is 94.4 percent, the BOM cost is $1.40, the BOM count is 5 components, the footprint is 93 mm^2. This buck-boost converter is a good candidate because it has low cost, high efficiency, a small BOM count, and a small footprint.

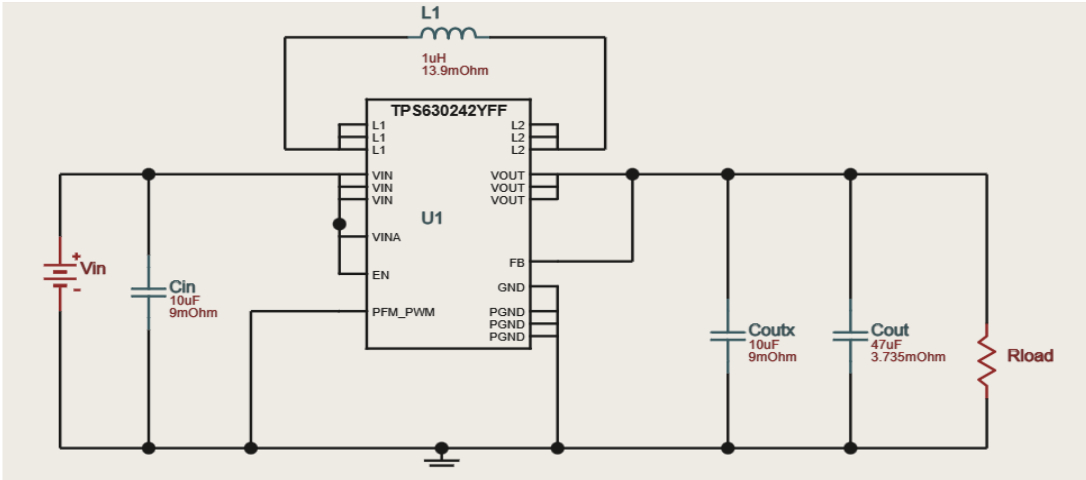


Figure 20: Candidate 1 for the 6th subsystem of the power circuit

The second candidate of the sixth subsystem has a buck-boost converter topology and is a 2.4V to 5.5V input, 4A synchronous step-down converter based around the TPS62865 chip and is shown in Figure 21. The efficiency of this buck-boost converter is 95.1 percent, the BOM cost is $N/A, the BOM count is 42 components, the footprint is N/A mm^2. This buck-boost converter is a good candidate because it has higher efficiency but other than that is may not be a good candidate

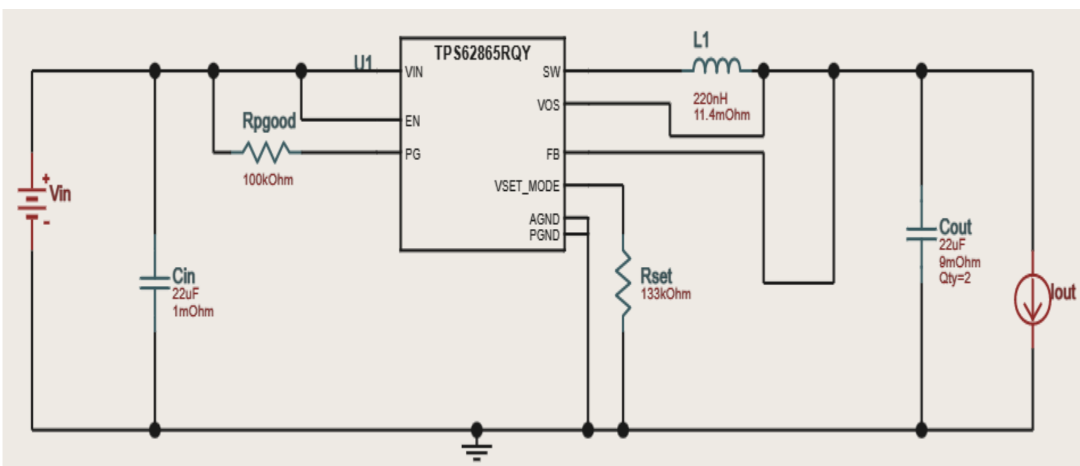


Figure 21: Candidate 2 for the 6th subsystem of the power circuit

Below is Table, comparing the two preferred candidates for the fourth, fifth, and sixth subsystem:

4.2V – 1.8V	Candidate 1	Candidate 2
Chip	TPS628682A	TPS62865
Efficiency	92.80%	94.30%
Footprint	49 mm^2	52 mm^2
BOM count	6	7
BOM cost	$1.46	$1.47
Chip	TPS630242	TPS62865
Efficiency	94.40%	95.10%
Footprint	93 mm^2	N/A mm^2
BOM count	5	42
BOM cost	$1.40	$N/A
4.2V – 1.2V	Candidate 1	Candidate 2
Chip	TPS62865	TPS628640B
Efficiency	91.90%	91.90%
Footprint	52 mm^2	45 mm^2
BOM count	7	6
BOM cost	$1.47	$1.48

Table 11: Candidates for 4^{th}, 5^{th}, and 6th subsystem of the power circuit

Ultimately, the best candidate for the fourth subsystem that would provide power to the first VDD(1.2V) of the microcontroller for our prototype would be the second candidate based on the TPS628640B chip. The best candidate for the fifth subsystem that would provide power to the second VDD(1.8V) of the microcontroller for our prototype would be the first candidate based on the TPS628682A. Finally, the best candidate for the sixth subsystem that would provide power to the third VDDIO(3.3V) of the microcontroller for our prototype would be the first candidate based on the TPS630242 chip.

At the end of Senior Design II, the power distribution network had gone through many redesign stages as hardware was developed. The final block diagram is presented below:

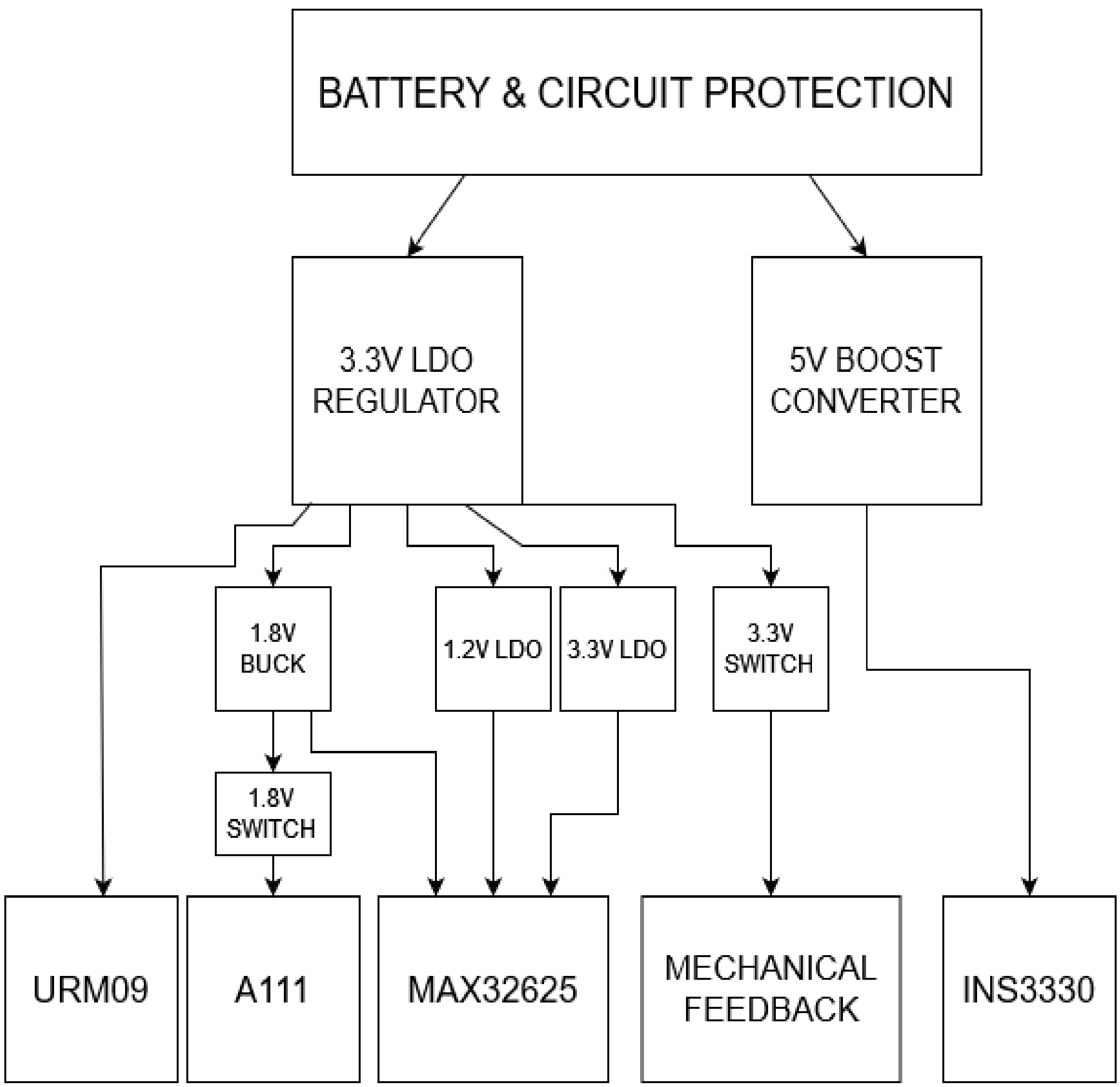


Figure 10: Power Distribution Network

Parts used to fulfill each role are tabulated below:

ADP3338AKCZ-3.3-RL	Analog Devices Inc.	IC REG LINEAR 3.3V 1A SOT223-3
ISL9111AEH50Z-T7A	Renesas Inc	IC REG BOOST 5V 800MA SOT23-6
ST1S12G18R	STMicroelectronics	IC REG BUCK 1.8V 700MA TSOT23-5
MIC5258-1.2YM5-TR	Microchip Technology	IC REG LINEAR 1.2V 150MA SOT23-5
MIC5205-3.3YM5-TR	Microchip Technology	IC REG LINEAR 3.3V 150MA SOT23-5
TS5A3160DCKT	Texas Instruments	IC SWITCH SPDT SC70-6
SIP32431DR3-T1GE3	Vishay Siliconix	IC PWR SWITCH P-CHAN 1:1 SC70-6

Table 11

All components needed for the correct functioning of each of these integrated circuits are summarized in the overall schematic at the end of the document.

3.4 Battery & Circuit Protection Subsystem

Choosing the power supply for the system is the most important part of the project because without providing power the wearable, or any device for that matter means it will not work. It does not matter if the system is powered via battery that was charged by the grid or through renewable energy, every technology will need power to run. That is something that will not change and is something the project must extensively research and decide upon. A bad choice of battery or circuit protection subsystem could ruin the components of the system. This could be very bad for the project, because currently there is a electrical component shortage, so it is imperative that our battery and circuit protection subsystem be heavily thought out. Below is intensive research on technologies that will be used in our project.

In a DC power supply, current streams in a single way while current shifts bearing in an AC power supply. Direct current uses electrons that move in an orderly fashion. This straight development, rather than AC wave movement, gives the current its name. DC comes from batteries, sun-powered cells, energy components, and alternators. Most hardware requires this power type and is the reason most gadgets have a DC power source that is as batteries or need to change over the AC power from outlets to DC power through a rectifier. It is liked for hardware since ACs highs and lows of exchanging current can harm the inner parts.

If a DC voltage is wanted, and an AC power source is utilized for the DC power supply, an AC-to-DC would be needed to acquire a DC yield voltage. The power comes from power plants with an AC power supply, and the power is accessible in the divider attachments. The power accessible in the divider attachment is 120-volt, 60-cycle AC power in the USA.

For Friendly Eyes, we would utilize a DC power supply in the circuit and charge the battery, so what follows is a description of technologies and parts related to charging and power handling for the subsystem.

3.4.1 Technologies Available

There is a choice of either having the wearable directly always connected to the power grid through a wall power adapter, or portable batteries that can be either primary single-use batteries or secondary rechargeable multi-use batteries. A wall adapter would allow us to simplify our power distribution but because the wearable should be portable to allow for ease of use, the need for a portable battery and a separate charging circuit would be required. Whether the batteries should be primary or secondary depends on how many times the intended user would use the vest, the duration of the battery's lifecycle, and how many times would the user have to replace the battery.

3.4.1.1 Battery Types

Most electrical devices used in the world today are either run on a battery or directly connected to a power supply. But, if electrical devices need to be portable, they will rely on battery power to support everyday use. Most commonly, cell phones, laptops, headphones and earphones, tablets, and cars, all rely on battery-sourced power. With the many different devices that use batteries, it is no mystery that there are two types of batteries and different variations of those types in the market today. It is the team's job to find the most suitable battery for the wearable. While a battery may not be the most efficient way to provide power, one of the goals of this project is to make the wearable portable for an extended period, and a battery can provide the most benefits to achieve that goal. It would be difficult to have the wearable not powered by a battery since it is navigational support for the blind and partially blind and if it needed to be connected from the PCB through a cable to a wall plug at all times, the user would be immobile or would run the risk of tripping over a cable and thus defeating the purpose of the wearable. So, it is the team's job to research different types of batteries and make sure our wearable can be used for the intended time.

Primary Batteries

Primary batteries are batteries that cannot be recharged once they have been depleted. This is due to the chemistry inside of the battery and once the chemical reaction inside the primary battery has taken place, the chemistry of the cells inside it cannot be reversed, and thus they cannot be recharged. [6] The most common type of primary battery ranges from coin to AAA batteries. These batteries can be found in any type of store around your neighborhood and are usually bought with the intention of use for weeks or months at a time. For example, most of us use these batteries for our TV remote controls. If you buy a new TV, they usually come with two AA batteries for you to put in the remote control and you don't think about the batteries dying in a few months or a year because you want to set up your new TV. Once they are dead, you simply buy new ones to replace the dead batteries.

The ease of replacement is a goal that came to mind when thinking about the wearable. Initially, there needed to be enough power getting to the PCB and additional components but whether the batteries would be accessible enough to be replaced by someone that was blind or partially blind and whether those batteries should be rechargeable or not was not much of a concern. If the wearable used primary batteries, primary batteries are usually lighter and smaller than most secondary batteries, they would have a longer service per charge, good charge retention, and because they are disposable but common, their replacement would readily be available. [7] But, if a user lived alone, and the wearable used batteries that are of the primary type, how long would the battery last and how many batteries would they need to support the system for hours, days, and weeks at a time became concerning questions. Doing the power distribution calculations for the system made the team realize that a user would have to go every week to a store and buy batteries for the wearable. This would cause the wearable to become expensive to the user when another one of our goals is to make the wearable relatively inexpensive. Additionally, although access to the batteries would be easy for the user, if a single battery of the wearable was drained while the others were not, it would be difficult for the user to test which battery was the one that drained and should be replaced.

Even with all the disadvantages of using a primary type of battery, these batteries were still looked at, and specifically, the most popular type of disposable battery was alkaline batteries. The amount of current an alkaline can deliver is dependent on the size of the battery itself. Additionally, the nominal voltage that was established by most manufacturers is 1.5V, and to achieve a higher total voltage alkaline batteries can be connected in series to generate a voltage like 4.5V or 6V. [8] The goal was to make the wearable cheap and environmentally friendly and alkaline batteries are cheap and are safe since there is no leakage from them. That being said, although they are safe, any type of battery that is frequently disposable is not very environmentally friendly. One of the biggest problems with alkaline batteries is that they have a low current flow. Most of the components of the wearable require low current but the long-range and sensor and perimeter sensors require a current higher than what alkaline batteries could provide if the size and amount of the batteries were to be kept down. Although the wearable is using secondary battery choices, primary battery options were still a way to make certain components of our wearable work at the beginning of our design

Secondary Batteries

Secondary batteries are distinctly different from primary batteries because they are rechargeable and therefore reusable. Secondary batteries are recharged by passing a current through the circuit in the opposite direction to the current during discharge. [7] Even when the original pre-charge is spent, the chemistry and internal setup of these batteries are built to be able to be recharged. When thinking about the wearable, it was wanted that the battery is a single unit so that the user could easily remove it from the wearable. Further, the battery needed to be lightweight and easily replaceable in the long run. Further, the charging station needed to be easy to use and easily replaceable as well. There were many types of secondary types of batteries that were looked at but the four that were thought to be worth looking into were lithium-ion, nickel-cadmium, lithium-polymer, and nickel-metal hydride batteries,

Lithium-Ion Batteries

Lithium-ion batteries are one of the most common and popular rechargeable batteries in the world. You can find them in just about any portable electrical device in the market today and are frequently used in our cell phones, laptops, and even electric cars. The way these batteries work is when the battery is charging up, lithium ions from the positive electrode move through the electrolyte chemical and into the negative electrode. [9] When the battery is discharging, the opposite happens with the lithium ions moving from the negative electrode through the positive electrode and finally moving back to the negative electrode.

There are several advantages to using lithium-ion batteries, but one is that they have a high energy density. Having a high energy density means a battery has a longer run time than the battery's size and weight. [10] This is especially desirable for the wearable because the battery supporting the components needs to have a large watt-hour per kilogram so that the battery that goes on the wearable is lightweight and of long use for the user. If the battery was too heavy for the user, the wearable would be undesirable since the intended goal is for it to be a staple in the intended user’s everyday life. The reason that lithium batteries have such a high energy density is that lithium is a highly reactive element that can store a lot of energy in the atomic bonds while also being able to release these same amounts of energy, all contained in a smaller casing than other types of batteries. [11]

A second advantage of using lithium-ion batteries is that they have no memory effect. What this means is that you do not have to completely discharge them to be able to recharge them. [12] In other batteries such as nickel-cadmium and nickel-metal hydride batteries, if they are recharged before they have been discharged completely, their ability to store and deliver energy would degrade over time. In addition to having no memory effect, lithium-ion batteries can handle hundreds of charge and discharge cycles and can also hold their charge well. A nickel-metal hydride battery has about twenty percent loss of charge per month, while lithium-ion batteries only lose about five percent of their charge per month. The ability to be able to recharge the batteries without having to wait for them to fully recharge, the ability to be durable for a long time before needing to be replaced are aspects the intended user would appreciate in the design.

A third advantage of using lithium-ion batteries is that they have a low self-discharge rate of about one to two percent per month. Batteries such as nickel-cadmium or nickel-metal hydride, when not used or stored for a long time, will get discharged over time, around twenty to thirty percent per month. Since lithium-ion batteries have a low discharge rate, a user could potentially buy a second battery, charge it, and know that if they had it in their bag or car for a month or two, that it would be available for use when necessary.

A fourth advantage of using lithium-ion batteries is that they are more environmentally friendly than their other secondary battery counterparts. One of the goals for this project was that the prototype is safe for the environment and safe for the user. Lithium-ion batteries do not contain toxic ingredients like cadmium, lead, and mercury, which makes these batteries a lot less toxic, easier to dispose of and recycle, and relatively harmless in the long run to the user.

Although lithium-ion batteries have many advantages, some disadvantages must be considered. Even though one advantage to lithium-ion batteries is that they can handle hundreds of charge and discharge cycles, the batteries suffer from aging, and will only be able to withstand around one thousand discharge cycles before the capacity starts to fall. [13] This is a problem all batteries have, so even though it is considered a disadvantage, it is not something uncommon. The adjacent problem to a lithium-ion battery suffering from aging is that they are higher in price than other rechargeable batteries. Even with this disadvantage, with the power distribution calculated, a lithium-ion battery would be a comparable price to other secondary batteries.

Another disadvantage with lithium-ion batteries is they are not as robust as other rechargeable battery types. The battery must have protection from being extremely overcharged or discharged and they must have their current maintained within safe limits and a tight voltage. [14] The battery must have additional protection circuity so that it is not overcharged, discharged, or over-heated. With this in mind, there are plans to incorporate a flame and shock-resistant pouch on the vest for safe storage of any battery is chosen because it is understood that any battery might be warm from constant usage. Additionally, although these batteries are safe during normal operation, if a lithium-ion battery is seriously damaged, moisture or oxygen intruding into the battery can cause a dangerous reaction such as a fire or even an explosion. Again, it is not intended for the battery to be put in a situation where this would happen, but as a precaution, the battery will be put in a fire and shock-rated pouch on the vest.

Lithium-Polymer Batteries

Even though Lithium-Ion batteries are one of the most popular batteries nowadays, those batteries have a small problem that cannot be solved because it comes from their chemical combination. Lithium-Ion batteries do not have a very high energy density, and because of that, projects that need a lot of energy use many cells to get the desired power. Lithium-Polymer batteries work in the same way as Lithium-Ion. Lithium ions from the positive electrode move through the electrolyte chemical and into the negative electrode when the battery is charging up. When the battery discharges, the opposite happens with the lithium ions moving from the negative electrode through the positive electrode and finally moving back to the negative electrode. The only difference between the batteries is that the Lithium Polymer uses a polymer electrolyte instead of a liquid electrolyte.

Lithium Polymer has many benefits over many batteries. The first advantage is high energy density. The weight of Lithium Polymer is at least half of the weight of a Nickel-Cadmium or a Nickel-Hydride battery of the same energy capacity. The battery volume is 50% less than the Nickel-Cadmium and 30% less than the Nickel-Hydride, and they are around 20% lighter than Lithium-Ion. This makes the battery a large-capacity battery.

The second advantage is thin thickness. Liquid lithium battery adopts a method that first customizes the shell and then plugs the positive and negative electrode materials. There is a technical bottleneck when the thickness is below 3.6mm. The polymer cell does not have this problem because the thickness can be less than 1mm, which aligns with the development direction of applications thinning.

The third advantage is the low internal resistance. The internal resistance of the polymer batteries is less than any other battery and that is because the current domestic internal resistance of the polymer batteries is below 35 milliohms. This means that the power loss across the battery is making the battery operate for longer.

The fourth advantage is customized shape. Polymer batteries have the characteristic of changing the dimension of their internal cells. That makes it so that the battery can have any shape that the final customer wants (i.e., circle, ellipse, semi-circle, triangle, etc.). The development of a new cell model decreases the price of the production and then the battery. The mold opening cycle is shorter and, technically, uses the full use of the battery shell space.

The fifth advantage is good charging and discharging characteristics. Polymer batteries can be fully charged in a period of one to two hours because of the constant current and constant voltage charger with a rated voltage of 4.2V. Polymer batteries use colloidal electrolytes, which have more stable discharge characteristics and a higher discharge platform than liquid electrolytes. Also, the output voltage of a single Lithium Polymer is around 3.7V which is the equivalent of three Nickel-Cadmium or Nickel-Hydride batteries in series. Finally, Polymer batteries have more than 500 cycles of charging and discharging.

The sixth advantage is that Polymer batteries are safer. The outer package is an aluminum-plastic package, which is different from the metal shell of a liquid lithium battery. Due to the use of flexible packaging technology, the internal quality hidden trouble can be immediately through the outer packaging deformation and show, once the occurrence of safety hidden trouble, will not explode, and will only swell. Also, Polymer batteries are free of harmful metals such as cadmium, lead, and mercury. For that reason, Lithium Polymer batteries passed the ISO14000 (which is a family of standards related to environmental management that exists to help organizations minimize how their operations negatively affect the environment), environmental system certification, and the products comply with the EU RoHS directive.

The last advantage is that they do not have a memory effect. Memory effect is a phenomenon that happens to Nickel-Cadmium batteries. This effect reduces the capacity of the battery and then eventually affects the charging and discharging cycle. Lithium polymer batteries do not have this effect.

Lithium Polymer batteries also have disadvantages that are not critical but important to take into consideration. The first disadvantage is that Polymer technology is relative a new product, and because of that, the price of this battery is 20% to 30% higher than Lithium-Ion. A small project where only one or two batteries are used does not show a considerable price difference but, it does make a significant gap for big projects.

The second disadvantage is that Polymer batteries need special care while charging and discharging. Because of its chemical combination, Polymer batteries, along with Ion batteries, can be dangerous if they are operated wrongly. This means that the charging station and the system where the battery will be used need to be working properly to avoid shorts or reverse currents to the battery. The problem with these batteries is when something goes wrong, or if they receive an impact, what will happen is that they can inflate from an internal reaction and eventually explode and catch on fire.

Nickel-Cadmium Batteries

Nickel-cadmium is a different type of secondary rechargeable battery. They were once very popular and were used in a variety of electronic devices such as portable computers, drills, and other small battery-operated devices. With the arrival and further development of the lithium-ion battery, the broadened use of the nickel-cadmium battery dwindled. One reason why the usage of these batteries fell is that if they are seriously damaged, NiCad batteries contain a solution called potassium hydroxide which is very dangerous and highly corrosive when encountering the human skin. [15] That being said, NiCad batteries are one of the most rugged rechargeable batteries, the battery would have to receive a significant enough impact for the battery to have any damage to it. The way nickel-cadmium batteries work is that in a fully discharged NiCad battery, the positive electrode contains nickel hydroxide, and the negative electrode contains cadmium hydroxide. [16] When the battery is charging, the nickel hydroxide in the positive electrode changes to nickel oxyhydroxide. In the negative electrode, the cadmium hydroxide changes to cadmium. As the battery is discharging, the process is reversed, and this is how and why a NiCad battery is rechargeable.

The usage of NiCad batteries brings several advantages, one of them being that they have a higher energy density than lead-acid batteries but adversely they do not have a higher energy density than such batteries like lithium-ion, lithium-polymer, and nickel-metal hydride. Additionally, NiCad batteries can handle tens to hundreds of charges and discharge cycles. A nickel-cadmium battery has a peak capacity of one hundred to three hundred cycles before the performance of the battery starts to fall [17]. Also, a nickel-cadmium battery has a twenty percent self-discharge rate, which means that it loses twenty percent of its charge per month, ten percent less than nickel-metal hydride.

Another advantage to using a NiCad battery is that they have a faster charge rate than most other batteries without any stress to the battery itself. NiCad batteries take around one hour to charge fully while Li-on and LiPo batteries take around two to four hours to charge fully. Also, NiCad batteries can be recharged at low temperatures and have a good low-temperature performance. Further, NiCad batteries have a long shelf life, only losing about twenty percent of their original charge if they were fully charged when stored. [???] One other advantage is that NiCad batteries are some of the more economically priced of the rechargeable batteries, so the intended user of the wearable would not have to worry about replacing these batteries since they are durable and if they do have to replace them or want a second NiCad battery, they are cheap.

A disadvantage of using a NiCad battery is that these types of batteries have a memory effect. What this means is that if the battery still has a twenty-five percent charge left in it, and the user goes ahead and recharges it from that percentage until it’s fully charged, the nickel-cadmium batteries will gradually lose their maximum energy capacity over time. For the NiCad battery not to lose its energy capacity, the battery should be fully drained before recharging. This could be inconvenient for the users who may need to recharge their batteries to be confident that their wearable will last for a prolonged time and might be in situations where they cannot wait for the battery to discharge completely.

Nickel Metal-Hydride Batteries

One of the most common batteries in the world is the alkaline batteries which are a primary battery type. Alkaline batteries can be used only once and after they need to be disposed of for new ones. NiMH batteries became very popular because they have the same characteristics as Alkaline batteries, and for that reason, people were able to change that alkaline battery to NiMH, which is rechargeable. NiMH batteries are based on electrochemical charge and discharge reactions that occur between the cathode that contains nickel oxide-hydroxide as the active material and the anode that is composed of a hydrogen-absorbing alloy. The electrodes are separated by a permeable membrane which allows for electron and ionic flow between them and is immersed in an electrolyte that is made up of aqueous potassium hydroxide that undergoes no significant changes during operation.

NiMH batteries have advantages over alkaline batteries. The first advantage is higher energy capacity. NiMH batteries have between 30% to 40% more energy capacity than an alkaline battery of the same size. This means that NiMH batteries can produce the same power output without being as heavy as Alkaline. Also, the volume of the NiMH battery is less than an Alkaline with the same characteristics.

The second advantage of NiMH is that they are not very prone to memory effects. This is a comparison between NiMH and Nickel-Cadmium batteries because, as was explained before, the memory effect can only happen to the secondary battery, and not to Alkaline batteries. That is why Alkaline batteries are not mentioned in this part. Due to the chemical combination of NiMH batteries, they can operate more cycles without having to decrease their voltage output. If the battery can have more cycles and a constant voltage, it will be able to last longer because the user will not need to charge it as often as Nickel-Cadmium.

The third advantage is that NiMH batteries can be recycled. The main reason why NiMH batteries were created is to reduce the contamination and the number of batteries produced. For that reason, after NiMH were used completely, around 300 cycles, they can be recycled to produce a new battery of the same type and have another 300 cycles.

The last advantage is that NiMH batteries are safer than Alkaline or Nickel-Cadmium. Both Alkaline and NiMH batteries can leak its chemical over time and more when they are stored and not in use. However, NiMH can last a long time without leaking anything. Also, NiMH batteries only have mild toxins, which make them safer than the other two batteries.

NiMH has many disadvantages compared to Nickel-Cadmium, and the first one is durability. NiMH battery can have a life of 300 cycles, while the Nickel-Cadmium can last between 400 to 500 cycles. This means that NiMH is more expensive in the long run for a project. The second disadvantage is the price. NiMH batteries are more expensive to produce than Nickel-Cadmium because they are safer and use less toxic chemicals. The third disadvantage is that they take longer to charge, between three to four times more time than Nickel-Cadmium. Lastly, NiMH batteries required more maintenance than Nickel-Cadmium.

Lead Acid Batteries

Lead corrosive batteries are the most commonly utilized battery in photovoltaic frameworks. Even though corrosive lead batteries have a low energy thickness, moderate productivity, and high support prerequisites, they have a long lifetime and low expenses contrasted with other battery types. One of the solitary benefits of corrosive lead batteries is that they are the most commonly utilized type of battery for most battery-powered battery applications and consequently have a grounded setup, mature innovation base.

A corrosive lead battery comprises a negative anode made of springy or permeable lead. The lead is permeable to work with the arrangement and disintegration of lead. The positive anode comprises lead oxide. The two anodes are inundated in an electrolytic arrangement of sulfuric corrosive and water. On the off chance that the terminals come into contact with one another through the actual development of the battery or changes in the thickness of the anodes, an electrically protecting yet synthetically penetrable film isolates the two cathodes. This layer likewise forestalls electrical shorting through the electrolyte.

The inside substance response to the arrangement of lead sulfate precious stones at both the negative and positive terminals, just as the arrival of electrons due to adjustments of the valence charge. The development of this lead sulfate utilizes sulfate from the corrosive sulfuric electrolyte encompassing the battery. Therefore, the electrolyte turns out to be less thought. The full release would bring the two terminals covered with lead sulfate and water rather than sulfuric corrosive encompassing the cathodes. The two cathodes are a similar material at full release, and there is no substance potential or voltage between the two terminals. Practically speaking, be that as it may, releasing stops at the cutoff voltage sometime before this point. The battery ought not to be consequently to be released beneath this voltage.

In the middle of the wholly released and charged states, a corrosive lead battery will encounter a slight decrease in voltage. The voltage level is ordinarily used to demonstrate a battery's charge condition. The reliance of the battery on the battery condition of charge is displayed in the figure beneath. Assuming the battery is left at low conditions of charge for expanded timeframes, giant lead sulfate gems can develop, which for all time diminishes the battery limit. These more giant precious stones are not standard for the average permeable design of the lead anode and are hard to change over once again into the lead.

Between the fully discharged state and charged states, a lead-acid battery will experience a gradual reduction in the voltage. The response changes the lead over to lead oxide at the positive terminal. As a result of this response, hydrogen is advanced. During the initial segment of the charging cycle, the change of lead sulfate to lead and lead oxide is the overall response. Notwithstanding, as charging continues and the vast majority of the lead sulfate is changed over to one or the other lead or lead dioxide, the charging ebb and flow electrolyze the water from the electrolyte, and both hydrogen and oxygen gas is advanced, a cycle known as the "gassing" of the battery. If the current is being given to the battery quicker than lead sulfate can be changed over, then, at that point, gassing starts before all the lead sulfate is changed over, that is, before the battery is completely energized.

Gassing brings a few issues into a corrosive lead battery. Not exclusively does the gassing of the battery raise wellbeing worries because of the dangerous idea of the hydrogen created, yet gassing likewise lessens the water in the battery, which should be physically supplanted, bringing an upkeep part into the framework. Likewise, gassing might cause the shedding of dynamic material from the electrolyte, subsequently forever decreasing the battery limit. Consequently, the battery ought not consistently be charged over the voltage, which causes an effect called gassing. The gassing's voltage changes with the charge rate.

Lead sulfate is a cover, and along these lines, how lead sulfate structures on not set in stone how effectively the battery can be released. Below is Table 11, comparing the five types of secondary batteries

Battery Types	Lithium-Ion	Lithium-Polymer	Nickel-Cadmium	Nickel-Metal Hydride	Lead Acid
Rechargeable	Yes	Yes	Yes	Yes	Yes
Nominal Voltage	3.7V	3.7V	1.2V/cell	1.2V	2V
Energy Density	100-265 Wh/kg	185-220 Wh/L	50-75 Wh/kg	170-420 Wh/L	80-90 Wh/kg
Shelf Life	3-6 years	3-5 years	1.5-3 years	3-5 years	2 years
Cost	High ($140 per kWh)	High (about $100 per kWh)	Low (about $7.50 per kWh)	Medium (about $83 per kWh)	High (about $500 per kWh)

Table 12: Battery type summary

3.4.2.2 Power Management Integrated Circuits (PMIC)

Power management integrated circuits (PMICs) are incorporated circuits for powering the board. Even though PMIC alludes to a broad scope of chips, most incorporate a few DC/DC converters or control parts. A PMIC is frequently remembered for battery-worked gadgets, for example, cell phones, and compact media players, to diminish the measure of room required. PMIC alludes to a class of coordinated circuits that fill different roles identified with power necessities. A PMIC might have at least one accompanying capacity like a DC-to-DC transformation, battery charging, power-source choice, voltage scaling, power sequencing, and random capacities.

Power the executives ICs are vital to state gadgets that control the stream and course of electrical power. Numerous electrical gadgets utilize different inside voltages and wellsprings of outside power, implying that the power plan of the gadget has various prerequisites for activity. A PMIC can allude to any chip with an extraordinary power-related capacity, yet for the most part, allude to ICs that fuse more than one capacity like unprecedented power changes and power controls like voltage management and Undervoltage assurance. By joining these capacities into one IC, various upgrades to the general plan can be made, for example, better change productivity, more modest arrangement size, and better hotness dispersal.

A PMIC might incorporate battery the executives, voltage guidelines, and charging capacities. It might incorporate a DC-to-DC converter to permit dynamic voltage scaling. A few models are known to highlight up to 95% power change effectiveness. A few models incorporate dynamic recurrence scaling in a mix known as DVFS (dynamic voltage and recurrence scaling). It could be made utilizing the BiCMOS process. They might come as a QFN bundle. A few models include I²C or SPI sequential transport interchanges interface for I/O. Models include a low-dropout controller (LDO) and a continuous clock (RTC) co-working with a reinforcement battery. A PMIC can utilize beat recurrence balance (PFM) and heartbeat width regulation (PWM). It can utilize exchanging intensifier (Class-D electronic enhancer).

For those reasons, chips for power management functions have been studied for integrating and added to final schematic. Will develop further on their application. Chips for power management functions have been studied for integrating and added to final schematic. Will develop further on their application.

3.4.2.3 Opto-isolators

An opto-isolator (additionally called an optocoupler, photocoupler, or optical isolator) is an electronic part that moves electrical signs between two confined circuits by utilizing light. Opto-isolators keep high voltages from influencing the framework getting the sign. Monetarily accessible opto-isolators withstand input-to-yield voltages up to 10 kV and voltage homeless people with speeds up to 25 kV/μs.

A typical opto-isolator comprises a LED and a phototransistor in a similar dark bundle. Different source-sensor mixes incorporate LED-photodiode, LED-LASCR, and light photoresistor sets. Typically, opto-isolators move advanced (on-off) signals. However, a few procedures permit them to be utilized with simple signs.

An opto-isolator contains a source (producer) of light, quite often close to the infrared light-emanating diode (LED), that changes over electrical information signal into light, a shut optical channel (additionally called a dielectric channel), and a photosensor, which identifies approaching light and either creates electric energy straightforwardly or balances electric current flowing from an external power supply. The sensor can be either of the following options, photoresistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR), or a trial. Since LEDs can detect light and discharge it, the development of even, bidirectional opto-isolators are conceivable. An optocoupled substantial state transfer contains a photodiode opto-isolator that drives a power switch, usually a correlative pair of

MOSFETs. An opened optical switch contains a wellspring of light and a sensor. However, its optical channel is open, permitting a balance of light by outer items blocking the way of light or mirroring light into the sensor.

Electronic hardware and transmission and power transmission lines can be exposed to voltage floods actuated by lightning, electrostatic release, radio recurrence transmissions, exchanging beats (spikes), and annoyances in the power supply.[8] Remote lightning strikes can instigate floods up to 10 kV, multiple times more than the voltage furthest reaches of numerous electronic parts. A circuit can likewise join high voltages by plan, in which case it needs a protected, reliable method for interfacing its high-voltage parts with low-voltage ones.

The principal capacity of an opto-isolator is to obstruct such high voltages and voltage drifters, with the goal that a flood in one piece of the framework will not disturb or annihilate different parts. Transformers and opto-isolators are the main two classes of electronic gadgets that proposition built up assurance — they secure both the gear and the human client working this hardware. They contain a solitary actual disengagement hindrance yet give insurance comparable to twofold segregation.

An opto-isolator associates' information and results with a light emission balanced by the input current. It changes helpful info signal into light, sends it across the dielectric channel, catches the light on the result side, and changes it back into the electric sign. In contrast to transformers, which pass energy in the two ways with extremely low misfortunes, opto-isolators are unidirectional and cannot send influence. Average opto-isolators can regulate the progression of energy currently present on the result side. In contrast to transformers, opto-isolators can pass DC or sluggish signals and do not need matching impedances among info and result sides. The two transformers and opto-isolators are compelling in getting things started, typical in modern and stage hardware, brought about by high or boisterous return flow in-ground wires.

The actual design of an opto-isolator relies principally upon the ideal disengagement voltage. Gadgets evaluated for under a couple of kV have planar development. The die is mounted on the lead frame of its package. The sensor is covered with a sheet of glass or clear plastic, topped with the LED die. The LED bar fires descending. To limit misfortunes of light, the helpful retention range of the sensor should match the result range of the LED, which perpetually lies in the close to infrared. The optical channel is made as flimsy as workable for an ideal breakdown voltage. For instance, to be appraised for momentary voltages of 3.75 kV and drifters of 1 kV/μs, the unmistakable polyimide sheet in the Avago ASSR-300 series is just 0.08 mm thick. Breakdown voltages of planar congregations rely upon the thickness of the straightforward sheet and the arrangement of holding wires that associate the bites the dust with outer pins. Actual in-circuit separation voltage is additionally diminished by creepage over the PCB and the outer layer of the bundle. Safe plan rules require negligible freedom of 25 mm/kV for exposed metal conduits or 8.3 mm/kV for covered conveyors.

Opto-isolators appraised for 2.5 to 6 kV utilize an alternate format called silicone arch. Here, the LED and sensor kick the bucket are set on the contrary sides of the bundle, the LED fires into the sensor on a level plane. The LED, the sensor, and the hole between them are epitomized in a mass, or vault, of straightforward silicone. The vault goes about as a reflector, holding all wanderer light and reflecting it onto the outer layer of the sensor, limiting misfortunes in a moderately long optical channel. In twofold shape plans, the space between the silicone mass and the external shell is loaded up with a soft dielectric compound with a matched coefficient of warm development.

3.4.2 Technology Selection

What follows describes the process of selecting a battery and associated components

3.4.2.1 Battery

By comparing the four batteries that were previously mentioned, the two best candidates for testing will be Lithium-Ion and Lithium Polymer batteries. To determine which battery will best fit the needs of the project, the batteries will need to be tested. The battery that will be used will have to have the best constant output voltage across the ten hours of use along with constant current output. The temperature of the battery should not increase to a point where it will not be tolerable for the user. Lastly, the battery should have a fast-charging time so it can be used again in a short period.

To test the batteries, including the Nickel-Cadmium and the NiMH, there will have to be the use of an Arduino to test those variables. Using the Arduino, there will be a collection of two types of data for the discharging experiment. A temperature sensor and a voltmeter will be connected to the Arduino in the analog ports to receive the data.

All the analog inputs in the Arduino have an ADC converter to generate an output between 0 to 1023. Using the conversion rules for the voltmeter and the temperature sensor, the actual values will be obtained.

The Arduino that will be used is the Arduino Uno. It is one of the basic microcontrollers that Arduino offers. It has two limitations to this experiment. First, the analog ports have a maximum voltage of 5V. Anything bigger can damage the Arduino. For the Lithium batteries, this will not be a problem because they have a voltage output of around 3.8V. However, the Nickel batteries have a voltage output of 6V, which is bigger than the 5V port. Because of that, there will be implemented a voltage divider to step the voltage from 6V to 4V. A resistor of 10k ohms will be needed to be connected in series to one of the 5k ohms. The measure of the two resistors will be needed as well. Using a conversion factor and changing the scale in the software, a value between 0V to 4V should be acquired and it will be stepped up to 6V.

Arduino already comes with software that allows anyone to read the analog pins and plot data to generate a graph. However, it was not used because the scale of the plots cannot be modified, so when graphs were plotting current over time, the only straight line near zero was being received.

For that reason, the only way found to generate a graph of the current was using MATLAB. MATLAB has an add-on to use with Arduino hardware. Using this, the ability to generate a graph with the right scale to obtain the values will be available. Also, there are plans to plot two graphs per battery. One of the graphs is going to be voltage and temperature versus time to see if there is a direct relationship between the increase of temperature and the drop of voltage across time. The second graph is going to be the same except that it is going to be current. Using those two values, the team will be able to have a better idea of how good the batteries are, and which one is going to be the best for the project.

The setup for the experiment is going to be simple. First, the battery will be attached to a metal surface. The Arduino is also going to be attached near the battery to have all the connections and collect the data. A group of resistors will also be placed to simulate the load of the system. The temperature sensor will be in contact all the time with the battery to collect the increase of temperature. After the experiment is done, all the data will be a graph and analyzed for the next steps.

This can be described as a two-stage system, where the first stage is the DC-DC converters and the second stage are the MCU, motors, and sensors. Again, due to the rapidly changing nature of the design, the currents and voltages stated below may not be the final ones for the components. The current flowing to the first DC-DC is 27 mA, and it has a voltage across of 3.6V, which represents 135 ohms resistors. The second DC-DC is 3 ohms, and the third is 10 ohms. The three motors represent a load of around 675 ohms. The three sensors are a load of 135 ohms. The MCU has a load of around 2.3k ohms. The total load of the system is around 70k ohms.

After all, batteries are tested, the results for each type of battery will be compared. Again, the best candidate will be a battery that does not heat that much and that it has a constant current and voltage supply along all the working periods.

Another experiment that we did recognized we need to consider and did is the safety part. The Lithium batteries are safer than Nickel but, we needed to see how much damage the battery can support until it stops working. Some of the experiments or information that will need to be collected is how much overcharge each battery can get; how many impacts the battery can resist and still provide a normal voltage. That is because the user can fall, and the system needs to work as normal after that.

Once the right batter is acquired and can pass all of the above requirements, the team will need to create a case or pouch for the battery that is waterproof, fireproof, and shockproof in case the user uses the system while it is raining and add thermal material to disperse the heat uniformly.

Testing is revisited in-depth under the Design section.

Below is Table 11 showcasing the most important specifications of batteries that were researched.

Battery Types	**Lithium-Ion**	**Lithium-Polymer**	**Nickel-Cadmium**	**Nickel-Metal Hydride**
Manufacturer	Adafruit Industries LLC	MikroElekronika	Battery Guy	BatteryGuy
Product Name	353	MIKROE-4475	BGN5500-5DWP-A800EC	BGNMH2700-5DWP-5481MW
Rechargeable	Yes	Yes	Yes	Yes
Nominal Voltage (V)	3.V	3.7V	6V	6V
Rated Capacity (mAh)	6600mAh	6000mAh	5500mAh	2700mAh
Charging Time (hours)	4 hours	5.5-6.5 hours	16 hours	N/A
Cost ($)	$24.50	$21.90	$25.10	$26.95
Availability	High	High	High	High

Table 13: Battery selection

If the prototype were to have a lithium-ion battery, the choice of the battery would be the Adafruit Industries model 353 battery. Some defining characteristics of this battery are that it has a nominal voltage of 3.7V, a typical nominal capacity of 6600mAh, a standard discharge at 0.2 C5A to 6.0V, and a maximum charging current of 1650mA (0.25 C). The dimensions of this battery are 69mm by 55.5mm and this battery is lightweight. It also has JST PH connectors.

If the prototype were to have a nickel-cadmium battery, the choice of the battery would be a BatteryGuy model BGN5500-5DWP-A800EC battery. Some defining characteristics of this battery is that is a nominal voltage of 1.2V per cell, a nominal current of 5500mAh, a standard charge of 550mA for 16 Hour, and a standard discharge of 1100 mA (0.2C). The weight of this battery is approximately 128 grams, and the dimensions of this battery are 165.0mm and 65.0mm. It also has wire leads with connectors.

If the prototype were to have a nickel-metal hydride battery, the choice of the battery would be a BatteryGuy model BGNMH2700-5DWP-5481MW battery. Some defining characteristics of this battery are it has a nominal voltage of 6V, a nominal current of 2.7Ah, and it has dimensions of 3.30 inches by 2.04 inches. It also has wire leads with connectors.

If the prototype were to have a lithium-polymer battery, the choice of the battery would be a MIKRO Model 4475 battery. Some defining characteristics of this battery are that it has a nominal voltage of 3.7V, a nominal current of 6Ah, a discharge rate of 3A, and has dimensions of 3.9 inches by 0.32 inches. It also has wire leads with connectors. Ultimately, this is the battery that the prototype will end up using due to its deigning characteristics that are most preferable to the project.

3.4.2.2 AC-DC Wall Adapters

A COTS (Commercial Off-The-Shelf) AC to DC adapter will be used for the purposes of charging the battery. This adapter will plug into an American-style 120V, 60Hz wall socket and deliver 12V power to the device via a barrel jack. A particular part has not been selected for this purpose, so it is not yet determined whether the barrel jack will be polarized center-negative or center-positive. Some candidate parts for this role are identified below in Table 12.

Part Number	AEP2EA-A5	B08ZS5LMGZ	4336304930	UC05U
Manufacturer	TMEZON	Belker	Smooth-Elec	SoulBay
Price	$8.99	$12.90	$13.99	$19.97
Voltage Rating	12VDC	12VDC	12VDC	12VDC
Current Rating	2A	2A	2A	2A

Table 14: AC-DC Wall adapter selection

3.4.2.3 Barrel Jack

Our wearable has a rechargeable battery that is going to be recharged by an AC to DC wall adapter. Although we have made selections for AC to DC converters, the polarity of the barrel jack on our wearable will be determined by the polarity of the power supply once selected. This is something that we would not have set in stone until we have designed our final schematic design in EAGLE.

The male barrel jack of the wall adapter will be connected to a female barrel jack directly on our board. For the most part, one barrel jack will be as good as any other. It is a simple connector that is hard to get wrong. The form factor we are looking for is a right-angle connector that will mount directly onto the PCB. A quick DigiKey search yields over 200 options, all of which are basically the same. We have selected four options from four different suppliers to compare in Table 13. Some of these options may surpass the voltage and current requirements that we have of 12VDC and 2Amax.

Part Number	ADC-039-6	EJ508A	PJ-019	4840.222
Manufacturer	Adam Tech	MPD	CUI Devices	Schurter Inc.
Price	$0.75	$1.27	$0.76	$3.19
Voltage Rating	30 VDC	12 VDC	24 VDC	$13.5 VDC
Current Rating	2A	5A	3A	2A

Table 15: Barrel Jack selection.

3.5 Other Considerations

In this portion of the document, we discuss other important components to our system that are not directly under the scope of any of the aforementioned subsystems.

3.5.1 Vibrating Motors

After the microcontroller has received data from the variety of sensors located on the lower part of the vest, the microcontroller will force the motors to start vibrating to inform the user that there is an obstacle in their way or coming their way.

DC Motors

DC motors direct flow electrical energy into mechanical energy. The most well-known sorts depend on the powers created by attractive fields. Practically a wide range of DC engines have some inside system, either electromechanical or electronic, to occasionally alter the current course in a piece of the engine.

DC engines were the primary type of engine broadly utilized, as they could be controlled from existing direct-current power. The DC engine's speed can be controlled over a broad reach, utilizing either a variable stockpile voltage or by changing the current strength in its field windings. Tiny DC engines are utilized in devices, toys, and machines. The general engine can work on direct current, yet it is a lightweight brushed engine utilized for convenient power apparatuses and machines. More significant DC engines are utilized in the impetus of electric vehicles, lift and raises, and in drives for steel moving factories. The force gadgets' approach has made supplanting DC engines with AC engines conceivable in numerous applications.

Electromagnetic Motors

A DC engine is any of a class of revolving electrical engines that converts direct flow electrical energy into mechanical energy. The most well-known sorts depend on the powers created by attractive fields. Practically a wide range of DC engines have some inside system, either electromechanical or electronic, to occasionally alter the course of current in a piece of the engine.

DC engines were the main type of engine broadly utilized, as they could be controlled from existing direct-current lighting power circulation frameworks. A DC engine's speed can be controlled over a wide reach, utilizing either a variable stockpile voltage or by changing the strength of the current in its field windings. Little DC engines are utilized in devices, toys, and machines. The general engine can work on direct current, yet it is a lightweight brushed engine utilized for convenient power apparatuses and machines. Bigger DC engines are right now utilized in the impetus of electric vehicles, lift and raises, and in drives for steel moving factories. The approach of force gadgets has made supplanting of DC engines with AC engines conceivable in numerous applications.

Brushed DC Motors

The brushed DC electric engine creates force straightforwardly from DC power provided to the engine by utilizing inside substitution, fixed magnets, and turning electromagnets.

Benefits of a brushed DC engine include low beginning expense, unwavering high quality, and straightforward engine speed control. Hindrances are high upkeep and miscreant length for focused energy employments. Support includes consistently supplanting the carbon brushes and springs that convey the electric flow, just as cleaning or supplanting the commutator. These parts are vital for moving electrical power from outside the engine to the turning wire windings of the rotor inside the engine.

Brushes are typically made of graphite or carbon, now and then with added scattered copper to further develop conductivity. The delicate brush material wears to fit the distance across of the commutator and keeps on wearing. A brush holder has a spring to keep up with tension on the brush as it abbreviates. A flying lead will be shaped into the brush and associated with the engine terminals for brushes planned to convey more than an ampere or two. Tiny brushes might depend on sliding contact with a metal brush holder to convey current into the brush or may depend on a contact spring pushing on the brush's finish. The brushes in tiny, brief engines, for example, are utilized in toys, might be made of a collapsed piece of metal that contacts the commutator.

Brushless DC Motors

Ordinary brushless DC engines utilize at least one highly durable magnet in the rotor and electromagnets on the engine lodging for the stator. An engine regulator changes DC over to AC. This plan is less complex than brushed engines since it disposes of the difficulty of moving power from outside the engine to the turning rotor. The engine regulator can detect the rotor's position through Hall impact sensors or comparative gadgets and can definitively control the current's circumstance, stage, of the rotor curls to streamline force, preserve power, direct speed, and even apply some slowing down. The benefits of brushless engines incorporate long life expectancy, practically no support, and high productivity.

Weaknesses incorporate high beginning expense and more confounded engine speed regulators. Whatever brushless engines are alluded to as simultaneous engines even though they have no external power supply to be synchronized with, as would be the situation with typical AC coordinated engines.

For this project, we used brushes motors because they are cheaper and get the same result as a brushless motor but at a lower price.

Power will need to be provided to the motors via the microcontroller. Each motor is going to be powered by the 3.3V rail of a GPIO pin. GPIO stands for general purpose input-output. Buffers can be made easily from op-amps and will prevent any current from flowing back to the GPIO pin unwanted. The topology for each buffer will be an op-amp voltage-follower schematic.

Something that should be noted there was no intention of using audio to alert the user of the wearable to stop because they are either about to collide with something or something is going to collide with them. The reason for this is that the prototype should not infringe on the other sensors of the visually impaired person for them to have 100 percent control over their other sensors.

Additionally, all three vibrating motors should be placed around the abdomen part of the vest since it is the least used for other senses. Below is Figure 10, which is a general schematic of how to power the motors.

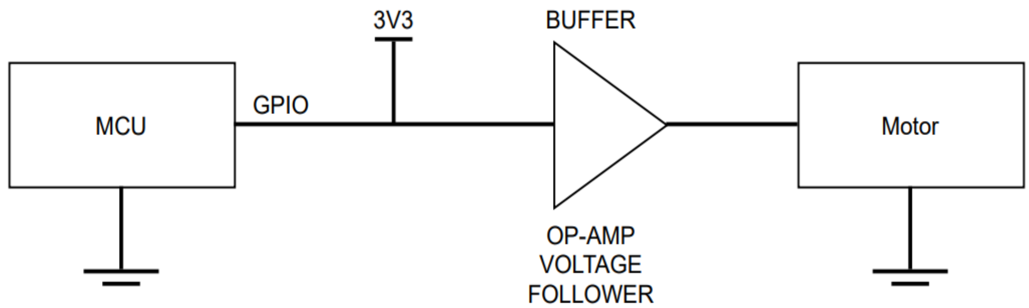


Figure 11 Power to Motors Design

The first way to power the motors is to use a simplified setup where three separate GPIO pins on the microcontroller will be attached to three separate buffers and each of the three separate buffers will be connected to three separate motors. Below is Figure 10, showcasing the simplified setup.

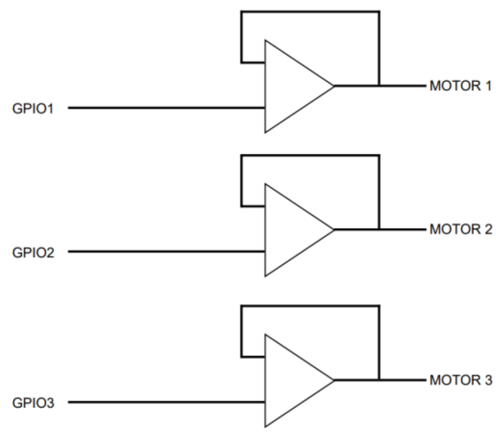


Figure 12 Simplified Power to 3 Motors

The second way to power the motors would be using a QFN package or a quad package op-amp. With the quad package op-amp, one would use three out of four of the op-amps inside of the package. The fourth one would go unused, at least for these purposes. Below is Figure ??? showcasing how the motors would be powered with the use of a quad package op-amp.

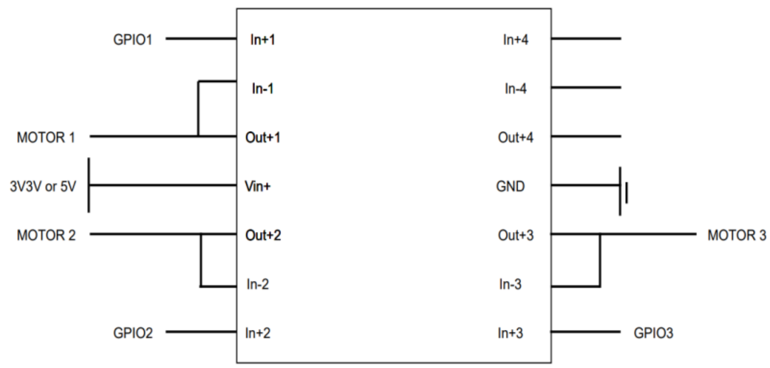


Figure 13 Quad Package Op-Amp

It was important to find vibrating motors that were small enough to fit within the vest comfortably, but be strong enough to properly alert the user that they were either going to possibly collide with an object. Below are two vibrating motors that are in contention of being selected for the prototype. Table 14 shown in the next page was kept brief since not too many choices were available, and our pick would not be detrimental for the performance of the system from sporadic use of resources in its direction

Manufacturer	Tatoko	Tatoko
Price	$10.69 (for 5 units)	$14.99 (for 20 units)
Voltage Rating	3V	3V
Current Rating	40mA	85mA
RPM	8k – 16k RPM	12k RPM

Table 16 Vibration Motor Selections

3.5.2 GSM/LTE Module

One stretch goal that we want to meet is to implement a GSM or LTE module into our device to facilitate the sending of messages from the vest to a cell phone on another person. This would give us the opportunity to work with some of the hardware used in other mobile devices, and also make our device more desirable for those who would be potential users.

Due to the sensitivity of our consumer-base, we would like to implement support in case of potential accidents that occur while wearing the device. A GSM module being connected to our MCU will allow us the ability to send signals to a third party to notify them that an incident has occurred involving the user. The signal would need to be sent via a mobile carrier, so a SIM card is required. This message will be sent to the third party as a text message, and thus the phone number will need to be stored on the MCU. However, SIM cards are capable of storing small amounts of data, and can be used to store phone numbers, so the easiest way to have the user input a phone number would be to simply have it stored on the SIM card entered into the module. There are two major modules that are popular today that were being considered.

The SIM900 GSM module is a popular module used to transmit messages via cell network. It can be communicated with via UART, which all of our MCUs in consideration support, and thus should be easily interfaceable. There is also plenty of documentation available online, and tons of projects that have used this module, meaning it should be trivial to implement. The module requires a 5v power supply and needs a SIM card inserted to send a message via a cell provider.

Due to the popularity of this device (since GSM is used all across the world), there are many companies that produce variants of this device, and they can be priced as low as $3.09. Unfortunately, most cellular providers here have stopped supporting the 2G networks that the SIM900 uses, and the last in the United States (Sprint) plans on shutting their network down by the end of the year. This means that by the time Senior Design 2 is complete, it is possible that our GSM module would no longer be functional if we chose the SIM900. It is important to note that other countries are still using networks compatible with this module, so this pitfall is mostly a United States issue, and mileage may vary in other locations. So, despite the popularity and relatively low price of this module, we did not be using it for this project. Luckily, SIMCom has designed a new module that can be used with more modern connectivity methods that are still being used.

The SIMCom SIM7000A module is relatively new and is used to transmit data using LTE networks. Despite its new-ness, SIMCom has tried to make it compatible with devices that used their old SIM900 by allowing it to share connection methods and many of the same commands, and since there were plenty of resources available online for the SIM900, there are effectively that many resources available for the SIM7000A. This module’s supply voltage range is from 3 to 4.3v, and also requires a SIM card to send messages via a cell provider. Since messages are sent over LTE, it will likely be supported for the foreseeable future. It is worth noting that unlike the SIM900, the SIM7000A is made to be used with networks in the United States, and will not comply with other nations network requirements. There are alternative SIM7000 models that must be used if adapting this design to another location.

This SIM7000A module also contains GPS tracking capabilities, and is able to use these features even without the inclusion of a SIM card. This was not a feature of the SIM900 and thus it wasn’t expected that we could easily implement GPS into our device. However, with these capabilities being added to the SIM7000A, we may be able to at least send the coordinates via SMS to the emergency contact given by the user, and allow them to more easily track down the user in case of an emergency.

The most popular SIM7000A module is produced by Botletics and is available from their Amazon shop for $65. The global edition is available for $69 but doesn't work with cell towers in the United States.

3.5.3 Gyroscope

One major stretch goal that we would like to accomplish would be to implement a gyroscope module to allow us to sense the rotation of our user. If our user were to have a sudden fall or other accident, a gyroscope would immediately allow us to see the massive change in orientation, and we could flag this as an accident, allowing us to notify a third party capable of assisting the user.

The gyroscope under consideration is the MPU6050 accelerometer/gyroscope combination sensor. This is an extremely popular sensor for DiY enthusiasts, and thus a ton of resources are available for interfacing this device with various microcontrollers.

The MPU6000 series contains a 3-axis gyroscope and 3-axis accelerometer, and has an I2C interface and an SPI interface, allowing it to quickly communicate with whatever microcontroller it would be connected to. All registers on the device can be read via either I2C at 400kHz or SPI at 1MHz however, faster communication can be made with the sensor and interrupt registers via SPI at 20MHz. A nearly identical device is also available, the MPU6050, that's only difference is its lack of SPI support.

The device also has six built in 16-bit analog-to-digital converters, three for both the gyroscope and accelerometer outputs, meaning that we wouldn't have to use the microcontroller's few external ADCs on this device.

The device supports other potentially useful features, significantly programable interrupt features such as gesture recognition and shake detection. Shake detection could be another useful way of detecting a sudden fall or other accident that the user may endure.

Adafruit sells a version of the MPU6050 for $6.95 on their website, and TDK InvenSense sells their own fir $11.77 on DigiKey.

3.5.4 Vest

We worked with three vibration motors, two ultrasonic sensors, and two radar sensors (one doppler). Each sensor and motor needs to be placed on the vest such that it doesn't impede the user's movement, but still can perform its respective function.

The three motors will be embedded in the front-center, left, and right of the vest. This will allow us to relay the maximum amount of information to the user that we can from just three motors. These will be placed right below the center of the vest, so that rotation of the user's chest will not affect the accuracy of the information given to them.

The ultrasonic sensors are used for step detection, and thus need to have a clear view of the ground beneath them. The best place to put these would be near the bottom of the vest, so that no close objects can block them and cause a false-positive reading.

The main radar sensor will be doing the bulk of the nearby object detection, and needs to simply be placed in the center of the vest. The doppler radar sensor will be placed directly above it.

The sensors and motors will need to be attached to the microcontroller, so wires will be run down through the inside of the vest to an external waterproof pouch that will contain the MCU and battery. Wires will be inside the vest to prevent any accidental interaction with them that could result in failure. By having the pouch external, we can minimize injury that could occur from any battery failure, since removal will be easier and the battery is already separated from the user's body.

3.5.5 GPS

Currently, there is a high percentage of individuals in the world that have cell phones and other electronic devices that have some form of GPS as an app for the users to interface with. In the long run, the prototype would benefit from being able to use either Google© Maps or Iphone© Maps to help guide the user through their daily activities.

The framework will incorporate an application that will interface with installed modules through Bluetooth to show data to the user. The application will upgrade the user's wearable experience and it will also expand the usefulness of the wearable. By utilizing equipment on the user's cell phone, there can be separate client area data which can be determined by the cell phone's GPS (Global Positioning System) module. This locational data will permit our prototype to give users data as to how close they are to their target locations. The application will likewise fill in as a dashboard to see the system's data for information such as battery life. The application can likewise be arranged to contact specific people if the user has an accident. Further, The application will have the principle screen where the user can get to the settings there, they can set crisis contact a custom message which can incorporate GPS area. Users of the prototype will also be able to set up Bluetooth through the app.

3.5.6 LCD Display

Charging the battery is essential. The faster it can be done, the better it will be for the user. Even though this project is designed for blind people or people with visual limitations, that person is probably next to someone who does not have that limitation. For that reason, including an LCD screen in this project will be a good interaction to the user because it can show the battery percentage, how many hours it will last, or how many hours it will need to charge fully.

For those reasons, considering an LCD screen for this project is not a critical part but, it can be a valuable accessory to add in future versions. LCD screens have many characteristics, but we need to summarize what we need because space is more important as a team. We would want this to be an interactive display that would dynamically update and show the user how many hours the battery can provide power. A color display would be nice to implement an informative GUI application, and display size is essential to balance convenience and readability. Even though a touch screen will be nice, the information will not be interactive with the user.

For this project, we are only considering two types of LCD, one that is touch and one that it is not, and they are shown on the table below.

Model	**Price**	**Size**	**Resolution**
E30RA-I-MW400-N	$29.12	3"	480 x 854
E30RA-I-MW350-C	$53.02	3"	480 x 854

Table 17: LCD Displays

The first LCD, E30RA-I-MW400-N, is relatively inexpensive because it lacks many characteristics. It does not possess the ability to be a touch screen or have color. For those reasons, the price haft of its touch and color competitor is.

On the other hand, the second LCD, E30RA-I-MW350-C, is the opposite. It can graph color objects and be interactive with the user. However, both LCD have the exact resolution, screen size, and power consumption (see table below for more information about the LCD).

By comparing both types of LCD with the future role in the project, the best candidate is the E30RA-I-MW400-N for its lower price. Because the screen will only display battery percentage and charging/discharging time, it does not need to have many functions.

3.5.6 Schematic & PCB Layout Software

We have experience working with Eagle CAD software so it has been the ideal option to get the project started, but it is expected that all work related to Friendly Eyes will be migrated to OrCAD by the end of 2021. The decision was made following the approval for a free student license by Cadence, but the idea to change programs comes from studying their features with input from a series of experienced electrical engineers. We tested them both comparing their UIs, customization possibilities, workflow display, and most importantly for us at the moment, the availability of premade packages and easy access to most components. All in the interest of keeping our designs practical and avoid increasing our margin for error while working on PCB layouts

4 STANDARDS & CONSTRAINTS

During our research and investigation of looking into products and patented items that were like our wearable, we realized that our design would be implemented with items like what was out there while keeping our main goal of keeping the wearable cheap for the intended user.

Our design will be a simplified version of what is commercially available to the public, and therefore we did not run into problems that big companies have invested capital into solving.

4.1 Wireless Spectrum

Along with wireless communications comes a series of considerations on free space propagation and their regulation. Moving around the intricacies and technicalities of the working within the RF spectrum is even a career some people make a living of off from office settings.

Rules and regulations on free-space transmission get complicated because most of the spectrum at the moment is licensed for military use and operation, which in itself is a trillion-dollar business, so it will get the priorities it warrants.

Added to that is the fact even though it has been taped in for some time now, wireless communications is still a very much emerging field, so not only you have a limited chance of partaking in their use, but these mentioned rules and regulations are constantly changing and updating.

4.1.2 Federal Communications Commission (FCC)

The FCC regulates the free air spectrum and assigns a frequency band to be used by specific applications. Most of the spectrum is reserved for military work, but there are small gaps where natural users can tap into the field. Officials regulating free space are hand-picked by the sitting president, and they are in charge of looking after the best way to split the resources available as they see fit.

. Working around regulatory hoops of this kind is a task that does not fall in our domain. Intricacies to get licenses to operate in the wireless spectrum are well known and studied thoroughly by any component manufacturer who wished to enter markets in the RF wing of electrical engineering. Our selections for radar sensors are both FCC compliant from the time of design, and compliant with European authorities as well, so we have worked around this constraint effectively and with relative ease. But having so little allocations in this spectrum has his downsides, and one of the main ones is that many radar and LiDAR sensors available for public use fall within the same band allocation, so finding two systems that could work together without introducing other difficulties is a mission all in itself.

4.1.2 Noise, Interference & Detection Error

One thing that does not work based on technicalities is the fact that the waves in wireless communications are susceptible to many external attenuators and distortion elements that may be prejudicial for the development of our system. Frequency classes and interference hailing from external sources cause wireless sensors to malfunction, and our system will implement 3 wave-propagating devices in close proximity of each other.

We took some consideration for which we made sure to select modules working different frequency bands, but we did perform various methods of testing to rule out the possibility of getting detection errors due to interference cause by harmonics of one in others, specially our main sensor A111, which poses the constraint of having the smallest wavelength of all three subsystems, making it susceptible to the effects of harmonics from a 24 GHz or even high order harmonics from the ultrasonic module.

4.2 Economic & Time

As previously stated before, one of the biggest goals of our project is to make our wearable low cost for the intended user. We want our design someday to see commercial distribution to help the blind or partially blind navigate the world around them without having a guide stick. Currently, there are no completely similar products but products in the concept that large companies will roll out in a couple of years. Most of these designs will have LIDAR sensors that can cost hundreds of dollars, but our project will be implementing radar or ultrasonic sensors that are much cheaper and therefore more easily replaceable. We do not want to sacrifice quality over budget so although we want to keep the design cheap, we do not want to create a wearable that would put the user’s life in danger.

The system is relying on two short-range sensors and one long-range sensor that will be but on the outside of the vest where it will be exposed to the occasionally bumping, fall, or weather conditions. One of our tasks is to find high-quality short-range and long-range sensors that will also be priced reasonably. Additionally, we do not have a sponsor for our project and most of our group are low-budgets college students who do not want to spend a lot of money on building this project. Due to our economic constraints, our maximum budget for our wearable should be $500. Our wearable will be portable and must be weatherproof and due to this, or budget is a realistic budget that should allow us to create a functional prototype of our design that meets our required specifications. We believe that this budget will help us meet a good quality design.

Additionally, there are time constraints that need to be considered and factored into our prototyping of your design. Three out of the four groupmates are working at their internships that require them to work a certain amount of ours. Also, all our groupmates have additional classes and projects, and time will be needed to be allocated to these additional things to graduate. To help with these time constraints, all group members should participate in weekly meetings to know what the member's schedules will be and how much time each must dedicate to the wearable. Further, one last time constraint due to COVID-19 is the delay in receiving parts that we may need to order for our wearable. Shipping delays following the shutdown of many electronic factories around the world due to product shortages is something we should always keep in mind and there is a component to our wearable that needs an alternative, our group just be quick to investigate and buy the item to finish prototyping the vest.

4.3 Environmental, Social & Political

Our wearable will be completely portable and therefore will be exposed to different climates and situations that may not be optimal for the wearable. The sensors on the exterior of the vest will be exposed to possible bumping from the user's arms and will also be exposed to rain. If the user takes off the vest at any point and drops it or leaves it laying around the sensors, battery, and wiring just be able to withstand mild cases of misuse. Additionally, the battery must be put in a fire-rated and chemical-rated pouch somewhere on the vest in case the battery suffers more than mild damage that could endanger the user's life. The wearable being able to handle mild forms of misuse and water is important because we want the user to be able to use the vest in different environments and not just in a controlled setting. Further, we have environmental concerns when it comes to our batteries as our potential two batteries which are lithium-ion or lithium-polymer are difficult to dispose of or recycle.

If we can achieve a working prototype that meets our specifications this would have a significant social impact. This product is being made for a group of people that have a significant disability so being making this product that is up to par with the expectations of the American Disabilities Act (ADA) while respecting an individual's medical record via HIPPA, is a constraint that we must always keep in mind. Our product must be made to help people with disabilities and should be a design that does not stigmatize the intended users. There are no major political concerns when it comes to our project, but it must pass safety standards for products that will be or will be mass distributed to a protected class of people who are blind or partially blind and we must be careful not be classified as an improper piece of technology. We also must be diligent in finding filled patents that are like our wearable so and properly cite to these technologies. We are not be selling this device or filling a patent on it as well.

4.4 Ethical, Health & Safety

Our wearable in meant to be for persons who are blind or partially blind, but anybody could be able to take our product prototype it a make it into something useful for themselves. We do not foresee any reason why design could be unethical or somehow be used to do unethical practices.

There are some safety risks when it comes to handling batteries and excessive load currents and improper ventilation can cause the battery to overheat and possibly burn the intended user. Additionally, if the battery is prone to overheating this can cause a very hazardous situation when the wearable is used for a significant amount of time. Batteries used in our project should be considered critical components and must be handled properly. Our wearable should be able to provide proper cooling and ventilation to the batteries and charging and discharging of the batteries should be done using efficient power electronic circuits. Further, batteries are considered charge storage devices and even if we ensure that the charging and discharging is done with efficient power electronic circuits, we should also guarantee that during charging, the device will also be controlled using power electronic converters for AC to DC power.

The battery choice for the wearable will be either lithium-ion or lithium-polymer. These two batteries are considered to have dangerous chemical compositions inside of them and are classified as Class 9 miscellaneous hazardous materials under United States Regulations (40 CFR173.21 ©). There are several causes of lithium battery failure, and this includes mechanical and physical defects to the battery from manufacturing and then redistributing or from user denting or puncturing of the battery.

Another safety risk that the battery can be exposed to is, again, overcharging the battery and then damaging the cells which will lead to a necessary replacement. We also used a wall adapter that is best suited to lithium batteries. Lithium batteries undergo thermal runaway, which is a process that occurs when too much heat and pressure are created then is lost instead. If even one cell in the lithium-type battery were to undergo this process, the cells next to it would also experience a thermal runway that could cause an explosion where the cells would release composition. Battery-made fires are not like regular fires and a person must be properly trained to handle this type of fire and know how to use specific extinguishing techniques. Knowledge of these risks will help keep our intended user safe from any potential fires.

Electricity has been one of the most important inventions in the history of humanity. Also, many products nowadays use current in some form to help the users in a defined task. One of the most important parts of this design is that it is safe for the user to use. In other words, it does not harm the user in any form. For that reason, Friendly Eyes is designed in accordance with all safety standards because the safety of the user is our primary concern of this product. However, electronic components always have a chance not to work or have a malfunctioning part. That can harm the user with electric shocks, burns from the high temperature of the battery, or damage on the skin due to the chemical elements inside the battery. For those reasons, we need to set up good safety mechanisms so that designers and users can be protected to the greatest extent. The OHSA (Occupational Safety & Health Administration) set up a series of standards to introduce, such as self-protection and standardizing the safe use of electronic appliances.

Wiring design and protection: This standard explains the equipment wiring labels and protection aspects of the Automated safety spotted design. This also allows the correct ground terminal connection to be properly marked during the production.

Hazardous locations: This standard defines the requirement for wiring and electric equipment at hazardous locations. For example, every occupancy has one of the following flammable materials. Those can be liquids, gasses, combustible clouds of dust and fibers, and flammable vapors that can classify as hazardous locations—for example, aircraft hangars and gas stations.

Electrical Protective Equipment: This standard shows a list of insulator products that can be used to prevent electric shocks. They are rubber insulating matting, rubber insulating covers, rubber insulating gloves, and rubber insulating sleeves, rubber insulating line hose, rubber insulating blankets.

Personal Protection: All the people that are around the system while testing must be equipped and should use electrical protection equipment suitable for the specific part of the body being protected and the work being performed to prevent fire or parts from being damaged due to a short circuit.

Electrical Power Generation, Distribution: Only qualified people can do installations and maintenance of electric power generation, control, transformation, transmission, and distribution lines.

Use of Equipment: Introduce the standard of use of cord and plug connected equipment. For example, we should observe the condition of portable cords, plug-connected equipment, and flexible cord set before we use them. A new one should be replaced if damaged or missing parts. Also, the outer jacket and insulation of the flexible cords need to be well protected.

In conclusion, safety is the top priority and concern at all moments. That is because those standards were created always to keep humans safe while testing electronic components. The incorrect use of any electric component in the device can create many problems, damage, and even harm humans directly by generating electric shocks, chemical fire, toxic gas, or high temperature. Furthermore, any accident can cause physical or monetary trauma, and physical trauma may prevent academics from continuing and severely cause disability. Finally, as senior students, money is a significant component in the design of this project. For that reason, we treat every component seriously and connect every wire carefully during the experiment and follow every regulation and standard.

4.5 Manufacturing

Manufacturability of our prototype wearable into a properly vetted and mass-produced product is something that we considered possible but also considered a constraint. Our job is two make something accessible that may be able to be marketed to potential consumers.

Manufacturability constraints are important to consider ahead of time during project design. We want to be able to make sure that if we design something and it gets picked up by a company sometime in the future that all the components will be available to buy again to fix or manufacturer our wearable. Even just to make our prototype, for example, one major constraint is not being able to purchase the components that our team plans to use for prototyping and testing because of the low availability of some components due to COVID-19. To avoid a delay in our prototype, all components should be bought as early, tested, and thoroughly researched. We must also ensure that the components we select will all work together and all fit in one final design. It might occur in senior design II that the products we selected may not be as compatible as originally thought and we may need to change or buy new products.

Besides, the components and related to the constraints of time are the manufacturing of the PCB. Since one of our main goals is to keep the project low cost but high quality, we may not be able to go with some American PCB makers since they are more expensive relatively. But again, due to COVID-19, there may be delays in PCB deliveries from other continues. Further, just because we say that we want a low-cost PCB, we are not willing to sacrifice the risk of getting a poor quality with defects PCB. These are all circumstances we must consider when purchasing all sorts of products for our project.

4.6 Sustainability

The device may need heavy maintenance if the intended user wants to use our prototype turned a product for years. Over time, there may indeed be damage to the vest, the sensors, or the battery. To mitigate this, we plan to embed the products as great as possible. If there is a problem with any of the sensors, maintenance of the device may require that the intended user knows about sensors. We want our product to last for a long time without any malfunctions. There should be no electromagnetic noise created by the device, to protect the functionality of the device. In the event of a part failing in the design, we would want to be able to diagnose the problem and repair the device. To do this, we must design our PCB with test points that will allow us to take measurements that yield meaningful data regarding the function of the different parts of the project.

4.7 Power Supply

Power Supply is very important in senior design because every election product needs to run with power, and there is a power supply standard "POWER SUPPLY SAFETY STANDARD, AGENCIES, AND MARKS" to create and regulate the electrical safety standards. Every country establishes different safety standards to prevent incidents happen such as electric shock, body injury, explosions, and fire caused by electricity. There is a table below to describe the safety standard for power supply equipment, such as batteries.

4.8 Plugs & Sockets

In the 21st century, almost any product needs electricity to operate, and every electronic must have a jack-plug to connect with the outlet to gain electrical power. Nowadays, the alternate current falls in two groups in any indoor electricity in countries around the world, which are AC 100V-130V and AC 220-240V. Any voltage that is between 100V to 130V is classified as low voltage. Any voltage that is around 220V and 240V is called high voltage. Low voltage is used due to safety purposes such as the United States, and Japan while other countries use high voltage because they focus on energy conversion efficiency, which includes China's 220V and Britain's 230V. In countries with 220-230V voltage, there are also cases where 110-130V voltage is used, such as Sweden and Russia. The table below illustrates the detail of the American wall outlets standard.

4.9 Florida Building Energy Code

Our device is marketed for everyday use in a home or in an office. The FBEC standards are important because they deal with the ideal power source for the device. The device will be battery operated because the wearable is inherently portable, but the battery will be plugged into a receptacle outlet on an undedicated circuit at home or the workplace. Plugging in the undedicated circuit receptacle in a home or at a workplace is important because the battery needs to have a proper power source. The 2017 Florida Building Code (FBC) – Residential Sixth Edition Section E4002 gives us some receptacle standards.

Another standard that must be adhered to is the Poison Prevention Packing Act Section 1700.14.A which states that hazardous substances must meet packaging requirements that would protect children from illness or injury from handling, using, or ingesting the substance. To follow this safety standard, we must ensure all our hazardous components are approved by CPSC as safe to use at home or workplace before ever considering marketing our wearable. Many of our batteries contain substances that are hazardous to any living thing. As a requirement from Consumer Product Safety Improvement Plan Section 102, it is a requirement from every manufacturer of a consumer product to issue a certificate of conformity based on testing and that the product complies with standards. (4.2.4 Code of Federal Regulations). In section 134 of CFR, under Customs and Border Protection Regulations, all imported products must meet the regulation of every foreign article be labeled legibly of its place of origin in its English name. This applies to our project since our products come from Amazon© and DigiKey© who are third-party sellers and have obtained their products as imports and so we must adhere to these requirements. This is true for our project because we may have to buy a PCB board through a non-US company.

Further, some other standards we must follow are the Federal Hazardous Substances Act, which is required to label our device for consumers that the product has some associativity to hazardous material. It also will require our team to label how to store product, first aid instructions, and out of reach for children labels where applicable and since our intended product is used for the blind or partially blind then we should offer these sorts of labels in braille as well. This act applies to our project since we have batteries that are made of hazardous products. Further, under the Mercury-Containing and Rechargeable Battery Management Act, that says that mercury-containing batteries are being phased out and just be replaced. It also has sub-rules on batteries containing cadmium or lead-acid batteries that say that these batteries but be packaged and sold separately. This act was relevant to our project since some of the batteries we were considering using were nickel-cadmium and nickel-metal hydride as one of our rechargeable batteries.

4.10 ANSI

We have talked a lot about being extra careful when it comes to the battery we choose and how we use and store these batteries. Additionally, we have also talked about the sensors and the standards of care that must be addressed there. But we have yet to talk about the standards of vest that must be followed, as vest quality and control are set forth by ANSI. ANSI Is short for the American National Standards Institute and a safety vest that is ANSI certified fits into one of three classifications: Class 1, Class 2, and Class 3. Each of the ANSI safety ratings is designed to help workers, or in our case, the intended user, choose a proper vest for the job based on their working environment.

The Class 1 ANSI safety vest is for workers whose job puts them at the lowest risk level. For our project, we have decided to use a vest like this because the visibility for this type of vest is for areas that are slow in traffic and are at a safe distance from oncoming or outgoing traffic. Specifically for our project, we would like this sort of visibility for our intended use. The next kind of vest is the **Class 2 ANSI Safety Vest**. An ANSI Class 2 safety vest is intended for working environments that pose a greater risk. This kind of vest can also be used for our project because it has higher visibility than the first vest of a vest and if the user is interested in being closer to traffic like on a sidewalk, the wearable will give them high visibility to do so. The last class of vest is **Class 3 ANSI Safety Vest**. Class 3 jackets and vests are reserved for people working in the most dangerous environments where visibility is the highest priority. We do not believe the intended user would need to use this type of vest.

One final standard we must adhere to is the NFPA 70 which is is a voluntary standard developed by the National Fire Protection Association (NFPA), the world's leading advocate of fire prevention and an authoritative source on public safety. NFPA 70E requires that employees wear proper arc-rated Flame Resistant (FR) clothing whenever there is possible exposure to an arc flash above the threshold incident-energy level for a second-degree burn. Such FR protective apparel must be rated for protection from electric arcs so they can be properly matched to the appropriate hazard levels. This arc rating, or ATPV, appears on the labeling of all FR protective apparel for easy referencing. Matching the arc rating of the Flame-Resistant apparel with the hazard rating maximizes worker protection against the chance of burn injury or death. This is relevant to our project because we want our batteries to be in this type of flame resistance apparel in case the batteries get damaged and start leaking or they are overheated and can cause a fire.

4.11 Programming

Programming standards are incredibly important to make sure code is clean and readable. If other members of our group have difficulty in deciphering code because our formatting methods are all different, it will become increasingly hard to read as the complexity of our software grows. These form differences can be everything from placement of parenthesis and brackets, to the declaration of variables and usage of dirty functions like “goto(),” or even the location of comments. By forcing everybody to have consistent form, confusion can be mitigated, and readability will improve drastically. With inconsistent formatting, it will be nigh impossible to merge code that other members have written following different methods.

We followed the GNU Coding Standards. These are well known standards that are extremely well documented. On the GNU website, they claim that the purpose of their standards can be read as a guide to “writing portable, robust, and reliable programs.” Their documentation focuses on C programming, but they believe their principles can be ported to other languages as well. Luckily, most of our code will likely be written in C, so we can follow their standards as written. They provide plenty of examples and explanations behind their choices within their documentation and using these standards from the beginning will hopefully save our group plenty of headaches and confusion in the future.

4.12 Software Testing

The ISO/IEC/IEEE 29119 Software and systems engineering – Software testing was created with the objective to define "an internationally-agreed set of standards for software testing that can be used by any organization when managing or performing any form of software testing." It consists of five international standards regarding software testing:

- Part 1: Concepts and definitions: Defined in ISO/IEC/IEEE 29119-1:2013. It introduced the vocabulary necessary to talk about the standards.

- Part 2: Test processes: Defined in ISO/IEC/IEEE 29119-2:2013. It defined a generic test process model for organizations to use when performing software testing at different levels: organizational, test management, and dynamic test process.

- Part 3: Test documentation: Defined in ISO/IEC/IEEE 29119-3:2013. It provided templates and examples of what test processing may look like while supporting the process levels mentioned above.

- Part 4: Test techniques: Defined in ISO/IEC/IEEE 29119-4:2015. It provided standards for test design techniques and divided them into categories: Specification, Structure, and Experience-Based Test Design.

- Part 5: Keyword-Driven Testing: Defined in ISO/IEC/IEEE 29119-5:2016.

4.13 GSM & SMS

The IETF Short Message Service (SMS) standards provide information on what is to be contained within an SMS message. As SMS is used across the world, it is important that any device that is capable of receiving a message from our system is able to interpret it.

IETF says that SMS messages have a maximum length of 160 7-bit characters from the GSM (Global System for Mobile Communications) character set, so it is important that our messages do not exceed this limit, and that they use proper characters that are supported by the standards. Improper interpretation of the standards could result in a message not being properly received by our user’s emergency contact, which could be disastrous.

4.14 Soldering

The making process of Friendly Eyes will involve soldering. For that reason, it is imperative to understand the standards behind soldering to ensure the safety of our product as well as the safety of the electrical engineers on the team.

According to the National Aeronautics and Space Administration's document "Soldered Electrical Connections," there are several aspects to a proper soldering technique. Some of these include through-hole technology, round lead termination, and other surface mount soldering techniques. Throughout the production of the Black Box, there will be several surface mount components as well as small components such as resistors. In an attempt to improve our knowledge and maintain safety, we have used NASA's soldering standards as a guideline to soldering applications throughout our project. [10]

Soldering should be completed in a controlled environment. To limit the entry of contamination, the soldering area should be controlled, and the temperature and humidity of the area be within the limits of what NASA defines as the comfort zone. The comfort zone is defined as between approximately 70 to 85 degrees Fahrenheit with respect to approximately 30 to 70 percent humidity.

5 DESIGN PROCESS

This portion of the text encompasses concepts of both hardware and software components of the project. Thought process, preliminary designs, prototypes, and testing will all be discussed in this section.

The way our project is intended to work crosses the border between hardware and software often, since we are taking samples of an analog world and processing their digital version. Although cross-references are made in text about what hardware and software are doing at specific times, we aimed to keep the bulk of explanations in their respective sections, limiting our narrative to comments as a manner of illustrating the run process of the system.

Figure 12 contains the overall block diagram of the system.

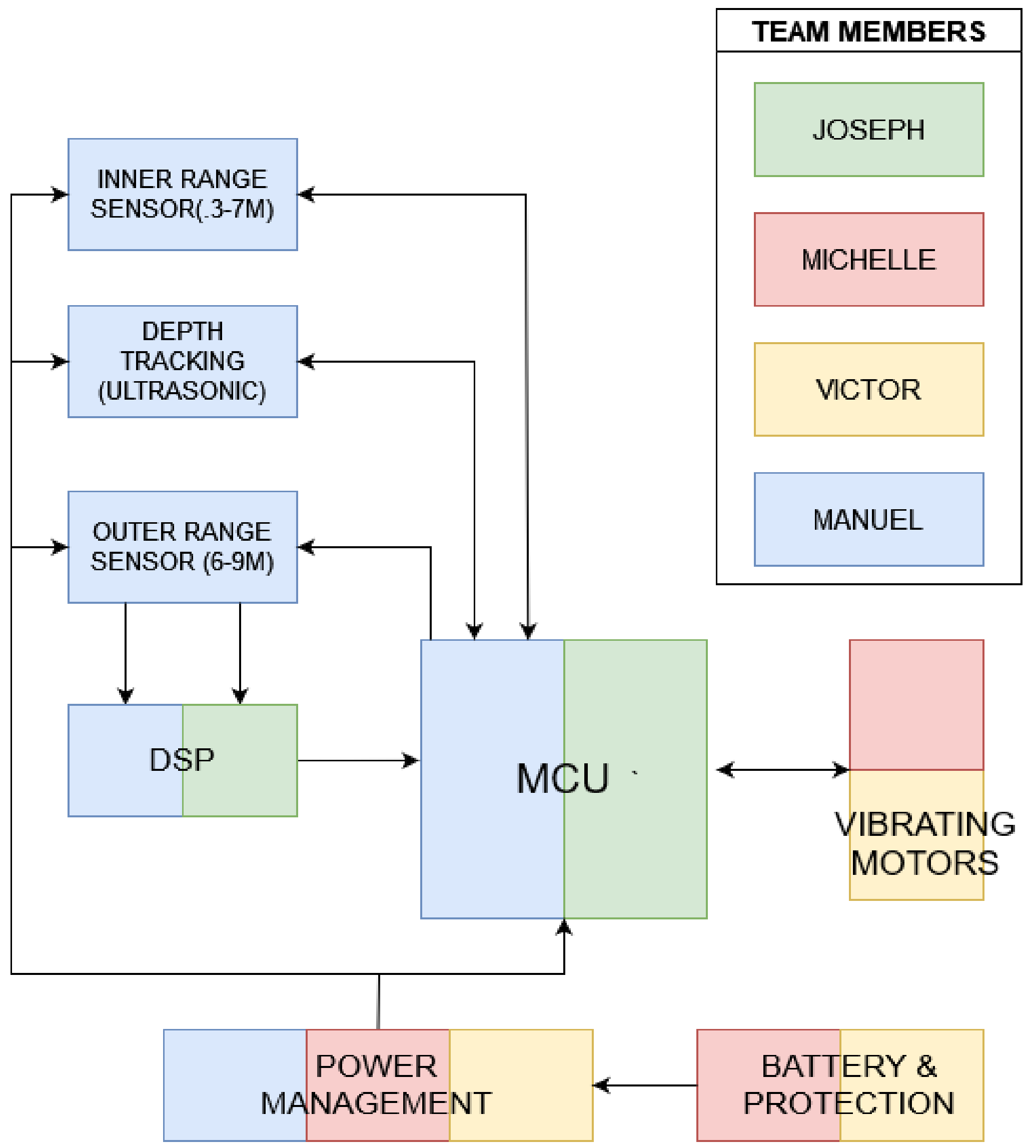


Figure 14: Overall Block Diagram

5.1 Sensor Subsystems

As laid out earlier in the document, neither the ultrasonic nor Doppler sensors will be a heavy load with regards to design. Ultrasonic sensors are particularly known for their use in hobbyist projects and electronics aficionados, with endless resources and libraries to base our algorithm on, and their implementation in hardware does not present a challenge. For the INS-3330 module, data handling promises to be simple since the output produced by the sensor must only account for two states (is there movement within its range of detection or not?).

The figure below is a representation of how our sensors will be connected, along with the output signal and signal description.

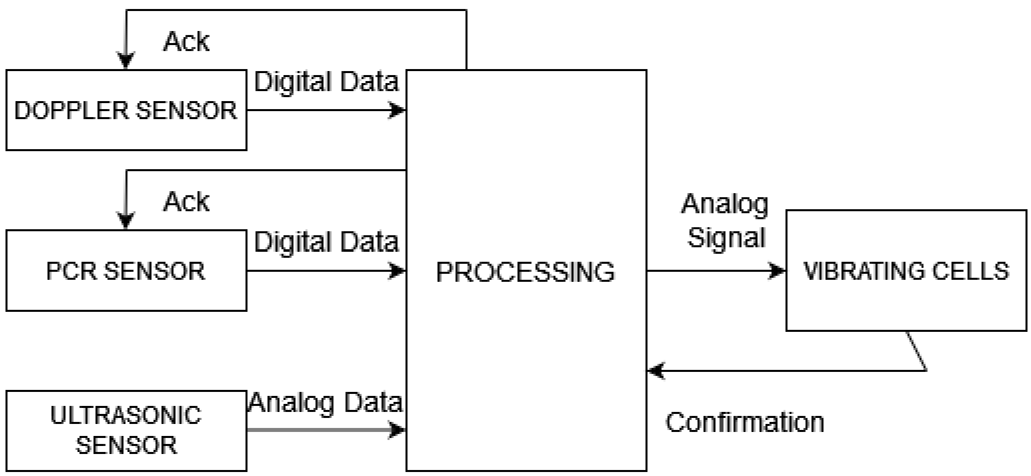


Figure 15: Proposed signal-flow chart

For the range going up to 7 m, the process to obtain and use the data becomes more intricate. The approach we have laid out consists of outputting pulses at a high frequency with predetermined times performing a kind of "sweep" to the volume covered between the sensor's azimuth and elevation angles. When these pulses are returned to the module, they carry information on the measure of power left from reflecting off surfaces. The processing unit must calculate Fast Fourier Transform (FFT) of these slices of data to then calculate the Power Spectral Density (PSD). For the system's MCU, this PSD is all that is needed to know to have awareness of its surroundings, with the possibility of developing algorithms that can detect more than one object in the path by setting appropriate threshold values.

Going further, if the system is in motion (i.e., the user has it on and is walking), information from the PSD can be manipulated by coding mathematical relationships using the difference in distance measurements obtained from these sweeps to calculate the angle at which objects in the range covered by the module are located.

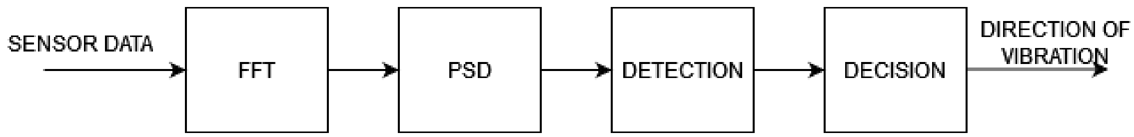


Figure 16: Simplified Operation Block Diagram for Inner-Range

To confirm that our approach at the use of this radar module is correct we need and were to be able to upload software to it and start an extensive process of testing under different conditions. For said purpose we moved to secure most of the components we would and did use and started the process of prototyping both with breadboards and PCBs.

5.1.1 Breakout Boards (BoB)

Since our radar sensors all have complex packages and forms, we are tasked with developing breakout board using PCBs to interface with them.

5.1.1.1 Inner-Range Sensor BoB using XM122 module

At the time of writing, we have acquired one of Acconeer's XM-122 IoT modules to get a feel for what we would be working on later in the project. The XM-122 is a rapid-integration board that packs the A111 together with an ARM Cortex-M4-based CPU as recommended by the manufacturer, hosted inside the Nordic nRF52840 System-on-Chip, allowing SPI communication with the A111 module and the possibility to use UART and even Bluetooth 5 or Zigbee protocols for software flashing. Nordic's SoC counts with 1 MB of Flash memory and 256 KB of RAM for uploading and accessing designer's code.

In order to test the capabilities of the Pulsed Coherent Radar technology and one of the recommended CPUs working in conjunction, we began the design of a breakout board that would allow us to install a software image, flash our application software to the chip, and evaluate the possibilities for wireless communication of data along with advantages measured against the value it would bring to the project.

We used the pinout found in the datasheet for the XM-122 to track the pins that were relevant to our implementation and defined appropriate stages designed to handle power delivery, data processing, and signal integrity requirements of the radar module and the CPU onboard. Our design for the breakout board takes a USB input which supplies a 5V bus, which powers the USB to UART chip and the CPU while supplies a steady 1.8V to the chip through a low-dropout regulator circuit. Other than that, to make use of some preinstalled protocols in the XM-122 module two buttons were added to help with flashing and debugging, a Device Firmware Update and a Reset button.

This was a relatively easy task taking into account that the XM-122 board has a 30-pin connector that provides easy access to power rails, as well as data rails for the UART communication to happen between the host computer and the nRF52840 SoC. Our breakout board is mainly a carrier for power rails and a USB to UART converter that we would use to load code to the M4-based system that operates the A111 and handles the information it gathers.

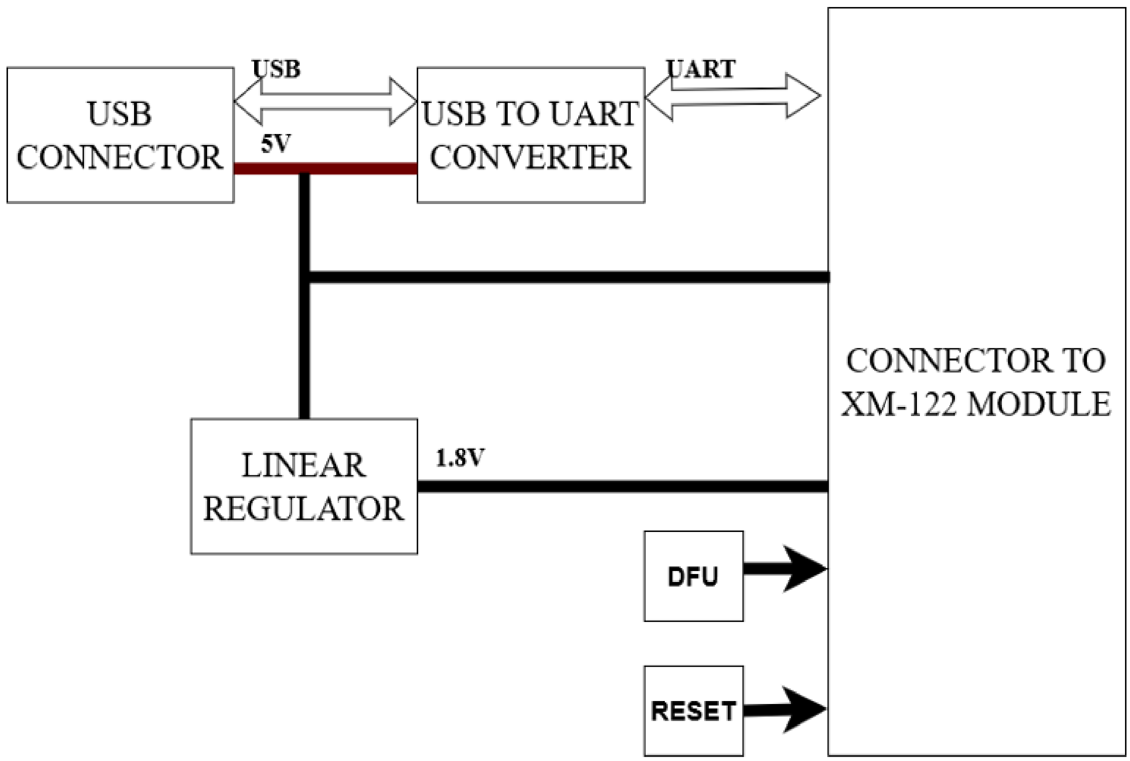


Figure 17: Breakout board block diagram

Having this functional block diagram in mind, we set to find components that would suffice the requirements.

It is worth nothing that the design and implementation of this breakout board serves as a first step towards integrating the A111 radar chip to our final PCB layout, since we are taking a phased approach by avoiding the need to make a new microcontroller, communication module, software/firmware and board design work together all at once. As explained before, this board will use only a few components for power management and digital logic to connect with the XM-122 through a board-to-board connector, nonetheless, most if not all components used in this design will find their way into our final design because they are necessary for the overall functioning of our system, so it is important to secure stock in these times, and to do it as early as possible and minimize the chance to be faced with complications that escape our control.

5.1.1.2 Outer-Range Sensor BoB using MSP430

We have already acquired the INS-3330 unit and we have moved on to study the best way to integrate it to the design. To test it out until we get a definitive answer on the main processing unit we would use, we soldered pins to those corresponding to the UART in the module, and we are working to develop a very simple board that will allow us to upload code and get a better understanding of how we were going to work to use the data obtained controlling it through a previously owned MSP430.

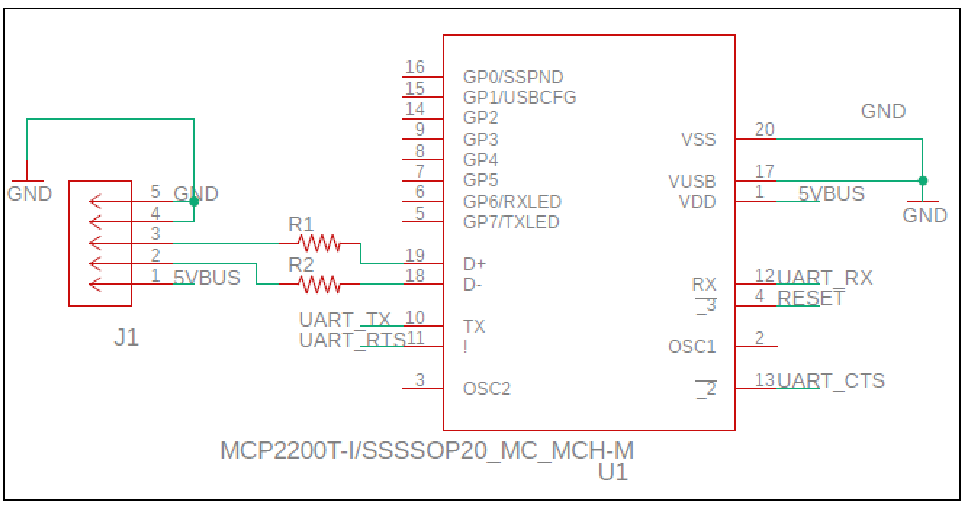


Figure 18: Schematic (Work-in-Progress) - USB to UART

5.1.1.3 Depth Tracking using Arduino

Libraries and instruction sets to interface ultrasonic sensors with Arduino are widely available. We followed a quick tutorial to set up our wiring and accounted for a method to test the system's depth tracking capabilities.

5.1.2 Testing

Before letting our vest be worn by anybody, it is important to make sure that all parts of the product are working as intended. Putting the software and hardware through tests can help prevent issues that could arise should we just throw the vest one someone and let them try to use it.

Most of our hardware testing can actually be completed with the same software we are testing, however it would be proper to create custom test cases just to make sure our hardware works, and it isn't the software, as the software is complex.

To test all of our sensors, we can connect each individually to our development boards, and output their measurements to a computer monitor. This way if any discrepancies occur, we can guarantee that they came from the sensor in question. Objects will be passed in front of ultrasonic or radar sensors, and gyroscopes will be rotated.

5.1.3 Integration without a PCB

During the hardware integration of the motor driver, ultrasonic sensors, and radar sensor, we were also working on our custom PCB and the A111 radar sensor. These are elements that were included in our design that we were unable to integrate into our final project.

The custom PCB contains connectors and power circuits and acts as a hub for the sensors, bringing all of their wiring to one place and delivering the power needed for them to operate. When our fourth group member left and kept our hardware, we ordered new copies of this PCB but were unable to find all of the components needed to assemble it. Due to this supply issue, we were unable to get the power system working during PCB integration and it was decided that we would simply keep the 9 volt battery-powered circuits that we had begun using for testing. If we were to remake this project, we would rebuild the power system with more readily-available components to minimize the risk of this happening again.

The A111 sensor gave us a lot of difficulty when attempting to make it work with the MAX32625 microcontroller. The MAX32625 is an ARM processor which should be good for this application, but unfortunately it lacks robust debugging tools and there is little troubleshooting documentation of it online due to its low popularity. We ported all of our existing code to the Keil environment for the A111 but ran into difficulties in getting this to flash to the MAX32625. In this case, we believe our choice in microcontroller held us back from being able to integrate the A111 sensor.

5.1.3.1 Ultrasonic Sensor Integration

Our hardware implementation began with the ultrasonic sensors. We began by testing SR04 sensors on a breadboard with our microcontroller. When we ran into difficulties with these sensors, we switched to the similar US100 ultrasonic sensor that is able to be powered by 3.3 volts as opposed to 5 volts.

This was easier to use with our microcontroller in a setting where everything has to be powered by voltage dividers. We receive data from these ultrasonic sensors by first triggering the sensor with an output from the microcontroller and then reading the response from the sensor with an input pin on the microcontroller. It is possible to do this with a single pin, however we encountered difficulties doing so with our microcontroller. It may have taken too much time to switch the GPIO pin from output to input for the trigger and read. We confirmed that the microcontroller was receiving data from the sensor by flashing it with a software load that would toggle an LED on the development board whenever the sensor sensed an object closer than one meter.

Once one sensor was working on the breadboard setup, we integrated a second ultrasonic sensor into this system. When it was confirmed that both sensors were working and the microcontroller was receiving data from both of them, these parts were transferred to through-hole circuit boards and soldered in place for a more permanent implementation. In the end, we have two US100 sensors each using two of the twenty available GPIO pins on the microcontroller and both are powered by the 3.3 volt pin on the microcontroller development kit. A voltage divider was implemented in this step that powered the microcontroller at 5 volts from a 9 volt battery.

5.1.3.2 L293D Motor Driver Integration

We are using three small vibrating motors to give tactile feedback to the Friendly Eyes user. Initial testing of these motors revealed that they begin to vibrate when a voltage of 3 volts or more is applied across their positive and negative terminals, however they required too much current for our microcontroller to power them directly with its GPIO pins. Each motor required 85 milliamps to operate which is almost twice as much current as the microcontroller is able to output in total. We explored several solutions to this problem by attempting to make switching circuits with JFETs or op amps but ended up using the L293D chip from Texas Instruments which was made for this type of application. The L293D contains two identical pairs of circuits, so it’s able to drive up to four individual motors at once. We connected three of the input pins from the L293D to GPIO pins on our microcontroller, connected three motors to the corresponding outputs, connected a 9 volt battery to Vcc2 which is used to drive the motors and stepped that voltage down to 5 volts to connect to Vcc1 which powers the chip. This configuration was tested on a breadboard with the microcontroller simply toggling each output pin one at a time to turn on each of the vibrating motors. Once proven to work by itself on a breadboard, this circuit was integrated with our previous work and made to work with the two US100 ultrasonic sensors. After this, the motor driver circuit was recreated on a through-hole circuit board and soldered in place to be a permanent part of the system.

5.1.3.3 INS3330 Radar Sensor Integration

The INS3330 was the final sensor integrated into the system. It has several options for how it can be utilized, starting with its choice in communication method. We opted for the analog output mode which is available in the advanced version of the sensor that we have. In this mode, the INS3330 uses three output pins to send data for three different parameters: the proximity pin will read high when an object is detected close to the sensor, the leave pin will read high when an object is detected to be moving away from the sensor, and the approach pin will read high when an object is detected to be moving towards the sensor. For the purposes of this project, only the approach pin was used, as it is the job of the INS3330 to help the user determine if there is something coming towards them. We simply had to power the INS3330 with 5 volts and connect this pin to a GPIO pin on the microcontroller which would read whether the INS3330 was outputting a logic high signal and toggle an LED accordingly. Once it was confirmed that the sensor was sending data correctly, we connected the motor driver circuit to the microcontroller to have the microcontroller activate a motor when it reads high from the INS3330. Finally the whole system was assembled with the inclusion of the US100 ultrasonic sensors and this system was tested to insure that the microcontroller was receiving data from each sensor and controlling the motors accordingly. With this test passed, the hardware integration phase was complete.

5.2 Processing Subsystem

For our project, the software will be key in performing the important calculations required to keep our user from colliding with objects and injuring themselves.

The software will need to read data coming from our sensors and translate it into a usable form. After translating the data, it must perform a calculation to detect approaching objects and determine relevant threats to the user. Once threats are detected, an appropriate signal must be sent to a corresponding vibration motor that will alert the user to incoming obstacles. We must also be polling a gyroscope sensor periodically, in order to detect a fall or other potential accident so that we can notify a third party for assistance. When a fall happens, we would also like to use the LTE module to send a message to a given phone number so that they can try to get in contact with the user.

This means that our software will be split into three major parts:

1. Object Detection – The algorithms associated with converting sensor data into usable form and then deciphering objects' location from that.
2. Obstacle Warning – The algorithms associated with ascertaining the threat of obstacles near the user and sending respective signals to vibration motors that will warn them.

3. Accident Notification – The algorithms associated with detecting sudden rotational shifts of the user and interfacing with the LTE module to send a warning message to an emergency contact.

5.2.1 Services & Functions

The next portion will explain in detail what our steps will be in developing the software and firmware that will run the heart of our project.

5.2.1.1 Object Detection

Object detection will be the core of the software design. We have to be able to detect obstacles in the environment before we can alert our user to them. The method of detecting objects will be different depending on the type of sensors we are able to decide on.

We plan on using a radar sensor to do the bulk of the detection, from between .3 to 7 meters of distance from the user.

When using a radar sensor to detect objects around the user, the calculations that need to be done are complex, but can be distilled into four basic steps:

1. We collect some number of radar sweeps at a specified frequency given by the radar sensor (60 GHz for the Acconeer radar sensor).
2. We perform a fast Fourier transform of some number of these sweeps and use that to estimate the power spectral density.
3. We perform peak detection on the power spectral density to determine where obstacles are found.
4. We determine the distance an estimate an angle for each of the peaks found in step 3.

Acconeer (the developer of the main radar sensor under consideration) provides python code that follows this algorithm and can be used with their sensor to detect objects. However, a potential problem with this is that Acconeer says for angle detection to occur, we need to be able to assume that our radar sensor is moving at a constant velocity and that all obstacles are motionless (or that the obstacles are moving, and the sensor is stationary).

Since we likely will have a moving user and moving objects, it appears that this implementation will lead to us being unable to ascertain the angle between objects and the user. Without the angle of the object, it may prove to be impossible to let our user know what direction an object is approaching in.

A doppler radar sensor is planned to be used for far object detection, that is from 6 to 10 meters away from the user. This sensor can relay the information about distant objects approaching the sensor, but not near ones. We should be able to simply read the data from the sensor granting us angle and velocity towards the sensor and vibrate the respective motor.

When using ultrasonic sensors, the detection methods' calculation becomes much simpler, but more hardware is required. Since ultrasonic sensors are only able to "see" what is directly ahead of them, there would be multiple surrounding the user. The direction each sensor is facing would be hardcoded based on the GPIO pin the sensor is attached to and detecting an object would be as simple as detecting what range the ultrasonic sensor is returning and using that value to determine an obstacle's distance.

Threat detection could also be improved by storing the previous distance held by the sensor and when the sensor is polled again, check if the returned distance is similar enough to be the same object, but closer than expected by something stationary. This would be used to warn a user of a fast-approaching object in a particular direction (fast approaching could also be a result of the user quickly going towards the obstacle).

Step detection will be done using downwards-facing ultrasonic sensors on the front of the vest. An average height will be calculated comparing the sensor to what it is facing. Should the detected height be largely different than the average, but only within one foot of it, then the software will flag the position ahead as a step.

5.2.1.2 Obstacle Warning

Once our obstacles/threats have been determined, the software needs to notify the user that an obstacle is in their way. The three vibration motors set up around the vest will connected the GPIO pins with their directions being hard-coded into the software based on their location on the vest. After we find out the direction of an obstacle, we can send power to the motor that will vibrate it.

The formula used with a radar sensor to detect obstacles returns a distance and angle for relevant objects, with 0 degrees being straight forward. Each vibration motor can be given their own degree range, and whenever an object is within ones' range, we can send a signal to the motor based upon the distance the obstacle is. That is, a farther object will result in a lower signal to the motor, and thus a weaker vibration, and a closer object will result in a stronger vibration.

With the ultrasonic implementation, notification is more straight forward. Since there will likely be as many ultrasonic sensors as vibration motors, a signal can simply be sent to the vibration motor that corresponds with the direction of the ultrasonic sensor. Vibration strength can be determined by the threat level given, fast-approaching objects will cause a stronger signal, as well as objects that are in the immediate vicinity.

Steps will be detected at the front of the user, and a pulsating vibration will need to be sent to the front most motor, indicating that there is a step in that direction. A stronger pulse means that the step is closer.

5.2.1.3 Accident Notification

Our device needs to be capable of granting awareness to a third party, should an accident occur while the user is wearing the device. If our user is to fall or be struck, it is important that we can let somebody know in case they require assistance, since they may be in a situation where they are incapable of helping themselves. The software needs to be able to detect an abnormality in the user's orientation, and in such a case send a message to a third party that can respond accordingly. When the device is powered up, the orientation received from a gyroscope sensor will be stored into memory. This will be a sort of calibration, determining what the predicted orientation is of the user should be always near.

While performing normal operations, the software will periodically receive information from a gyroscope sensor. If the information received is drastically different from what should be expected, such as a sudden rotation towards the ground that could be indicative of a fall, the software will begin a countdown. If the user is incapable of correcting their orientation within a short period (thirty seconds, to prevent potential false positives), then a message will be triggered and sent via the connected LTE module. This message will be sent via SMS to the third party, whose phone number is saved onto the SIM card that is required to be placed in the LTE module, and they will receive the alert as a text message on their mobile phone.

Safety for the intended user who happens to be of the more vulnerable citizens of the world is of utmost importance. There are fall detection devices that could be integrated into the prototype in the long run. Fall detection devices would employ devices to detect if a user had fallen and would try to get immediate assistance for the fallen user. A fall detection alert system would allow the user to get help in the event of a fall without the need to press a call button. The prototype could employ a sensor such as an accelerometer, which is a type of low-power radio wave technology sensor, that would monitor the movements of the user.

Devices like smartwatches employ at least three accelerometers to accurately detect if the user has fallen. Further, the prototype could employ a fall alert detector to measure whether the user had suddenly fallen by detecting abrupt changes in body movements. There would have to be fall detection technology embedded into the prototype that could accurately detect movements that are associated with falling. Further, once the prototype was alerted to a fall by the user, it would have to automatically send an urgent care response. Every partially and fully blind user's situation is different, but the prototype should be able to handle a fall from a person at any age and in any health situation. Having these goals in consideration, we devised the following diagram for the software function:

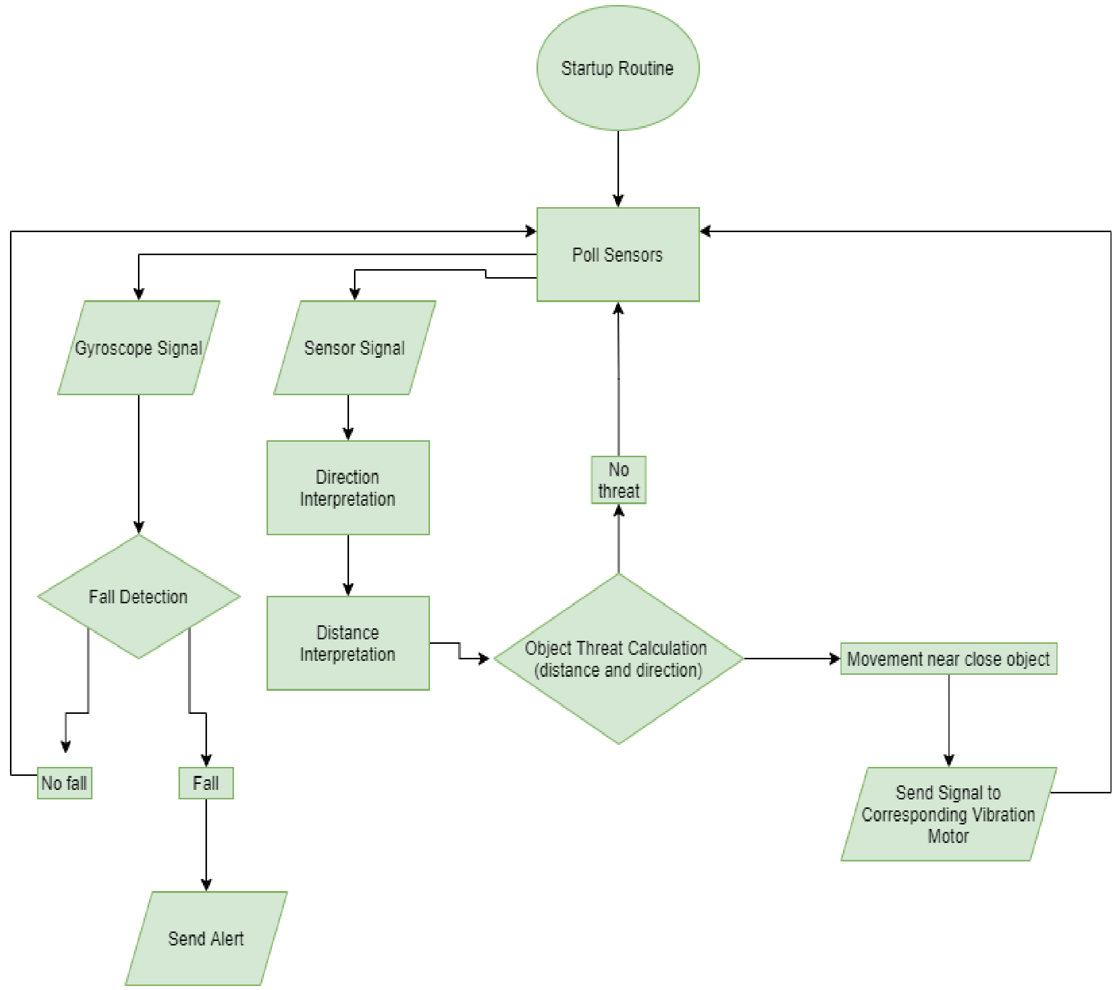


Figure 19: Software Block Diagram

5.2.2 Interfacing

Each of FriendlyEyes' sensor module uses a different communication method, and their companies provide independent resources and methods to establish data transfer with the MCU. In this subsection we touch on the specifics of their implementation for each of our sensor subsystems.

5.2.2.1 INS-3330

Communication with the INS3330 is done over UART, working with the master/slave principle. This means that the master will be sending requests the radar module, and the module will then be sending appropriate answers back to the master.

The frame structure required is as such:

1 byte	3 byte header			1 byte	8 PDU bytes								1 byte	1 byte
Dummy	SD	DA	SA	FC									CS	ED

Figure 20: UART frame contents

That is, there are three header bytes representing a start delimiter, destination address, and source address. This is followed by a single byte for the function code, then eight bits of data, then finally a byte for the checksum and a byte for the end delimiter. The dummy bit is only for the device sending commands to the INS3330, and isn't included in the frame sending data back to the device.

If a frame is unable to be executed by the device, an appropriate reply will be sent back to the microcontroller, allowing failure to be known. Data transmission failure can be detecting by calculating the checksum of the frame and comparing it to the checksum received in the frame. If the checksums mismatch, then the frame can be thrown away and no reply is sent back to the device.

When a frame is sent to the INS3330, it is required that a dummy bit precludes the rest of the frame. This is so that the INS3330 can be woken if the sensor is in sleep mode, and its value is not read. Frames sent back to the microcontroller do not have this dummy bit in place.

When the INS3330 relays information back to the MCU, the data is sent in the frame like this:

The first byte of data contains whether or not proximity was triggered. If a 1 is received, an proximity was detected, otherwise a 0 will be sent in this byte.

The second byte then contains a basic idea of movement direction (0 for no movement, 1 for approaching, 2 for receding, and 3 for motion only, which occurs when an object is too close to the sensor for accurate detection).

The third byte will return the movement velocity of the detected object, but only if the sensor was able to detect the direction that the sensed object was moving in. If no direction can be ascertained, the velocity will be returned as 0 km/h.

Fourth and fifth bytes contain data for the I-component of signal strength, and the sixth and seventh contain the q-component.

5.2.2.2 SEN0388/URM09

The URM09 series ultrasonic sensor is the sensor that we used for step detection on our vest has a fairly simple interface with our MCU. After being powered, data is sent via a single digital IO port to determine distance.

The sensor will await a signal from the MCU to start measuring with the sensor, so the pin connected will originally be set to output mode. After a ten-microsecond high pulse signal is sent to the sensor from the microcontroller, the MCU must change the port to input mode as the sensor will return a signal to determine distance. When a pulse is received, the high-level time of that pulse will be equal to the ultrasonic flight time in microseconds.

To convert this flight time to usable distance, we have to use the following formula:

$$D = \frac{t \times c}{2}$$

Where t represents the flight time in microseconds, c represents the speed of sound per microsecond, and D represents the distance traveled.

After this we can easily use the distance to make the required calculations in software.

5.2.2.3 A111 Radar Sensor – Issues

Acconeer's A111 radar sensor was intended to be used as our mid range sensor for obstacles approaching our user. However, we had some incredible difficulties introducing this part into the project. Acconeer does provide pre-compiled libraries meant to be used with any Arm Cortex M0, M4, or M7 devices, and provides these libraries for both Armcc and Armclang compilers. This pre-compiled nature ended up being extremely important - this meant that the libraries were 'closed-source', we couldn't actually dig in and make important changes that would allow them to interface with our device. We were only provided APIs and some documentation regarding functions that had to be integrated within the project for the libraries to function properly.

Arm Mbed OS is primarily written in C++. Basically every function regarding anything that you want to do with the microcontroller interfaces with their hardware abstraction layer and uses C++ functions in some way, shape, or form. These precompiled libraries were written in C, which would have been fine had the APIs not required us to implement pin-out changes and the entire SPI interface within them. All SPI and pin-changing calls rely on Mbed OS, which meant that these functions could NOT be called from C. Since the libraries were closed-source, we were absolutely incapable of changing the way that they worked within Mbed outside of illegally decompiling them and altering them manually.

Because of this pitfall, we decided that we could perhaps use Keil - it is more bare metal but entirely written in C. They have the MAX32625 on their target list, so we believed that it would be fine to use with our device. After going through and rebuilding the required functions using the new hardware abstraction layer, we wrote some basic code to get information from the sensor and compiled it. Compilation went well, everything properly linked with the libraries, however after converting the output AXF file to the BIN file that can be flashed to the device, our MAX32625PICO refused to run the firmware. The only error message that was returned to us was that the 'device has timed out.' This was not an issue that we had with binary files compiled via the Mbed SDK, and there were few resources available online. However, we did see that there is an old Maxim tool chain that includes a custom Eclipse editor and is written with the same hardware abstraction layer that was used in Keil, so we thought that perhaps moving to their own tool chain would solve the issue that we were having.

Maxim's tool chain also has the MAX32625 on their target list, so whenever we try to compile any code via their SDK, it should be configured to run on that microcontroller. We made the changes that needed to be done to the functions written, imported the Armcc libraries from Acconeer, and again compilation finished successfully. Also again did the software refuse to run on the device, with no useful error message besides the device had 'timed out.' From research about this error message, it apparently seems to be a general catch-all for all sorts of issues, making it extremely difficult to pin down what was going on.

Thinking that perhaps there was an issue with the libraries or the code we were using, we went on to start trying out the example projects that Maxim includes in their tool chain that are meant to be run on the MAX32625. We found that these projects, too would compile fine but wouldn't flash to the PICO. We even tried an effectively blank file, consisting of only a main function an empty while loop, and the same issue arose.

At this point we were lost for what we could do. We began talking with Maxim's support team and got some advice regarding compiling the binary file within the SDK itself - however this did not prove to be fruitful either, and the device still failed to program. We currently still have an active case with their support team, but it doesn't appear that we would be able to solve the problem before the due date for the project.

5.2.3 Power Usage

It is one of our project’s stretch goals to be able to implement scheduling to save power and maybe implement a cheaper option for the battery in a future revision. Maxim Integrated’s MAX32625 contains four low-power operating modes that can be selected from depending on your use case and this is a perk we looked after during technology selection too.

- In Low Power Mode 3 (LP3), all of the analog and digital peripherals on the system are fully powered, and the CPU is executing application code. There is a dynamic clocking option that can disable peripherals that are not in use in this state, giving a more optimal mix between low power consumption and high performance.
- In Low Power Mode 2 (LP2) the device lets analog-to-digital converters and some of the peripherals operate while the CPU is sleeping. These enabled peripherals can be dynamically clocked so that they consume minimal power.
- Low Power Mode 1 (LP1) disables all voltage supplies on the system besides the supplier for the real-time clock, meaning all peripherals are disabled. However, data retention is still able to be maintained in this state, and the CPU is capable of quickly waking up from this low-power mode.
- Low Power Mode 0 (LP0) puts all peripherals and the CPU into a low-power mode, disabling most features on the device. The only things that can be

enabled are voltage supply monitoring, power-on reset, RTC clock, power sequencer, and the key data retention registers.

In our use cases, most of these low power modes will not be applicable. The low power mode we are most likely to use would be LP3, since we can still execute application code while in this state. We need to constantly be making calculations from the data we receive from the sensors, so any low power modes that disable the CPU or place it into a sleeping state would be unusable for us.

5.2.3 Testing

Software testing will be done among different modules within the program that will first need to be tested independently. In the software section, the software program that will be run on our microcontroller is divided into three major parts that will each need to be tested. These three parts are the Object Detection, Obstacle Warning, and Accident Notification segments. This software will be tested by running that portion of the program while our development board is hooked up to the required hardware for that segment.

5.2.2.1 Software Test Cases

Object Detection is the core of the program and will need to be tested most extensively. Our chosen sensor(s) will need to be connected to our development board, and we did run the isolated program segment that is supposed to detect objects on those chosen sensors. An object will be passed in front of the sensor(s), and data will be written to a computer monitor letting us know the distance from the sensor, and if the object is approaching, what rate it is approaching at. This test is successful if the sensor properly detects the object’s distance within 10mm, and is able to detect its approaching velocity within 10 cm/s.

The Obstacle Warning segment of the program will be tested by trying to vibrate specific motors that will be connected to the development board. The isolated program segment will be run, passing in the desired motor to be vibrated, and the level at which it should vibrate. The segment passes the test if the chosen motor begins vibrating at the correct level chosen.

The Accident Notification segment will be tested by trying to send a message to a group member if the connected gyroscope is placed on its side for thirty seconds. If the development board properly sends the information to the GSM module after the gyroscope lying has triggered it, and our group member is provided with a text message, then the program segment is confirmed to be successfully working as intended.

If each of these parts works separately as intended, combining the segments should result in the software working properly, as there is effectively nothing that can go wrong in between functions, as data will simply be passed from one function to another, with no calculation or anything happening in between them. Any error that occurs here would have to be because of an error in the MCU, rather than in the software.

5.2.2.2 MAX32625PICO Evaluation Kit

Before we are able to fully construct Friendly Eyes, we need to be able to test the software that will be running on our MAX32625. We need a way to debug software and make modifications to code involving communication with sensors, calculations, etc. Luckily this microcontroller does have an associated development board that is available from Maxim Integrated.

The MAX32625PICO is a development board based off of the MAX32625 microcontroller that we did use, and thus contains all of the specifications of that product. This means that it will have the 512 kilobytes of flash memory, the 160 kilobytes of SRAM, and the ARM Cortex M4 processor running at 96 megahertz, as well as all interfacing features of the MAX32625. This device is made to be easily interfaced with a breadboard for rapid development of software.

Most importantly, this device contains a USB slot that is used for programming the device, as well as powering it for debugging purposes. The MAX32625PICO is capable of powering other devices via the on-board MAX14750 PMIC, which is able to provide all rails needed from a single +5v supply (which can be provided via USB). This MAX14750 provides 3.3v, 1.8v, and 1.2v to the MAX32625.

The device is shipped with a bootloader preloaded onto the MAX32625 from the factory as well as DAPLink application firmware. This bootloader is triggered by holding the single button present on the board when the device is powered on.

DAPLink

Programming the device will be done via DAPLink, which is an open-source software project meant for allowing software to be programmed onto Arm Cortex CPUs. The DAPLink source code is available on the Arm Mbed GitHub page, and is constantly being developed by the community, including Arm themselves, and many other hardware vendors.

A secondary MCU attached to an application MCU runs DAPLink allowing you to easily develop software for the application MCU by dragging and dropping software onto the first one. DAPLink presents itself as a storage device when it is connected to a computer, so all that needs to be done is the application code needs to be placed onto it.

DAPLink can be run on any of our computers, since it supports all known versions of Windows, as well as all known versions of Linux and OSX. Any operating system using the most recent DAPLink firmware does not require any special drivers to be installed to interface with the connected board.

5.2.2.3 Data Transmission Reliability using Wireshark

In testing our sensors, it may prove to be important to be able to read the data from them without having to connect them to our development board. However, by default there is no connector for interfacing these sensors with our computers. The devices can be connected to a computer via a USB UART bridge, allowing us to interface with the devices connected.

A popular device used to bridge UART and USB is the CP2102. This is a simple device with five pins on one side that can be connected to any UART device via jumper cables. The other side of the CP2102 is a classic USB2.0 connector, allowing it to attach directly to a computer's USB port. This device is supplied by Silicon Labs and is available via DigiKey for $5.06 per unit in quantities of one.

However, just connecting the device to the port will not immediately allow us to read data from it in a usable way. A program needs to be used to help capture traffic from the device. USBPcap is what we used as a USB sniffer, since it is compatible with Windows 10 and has much documentation available online. USBPcap stands for USB Packet capture, and it allows the capture of packets that are coming from the USB slot. It is a free open-source program, and all files are available on their public GitHub repository. This program only grants us the ability to read packets though and doesn't offer any built-in way for helping us display them.

Once we have the program for capturing packets, we need a way to display them. Wireshark is known as a program used for displaying network packets for debugging purposes, but it is also capable of displaying packets from other sources. USBPcap allows easy communication with Wireshark, giving us an easy way to quickly read the data coming to the computer via UART. Wireshark is also a free program that is compatible with windows and macOS and has public source code available on their official website.

5.2.2.3 Prototype Debugging using USB

By the time we get our hands in our first prototype PCB, we were able to debug on board without any added hassle since we picked a MCU with a USB Micro 2 interface and added a connector jack with proper circuitry. This would expedite the process of testing new ideas and fixing bugs.

5.3 Battery & Circuit Protection Subsystem

For the power portion of the prototype, it will have to be decided what kind of battery the prototype will use, the voltage and current output of the battery, and how power is going to be distributed from the battery to each component of the prototype. Accurate power calculations and distribution is important because it will ensure that power is managed throughout the prototype for smooth operation and to ensure complete safety to the user. There are several main components that must be considered for the power calculations and distribution such as the microcontroller, a variety of sensors, and vibrating motors. These components will have different voltage requirements from one another and will require separate power rails for this reason. Separate power rails may also be required for components with the same voltage requirements for isolation purposes. In order to identify and troubleshoot problems, isolating power going to the microcontroller from the power going to the sensors is necessary. The use of TI WEBENCH is purposeful since it will be used for the power design of the PCB.

There is a need to look for a battery supply that is low voltage and has a high current density. To use a type of battery that will include both low voltage and a high current density, the power design will need to use step-up or charge pump DC-DC voltage converters to raise the voltage to levels usable by the components on the prototype. To have appropriate headroom in the power supply, it will be assumed the efficiency of the DC-DC converters has to be a lower value than specified by TI WEBENCH. In addition to derating the efficiency of the DC-DC converters, it will need to be ensured that the power supply exceeds the maximum power consumption by some margin. To make sure that the prototype works properly and is safe to use, appropriate power input to all components should be researched through the use of datasheets, and power circuits should be designed with enough time and consideration. The wearable is designed with portability in mind, so the battery should be easily accessible and replaceable in the design for convenience to the user. When removed for storage, the battery should easily be able to be put back to its former location for recharge.

Additionally, splitting the PCB into several parts may be advantageous for the prototype overall. If the prototype main circuitry were to be split into three PCBs, a processor card, a power card, and a connector card, there would be no large and clunky PCB and there would be the ability to spread the parts around the vest to make it more comfortable for the user. Separate PCBs are also advantageous for testing. For example, if a failure occurs in the power section, the microcontroller would not be affected, and there could troubleshooting for the problem before integration. If the system were to be connected, the risk of burning the components due to too much power running through the system is a problem that would have to be addressed before integration.

Below is one of the first looks at a block diagram for the power distribution.

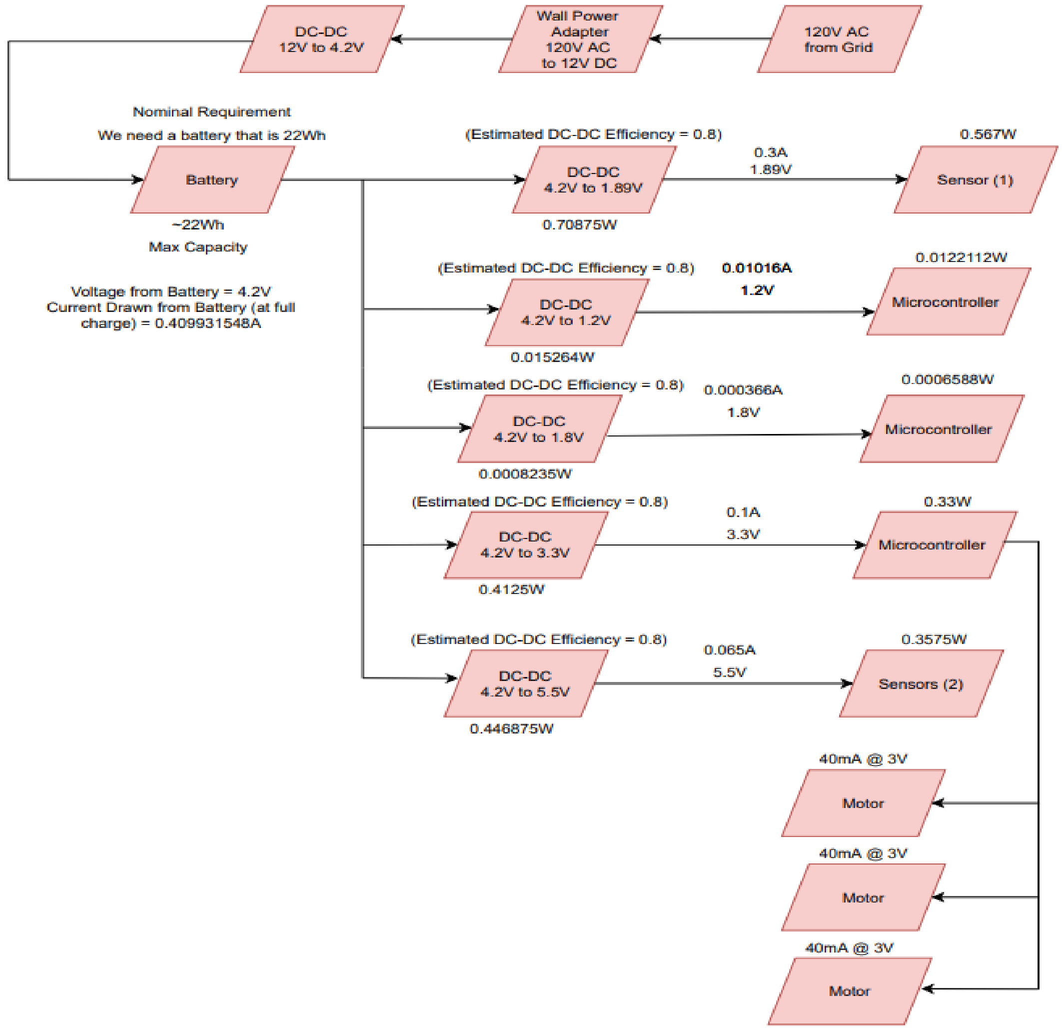


Figure 21:Power Distribution Block Diagram

In addition to the power diagram, there will be a power budget, which is a part-by-part analysis of how much power is consumed and how the battery should deliver power. A power diagram is a tool that will become a lot more useful for the project when final part selections are populated next semester when the team is building the prototype. When it is completed, there will be a list of all electrical components on our bill of materials, showing the number of each device used, the current drawn by each part, and the power consumed. For now, the total power and the efficiency of the parts and the battery can be estimated based on what was chosen this semester but may change next semester which will then determine the final value for the power required.

5.3.1 Circuit Protection Methods

Short circuits are not the only problems a circuit can suffer. For example, when working with any electrical board, we can generate more voltage or less, which will affect the current flow in the system and, in the worst case, flip the voltage and damage all the components in the circuit. Because this project has a battery, we needed and did take into consideration having a higher voltage than the recommended while charging. This is a charging system that will control the current flowing into the battery, and it will monitor the voltage across it, so it does not overpass the safe limit. The minimum voltage system will disconnect the battery from the system when the battery gets to a specific voltage which is the minimum to do not damage the battery. An overcurrent protection will monitor the flow of current at the output of the battery, and it will open once the current flowing is bigger than it should. This protection will be the short circuit because they both open the system when the current increase, and that can be due to a short

As we previous mention in the paper, the battery that we choose has a capacity of 6000mAh which is a large value compared to the normal lithium batteries of 1820mAh. For that reason, this battery has the need to use high current to charge itself in a small period. According to the manufactory, when a current of 6 amps is apply at 4.1 volts, the battery will be fully charged in 2 hours, if we use 3 amps, it will be charged in 6 hours. For those reason, the amount of current that we decide to use is very important. That is because even though the user can use the battery for a full day, that person will need ten hours to charge the battery using a standard AC-DC that pulls 1.5A from the wall. [1]

On the other hand, choosing longer charging time because we apply low current has its benefits. Nowadays, the field is full of integrated circuits that have all kind of protection for batteries. However, most of those integrated circuits that we can buy have a main limitation, they have a maximum input current of 1.5 to 2A. If we decided to use a standard charging method, we can select the intergraded circuit that best fits our project and test all its protection to make sure that the chip does not have any problem. However, if we decided to use a faster charging method, we would and did to research, design and test new circuits that can handle a current of 3 to 6 amps.

Those protection systems that will need to handle a current of 3 to 6 amps will need to monitor the voltage of the battery while charging and be able to disconnect the or open the circuit from the wall to the battery to avoid overcharging. We have come up with three different types of circuits that all have its benefits and problems, and they are using a diode, and MCU and an IC with high current range.

Diode is a simple IC that just allows the flow of current in one direction if the voltage across the diode is around 0.6V. For that reason, the diode will allow the flow of current until the voltage of the battery gets around 3.5V. At that point, the diode will stop the flow of current to the batter and the battery can start giving all the power to the system. This system is a simple solution and very cheap, but the main problem is that the battery will only get a charge up to 85% of its maximum rating.

The second solution is either to design an overvoltage protection with short circuit protection using MOSFETs that can handle a high current or find an integrated circuit that that is available during the shorted of chips that can handle the current. The main problem of this idea is to find the proper design.

The last option is to design a small circuit compose of a microcontroller, a voltage comparator, and a relay or optocouplers or MOSFET. Using this design, the main challenge is to find all the parts but, the main benefit is that the battery will always be fully charged, and the overcharge scenario will be impossible with this circuit. Also, to avoid problems, the microcontroller will not use the power from the battery because it will only be working if the system is connected to the wall

5.3.1.1 Short Circuit

One significant problem with any circuit with a power supply is that when a short happens, all the energy will go to the circuit, and all the components can get damaged. Also, if the battery is charging, and a short happens, all the current goes to the battery, and that will generate toxic gas inside that will damage the battery and eventually make it explode. For that reason, two short circuit systems will be needed. One of the circuits will be between the AC-DC converter and the battery to open the system and avoid an overcharge to the battery. The second circuit will be after the battery in case a short happens to save all the components.

A short circuit system needs to avoid the two types of shorts that can happen. The first one is a nominal short circuit. This is when a wire-carrying current touches a neutral wire. When that happens, the resistance will go down, and a large volume of current will flow through an unexpected pathway. The second type of short is the ground fault short. It happens when the hot wire carrying current meets some grounded portion of the system. It can be a grounded metal wall box, bare ground wire, or a grounded portion of an appliance.

Any of those shorts can happen for many reasons. Faulty Circuit Wire Insulation is one of them. If the insulation is not good, it can allow the wires carrying current to touch the neutral. This will cause a short circuit. The age of the wire or screws can damage the insulation and allow a short circuit. There is a risk of pests gnawing the insulation and exposing the wire conductors too. Loose Wire Connections is another cause of shorts. If there are any loose wire connections, it can touch another wire that can be live or neutral.

Faulty Appliance Wiring is the last reason to make a short. When the user plugs the charger into a wall socket, it is wiring essentially becomes an extension of the circuit. Therefore, if there are any problems in the appliance wiring, it will become circuit problems. For that reason, short circuits can occur in the power cords.

For all the reasons mentioned above, the circuiting of the system is critical. Also, because the user will use the system in open areas, any water that touches the wires can generate shorts. Also, all the wires need to be well connected and do not have any part of the cable exposed that can touch any part of the system.

The circuit that we used contained a relay with two positions. The relay has a coil that, when current flows through it, will generate a magnetic field that opens the terminals, and the systems can connect. This circuit will be controlled by two PNP transistors that use the base current to activate or deactivate the relay. The base current of the transistor will be amplified by two op-amps in a cascade to increase the initial signal from the system. In the end, when a short happens, some current will be amplified and sent to the base of the transistor, which will allow the current to the coil that will generate an electric field that will open the system. A reset button will be placed to eliminate the electric field in the relay so the system can work as usual.

5.3.1.2 Relays

In the short circuit system that will be implemented in Friendly Eyes, relays are used to open or separate the battery or power supply from the load or all the electrical components. The function of the relay in any of the systems that we did implement must have the same functionality. For that reason, it is important to understand the basics.

The relay will act as a switch to turn on or off the desired system. The way that this relay works as a switch is that it is electronically operated. The type of relay that will be implemented in the hydroponic system is one that uses an electromagnet that is responsible for opening and closing the contacts. When connecting the power supply and the system to each relay, the normally open configuration will be used. This means that unless a signal is sent from the microcontroller, then the circuit will remain broken. An input signal will be sent to the relay, which will switch the contact to the proper position allowing for the circuit to close.

To implement this relay, there needs to be additional circuitry. For this, there are two potential approaches. The relays may be used as a module that will have the additional circuitry necessary, or this will be implemented on the PCB. In either case, the necessary circuitry will be almost the same. This circuitry will be described in more detail in the design chapter. The relay module that will be used for testing is the KY-019 5V. This relay can handle either an AC or DC load which will allow for flexibility of the parts chosen. Below is a table showing some of the important specifications for this relay module

5.3.1.3 Regulator

Three types of voltage regulators are mentioned below, and one of them will be included in the system in the voltage across the battery changes a lot. Voltage regulators are designed to maintain a constant voltage level even if the input voltage or load current changes. They are used in many electronic devices to maintain the DC voltage used by the processor and help minimize power consumption. In this project, a voltage regulator will be used in the power supply to make sure all components are receiving the correct voltage to function.

When selecting a voltage regulator, it is essential to consider at least three factors:

1. The input and output voltage should be known to choose the specific output voltage the regulator chip should operate.
2. The dropout voltage should also be considered. Dropout provides a buffer between the output and input voltages, so if the Babel glove has a slight difference between the input and output voltage, a low-dropout voltage regulator (LDO) or even ultra LDO may be considered.
3. Voltage regulators can produce output noise, so the sensitivity of the system needs to be considered.

The response time of the voltage regulator should also be considered. The Babel glove needs to respond to the user's gestures in a reasonable time frame. Finally, the power draw of the voltage regulator should be considered. If the current becomes too high, the heat generated can become too high. In conclusion, these five factors should be considered when choosing the voltage regulator for the project.

Series Voltage Regulator

The series voltage regulator is also known as the series pass regulator. It is one of the most used regulators for a linear regulated power supply. These regulators provide a high level of performance when there needs to be low noise, ripple, and transients in output. It is made up of a variable element that is in series with the load. When the resistance of the series element is changed, the voltage of the element can be varied, so the regulated output across the load remains the same. The main advantage of using a series voltage regulator over other types is that the amount of current drawn is effectively the same as the load used; therefore, it is more efficient. Although it should be noted that these regulators are much less efficient than switch mode power supply, they have the advantage of being much more straightforward, and the output does not have switching spikes.

Shunt Voltage Regulator

As the name suggests, this regulator works by the regulating element shunting the current to the ground. The shunt voltage regulator maintains a constant voltage and uses the excess current to maintain the voltage across the load. The load is in series with a resistor, and the voltage source and shunt regulator are in parallel with the load. The shunt regulator will draw negligible current at maximum load current and total current at minimum load current. This can make shunt voltage regulators inefficient compared to other regulators.

Switching Voltage Regulator

The switching voltage regulator works by moving bits of energy from the input voltage source to the output. This is done by using an electrical switch and a controller which can regulate the rate at which energy is transferred. Essentially, the switching element transforms the input power into a pulse voltage that is smoothed using elements such as capacitors and inductors. The switch element is turned off once the output voltage reaches the desired value, so input power is reduced. Switching regulators can have up to 85% efficient, making them one of the more energy efficiency regulators.

5.3.1.4 Battery Noise Filtering

Battery noise is the combination of unwanted periodic ripple and spikes combined with random noise from the devices or external sources. The amount of input-referred ripple will be governed by the line regulation of the design. This is a similar concept to the power-supply rejection ratio (PSRR). A PSRR of 60 dB means any deviation at the input will be attenuated by 1000 at the output. A primary way to improve line regulation is to increase the gain of the control circuit. The higher the gain of the control loop, the smaller the error at the output; input ripple is just another error that the loop must deal with. We can also use larger input capacitors, which will reduce the ripple on your dc input bus, so the PSRR of the control loop will apply to a minor deviation.

Utilizing channels can eliminate commotion from the battery, like using media to eliminate clamor from a sign. Without a doubt, one thought is utilizing the result capacitors part of a channel that responds against the result impedance of the battery circuit. Expanding the worth of the result capacitance will diminish commotion.

Capacitors have and equivalent value as a series resistance (ESR) and series inductance (ESL), so choosing capacitors with lower ESR and ESL would help minimize rogue frequencies rolling into our circuitry.

5.3.2 Battery Testing

Battery monitoring is an important aspect of this project as most battery types available due to sizing constraints are prone to self-ignition, which would ultimately defeat the purpose of this project. How good would a fire detection system be if every so often the systems caught fire? To alleviate this issue, the state of the battery is constantly monitored at every start of the detection system to make sure that the voltage and current are within the specifications laid out by the manufacturer.

5.3.2.1 User Safety

To accomplish this task, the MCU would read the voltage and current across a resistor and compare it to a set of known values to check if the battery is within its specifications. The state of the system will be converted from analog to digital and transmitted if any anomalous behavior is detected, at which time the system can power down and wait for a technician to repair it.

Since Li-Ion and Li-Po batteries are being used in this project, it was important to understand their thermal limitations. Lithium batteries have an issue with thermal runaway, which is when a battery reaches a certain temperature and crosses a threshold that will cause the battery to rise in temperature rapidly. The battery will ultimately fail and catch fire, and due to the chemical makeup of the battery, the fire cannot be extinguished easily and normally burns until the fuel source, the chemicals, and metals in the battery burn out. The group should especially use these standards to follow proper management and maintenance of the polymer li-ion battery used. The following standards are for small lithium batteries:

- UN/DOT 38.3 5th Edition, Amendment 1 – Recommendations on the Transport of Dangerous Goods
- IEC 62133-2:2017 – Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications – Part 2: Lithium systems
- UL 2054 2nd Edition – Household and Commercial Batteries

5.3.2.2 Charging Mechanisms

When looking at the power supply options for our wearable the best choice would be to use a rechargeable battery so that it can be convenient for the intended user due to portability. There are two different ways that we considered charging our batteries, either with an AC to DC wall adapter, or a solar charger. Solar charging isn't something entirely new, but the public has come to see that it is a great alternative to other forms of charging. Our wearable is being designed in Florida where we have more sunny days than rainy days so solar charging would a good method to charge our batteries. It eliminates the need for electricity and allows the user of our wearable to take it places that they wouldn't have been able to travel to before.

Although solar power would be a great option, unfortunately, solar power has low efficiency. On average, a solar power system has an energy-efficient rating of about ten to twenty percent of their on cloudy days that is being converted to usable energy. Additionally, if there are many cloudy days or a solar charger isn't hit with direct sunlight, it would take a couple of days for our batteries to be able to fully charge. This could turn out to be inconvenient for our users because our wearable is intended to be for everyday use and if they must wait a couple of days to charge their wearable, it will defeat the purpose of the use. Further, because our project is wearable, a solar charger would have to be placed on the outside of the device if we are not using a power back to store the solar power, we would have to make sure that the entire project is waterproof and fireproof since the solar charge would have to sit somewhere on the vest that can have direct sunlight.

Considering all the advantages and disadvantages of a solar charger, an AC to DC wall adapter would be better suited for our project. One option would be to have a wall adapter that comes with a Raspberry Pi built into it that would connect to a charging board and then the charging board would directly connect any one of our batteries. The wall adapter would do its job of converting AC to DC power and recharge the battery while being able to connect to any receptacle around a user's house or workplace. If the user has access to electricity there should be no issues with using this form of the charging method. Another way to charge the batteries would be to use a power supply that connects to AC power and converts it to a smaller DC power that is specifically suited for your battery cell. For our wearable, we would need to specifically buy an AC to DC power supply that will convert power from the wall from the grid to a rectified DC voltage of either 3.7V for our lithium-ion or lithium-polymer or 6V for our nickel-cadmium or nickel-metal hydride.

Another different way we could charge our batteries would be to use an adjustable power supply that comes than can come in all sorts of different sizes while also using and connecting it to an AC to DC power supply. With an adjustable power supply, you have some control over what the input voltage and output voltage can be, and it can be used to charge out battery cells. An adjustable power supply is set to a certain voltage, it would then be connecting the positive terminal of the power supply to the positive of the battery cell, synonymously, you place the negative of the power supply to the negative of the battery cell. The other positive of the power supply is your input and that is going to be a bigger voltage like 12V.

The AC to DC power supply wall adapter will be supplying 12V to the power regulator, the adjustable power supply will regulate to 4.2V, and if the battery is fully depleted, then energy is going to flow from the adjustable power supply at whatever maximum rate of amperage it can do. Once the battery cell is fully charged, the user would not have to disconnect the adjustable power supply from the battery cell, because the battery cell will not be able to take any more energy in. After all, it is already matching what the adjustable power supply is providing and the battery cells' voltage will not go up higher than that the power circuit can supply. The adjustable power supply could be adjusted to supply more voltage with the risk of overcharging to the battery cell.

6 PROTOYPE SUMMARY

In this section we cover issues as they relate specifically to our final design. It will be kept solely as a means to easily keep track of advancements and changes in the device and information we address in our final documentation and demonstration.

6.1 Bill of Materials (BOM)

Our first version for the bill of materials is completed, having accounted for all the details that could impact our product-development process down to the level of component package, temperature and frequency tolerances, power dissipation, ratings, and of course, availability.

We took the liberty to do a thorough selection of components at this point in time because of the aforementioned global supply chain shortage, but this also gave us an advantage that will allow us to expedite development and testing of our system. Having gone through the process of understanding what specifications are important for which purpose, - such as capacitor build and its temperature coefficient for use in bypassing – will minimize chances to get caught in pitfalls brought upon by ignorance of how the real world really works, as opposed to the ideal cases usually visited.

Another motivation to do an early deep-dive into the specifics of passive-component selection and Integrated circuits was that even though we count with experience in circuit design and even sensor integration, printed circuit boards using radio frequencies tend to have added levels of complexity when it comes to ESD, signal integrity, soldering, and more. And even though two of our sensors have independent PCBs, it is known that not only radiated emissions can mess with the performance of a system, but conducted emissions through our PCB traces and wiring could cause damage too

Our bill of materials is split into two modules for easy access. Table 18 contains information on pricing, while Table 19 displays reference designators to find in the schematic.

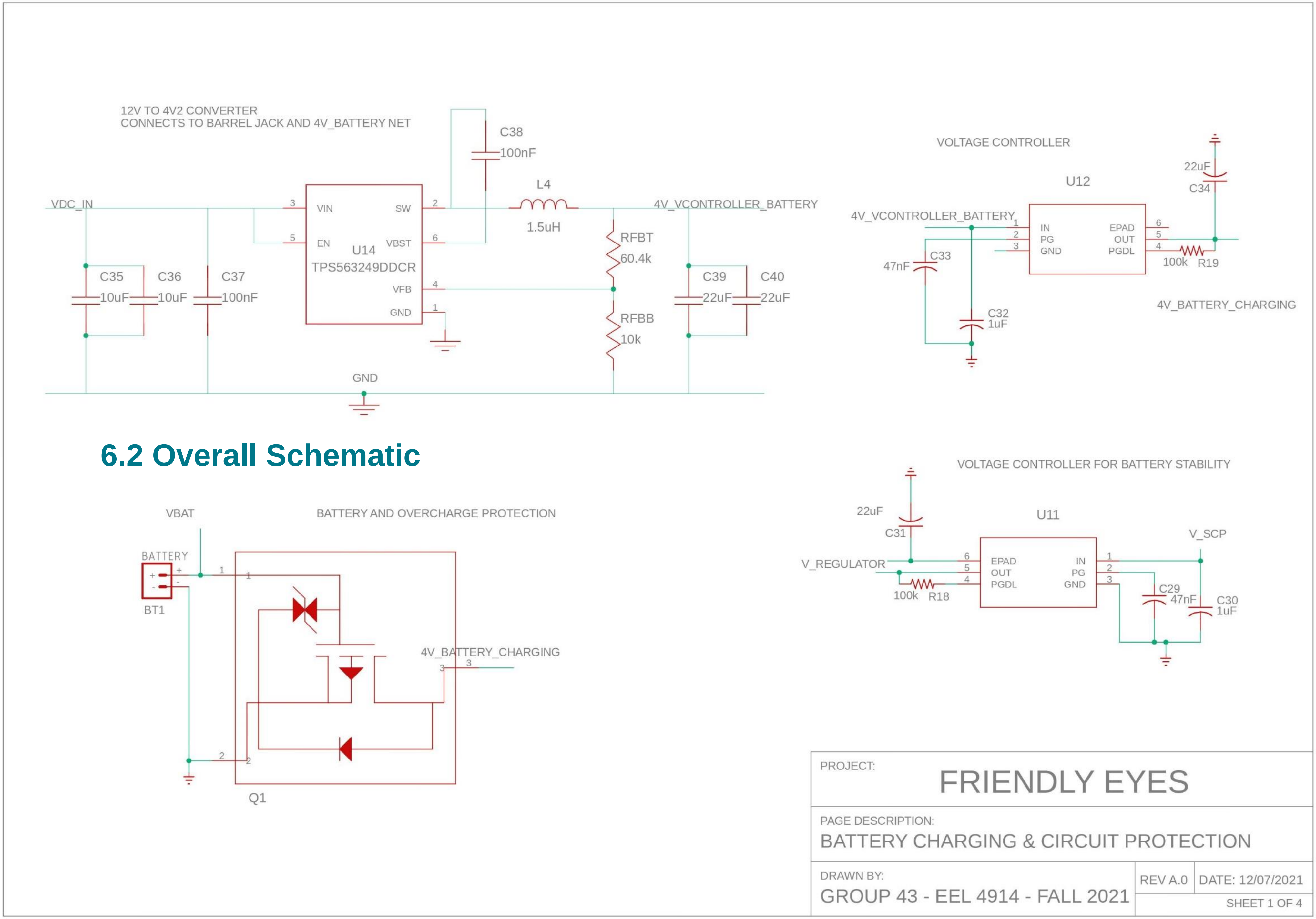
Qt	Manufacturer PN	Description	Unit	Ext
1	MLP806696	LI-ION POLYMER 3.7V 6000MAH	21.9	21.90
2	MP2018GZD-33-P	IC REG LINEAR 3.3V 500MA	2.09	4.18
1	ST1S12G18R	IC REG BUCK 1.8V 700MA	0.99	0.99
1	NCP115ASN180T2G	IC REG LINEAR 1.8V 300MA	0.25	0.25
10	C0805C105K8PAC7800	CAP CER 1UF 10V X5R 0805	0.14	1.40
6	CL21A226KPCLRNC	CAP CER 22UF 10V X5R 0805	0.27	1.62
2	CGB3B1X5R1A475K055A	CAP CER 4.7UF 10V X5R 0603	0.11	0.22
1	TAJA225K010TNJ	CAP TANT 2.2UF 10% 10V 1206	0.25	0.25
3	CL21A106KPFNNNG	CAP CER 10UF 10V X5R 0805	0.09	0.27
1	SIP32431DR3-T1GE3	IC PWR SWITCH P-CHAN 1:1	0.49	0.49
1	RC0805JR-070RL	RES 0 OHM JUMPER 1/8W 0805	0.02	0.02
2	DFE252012P-2R2M=P2	FIXED IND 2.2UH 2.2A 84 MOHM	0.29	0.58
1	MIC5205-3.3YM5-TR	IC REG LINEAR 3.3V 150MA	0.49	0.49
1	MIC5258-1.2YM5-TR	IC REG LINEAR 1.2V 150MA	0.57	0.57
1	ISL9111AEH50Z-T7A	IC REG BOOST 5V 800MA	1.31	1.31
1	A111	IC SENSOR PCR RADAR 60GHZ	12.1	12.17
1	ECS-240-18-33B-7KM	CRYSTAL 24.0000MHZ 18PF	0.50	0.50
5	C0603C104K5RAC7867	CAP CER 0.1UF 50V X7R 0603	0.05	0.25
2	CC0805CRNPO9BN6R0	CAP CER 6PF 50V C0G/NPO	0.08	0.16
3	AC0805FR-0730RL	RES SMD 30 OHM 1% 1/8W 0805	0.05	0.15
4	ERA-6AEB104V	RES 100K OHM 0.1% 1/8W 0805	0.10	0.40
1	INS-3330	INS-3330 24GHZ RADAR	42.8	42.86
1	SEN0388	URM09 ULTRASONIC SENSOR	4.21	4.21
1	MAX32625ITKL+	IC MCU 32BIT 256KB FLASH	10.5	10.52
1	ECS-.327-6-12-TR	CRYSTAL 32.7680KHZ 6PF SMD	0.89	0.89
5	CC0805KKX5R5BB105	CAP CER 1UF 6.3V X5R 0805	0.08	0.40
1	SSM3J378R,LXHF	AECQ MOSFET PCH -20V -6A	0.42	0.42
1	VLS201612CX-4R7M-1	FIXED IND 4.7UH 1.12A	0.38	0.38
1		12V 2A AC-DC WALL ADAPTER	8.99	8.99
1	PJ-077	CONN PWR JACK	1.08	1.08
1	10118193-0001LF	CONN RCPT USB2.0 MICRO B	0.35	0.35
2	C0805X470J5GACAUTO	CAP CER 47PF 50V C0G/NP0	0.37	0.74
3	885012007007	CAP CER 470PF 10V C0G/NP0	0.07	0.21
1	CSR0805FKR500	RES 0.5 OHM 1% 1/4W 0805	0.22	0.22
3	B07KYLZC1S	DC VIBRATING MOTOR 1.5-3V	2.19	6.57
1	VLP8040T-1R5N	FIXED IND 1.5UH 5.3A 22 MOHM	0.44	0.44
1	RE1206FRE0710KL	RES SMD 10K OHM 1% 1/4W	0.03	0.03
1	CRCW120660K4FKEA	RES SMD 60.4K OHM 1% 1/4W	0.08	0.08
1	TPS563249DDCR	IC REG BUCK ADJ 3A TSOT23-6	0.92	0.92
				127.48

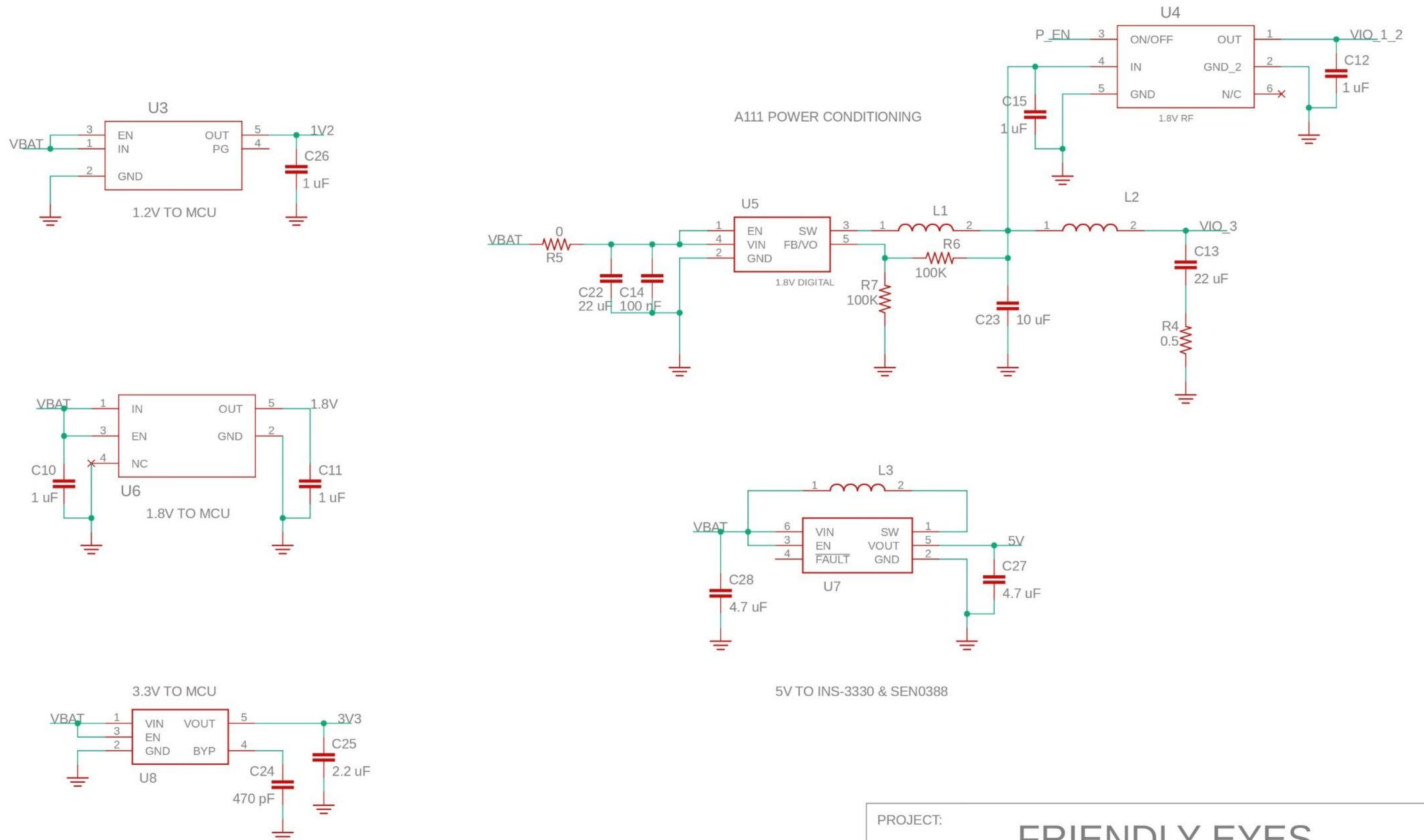
Table 18 BOM (cost)

Qty	Description	Reference Designator
1	LI-ION POLYMER 3.7V 6000MAH BAT	BT1
2	IC REG LINEAR 3.3V 500MA TO252-5	U11, U12
1	IC REG BUCK 1.8V 700MA TSOT23-5	U5
1	IC REG LINEAR 1.8V 300MA 5TSOP	U6
10	CAP CER 1UF 10V X5R 0805	C1, C2, C3, C10, C11, C12, C15, C26, C30, C32
6	CAP CER 22UF 10V X5R 0805	C13, C22, C34, C31, C39, C40
2	CAP CER 4.7UF 10V X5R 0603	C27, C28
1	CAP TANT 2.2UF 10% 10V 1206	C25
3	CAP CER 10UF 10V X5R 0805	C23, C35, C36
1	IC PWR SWITCH P-CHAN 1:1 SC70-6	U4
1	RES 0 OHM JUMPER 1/8W 0805	R5
2	FIXED IND 2.2UH 2.2A 84 MOHM SMD	L1, L2
1	IC REG LINEAR 3.3V 150MA SOT23-5	U8
1	IC REG LINEAR 1.2V 150MA SOT23-5	U3
1	IC REG BOOST 5V 800MA SOT23-6	U7
1	IC SENSOR PCR RADAR 60GHZ CSP	U2
1	CRYSTAL 24.0000MHZ 18PF SMD	Y1
5	CAP CER 0.1UF 50V X7R 0603	C4, C5, C6, C14, C37, C38
2	CAP CER 6PF 50V C0G/NPO 0805	C7, C8
3	RES SMD 30 OHM 1% 1/8W 0805	R3
4	RES 100K OHM 0.1% 1/8W 0805	R6, R7, R18, R19
1	INS-3330 24GHZ RADAR MODULE	U10
1	URM09 ULTRASONIC SENSOR	U9
1	IC MCU 32BIT 256KB FLASH 68TQFN	U1
1	CRYSTAL 32.7680KHZ 6PF SMD	Y2
5	CAP CER 1UF 6.3V X5R 0805	C9, C18, C19, C20, C21
1	AECQ MOSFET PCH -20V -6A SOT23F	Q1
1	FIXED IND 4.7UH 1.12A 252MOHM SM	L3
1	12V 2A AC-DC WALL ADAPTER	EXTERNAL
1	CONN PWR JACK	J2
1	CONN RCPT USB2.0 MICRO B SMD R/A	J1
2	CAP CER 47PF 50V C0G/NP0 0805	C16, C17
3	CAP CER 470PF 10V C0G/NP0 0805	C24, C29, C33
1	RES 0.5 OHM 1% 1/4W 0805	R4
3	DC VIBRATING MOTOR 1.5-3V	M1, M2, M3
1	FIXED IND 1.5UH 5.3A 22 MOHM SMD	L4
1	RES SMD 10K OHM 1% 1/4W 1206	RFBB
1	RES SMD 60.4K OHM 1% 1/4W 1206	RFBT
1	IC REG BUCK ADJ 3A TSOT23-6	U14

Table 19: BOM (function)

6.2 Overall Schematic





PROJECT:

FRIENDLY EYES

PAGE DESCRIPTION:

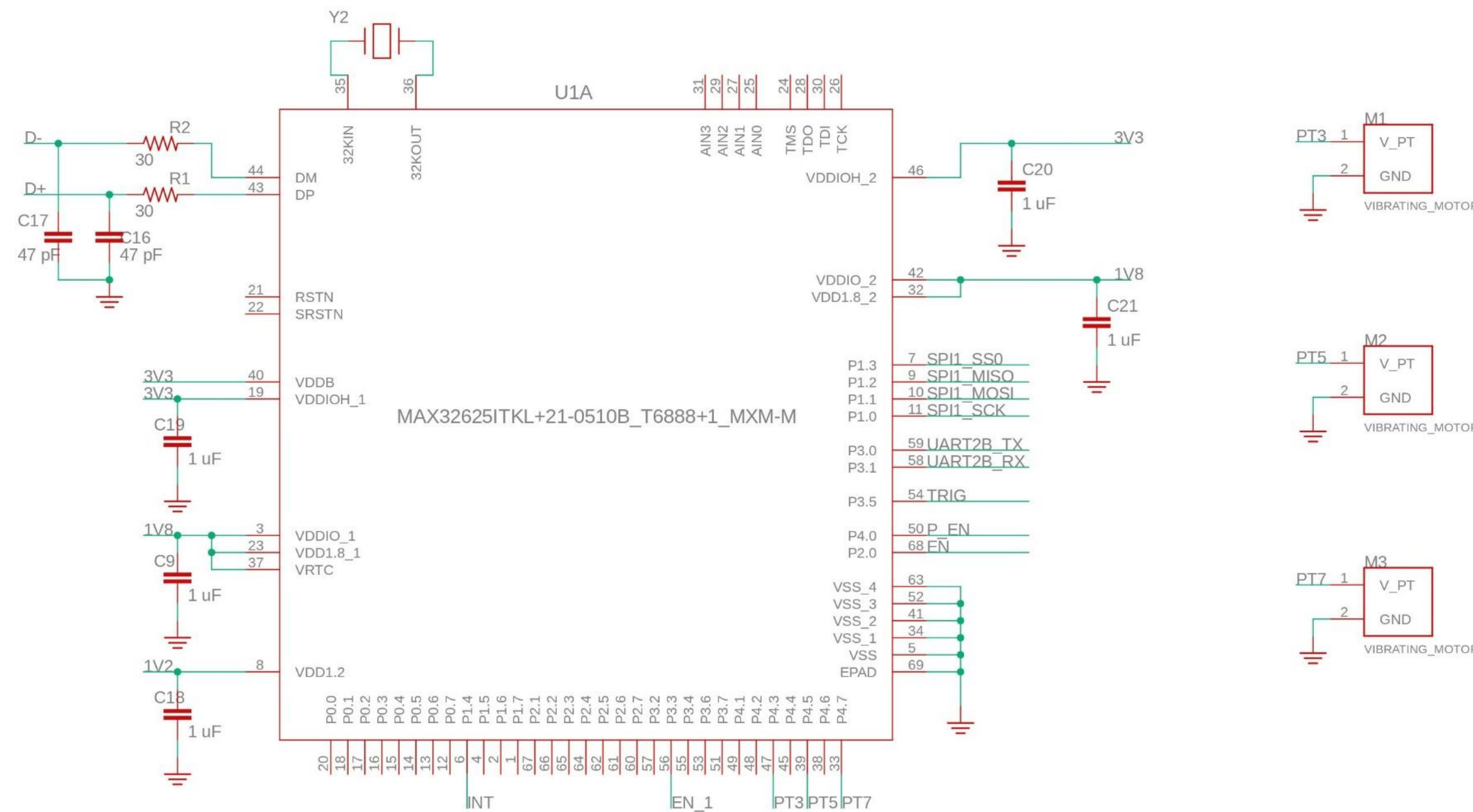
POWER MANAGEMENT

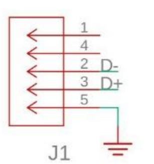
DRAWN BY:

GROUP 43 - EEL 4914 - FALL 2021

REV A.0

DATE: 12/07/2021





USB MICRO 2.0 CONN

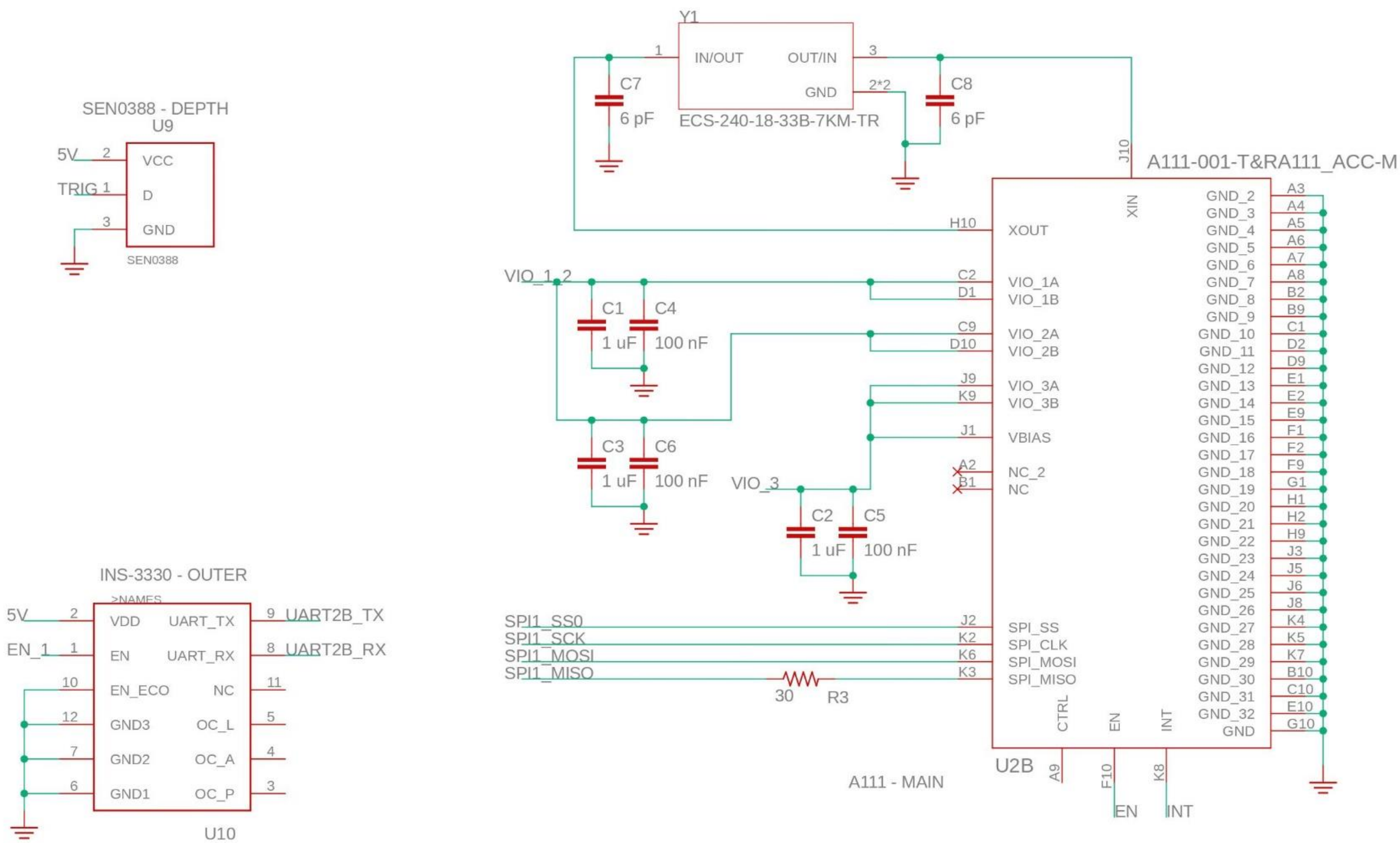
PROJECT:

FRIENDLY EYES

PAGE DESCRIPTION:

PROCESSING SUBSYSTEM

DRAWN BY:	REV A.0	DATE: 12/07/2021
GROUP 43 - EEL 4914 - FALL 2021		SHEET 3 OF 4



PROJECT:

FRIENDLY EYES

PAGE DESCRIPTION:

SENSOR SUBSYSTEMS

DRAWN BY:

GROUP 43 - EEL 4914 - FALL 2021

REV A.0

DATE: 12/07/2021

6.3 PCB Layout & Hardware Integration

We have not gotten in-depth into PCB layout, but for the time being we are aware of different considerations regarding signal routing, placement of power rails, grounds and reference planes, and the importance and implications of component placement.

All this factors can and will introduce difficulties with the correct functioning of our device, with issues hailing from capacitive and inductive sources, to radiated and absorbed emissions by our own design.

The actual physical positioning of our sensors will also play a key role for the proper function of the system. Interference caused by other wave inputs is more prevalent in some zones than others, and the pattern at which this happens can be measured with specialized tools like spectrum analyzers and such, but unless we find a way to borrow one, we needed to define the position of the sensors based on carefully crafted trials and subsequent analysis of the data obtained.

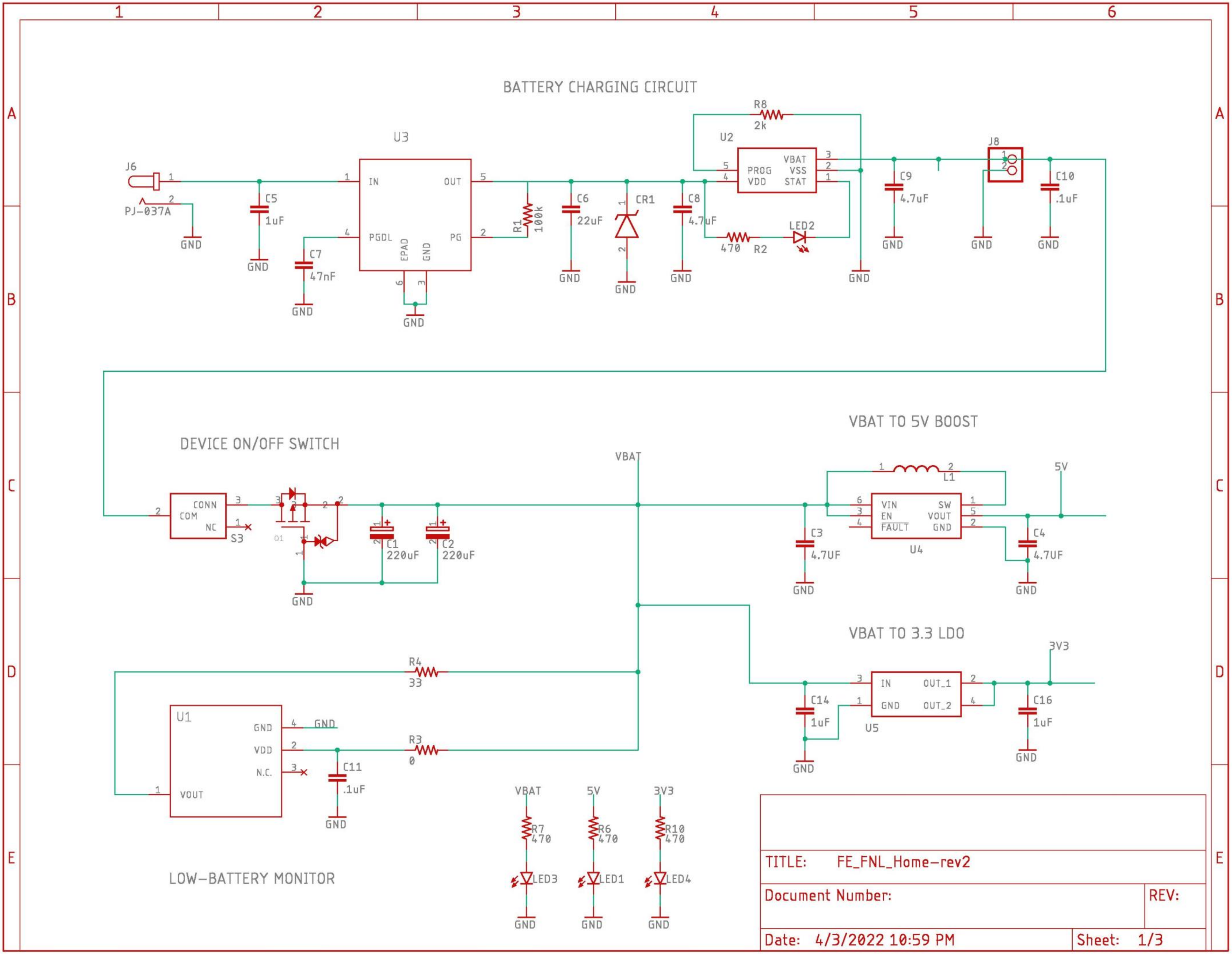
These radar chips also happen to have requirements regarding their housing and covers. It was explained before that some mechanisms of wireless detection are not good with specific materials, but the manufacturers for our technologies all provide in-depth guides filled with recommendations coming from testing in their own labs, so we know we have reliable guidance in that area.

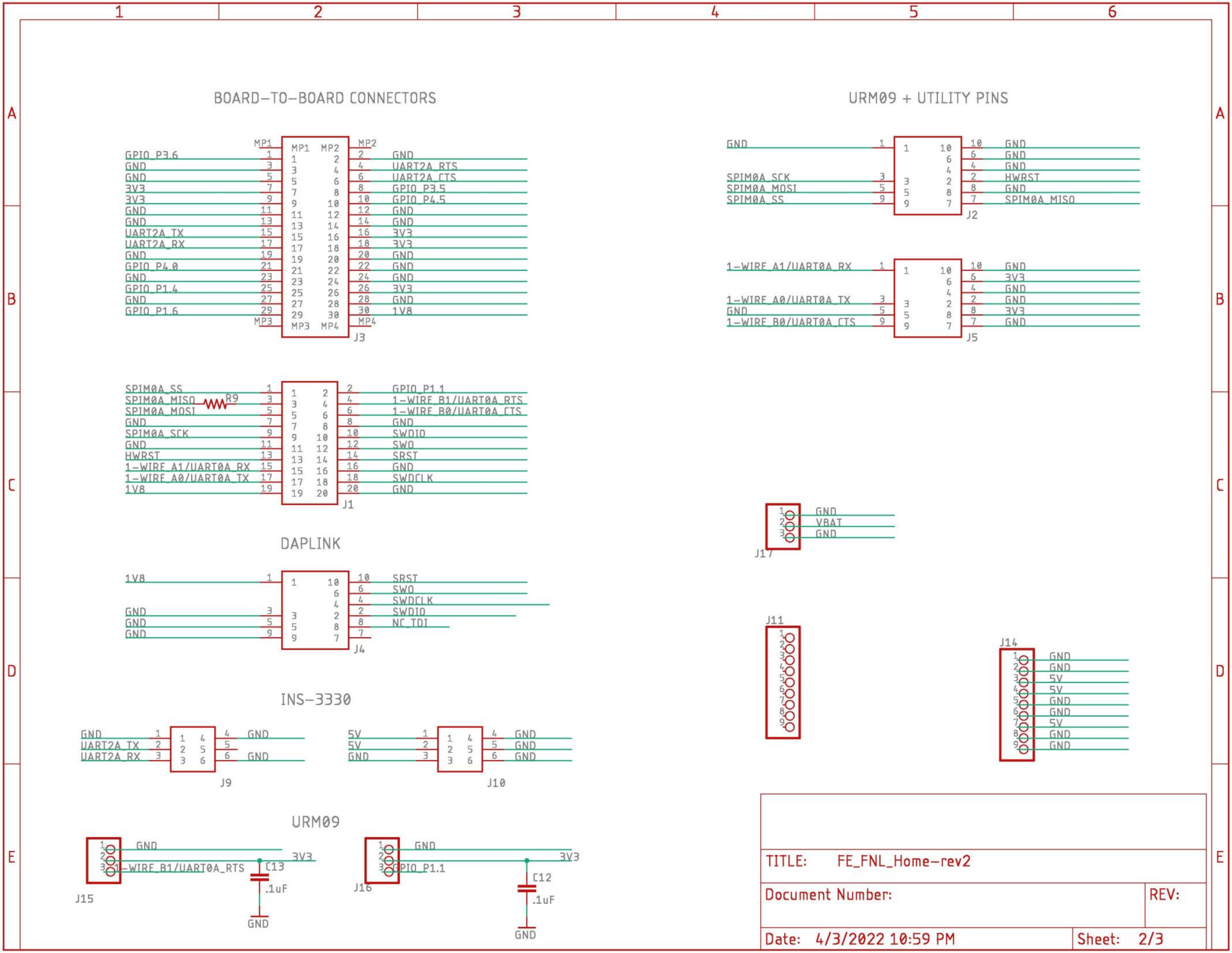
A closer look must be taken on the housing used for each sensor, as directions to get the best performance possible touch on differences in millimeters in the placement of a plastic cover, and the specific molecules the plastic is made of too.

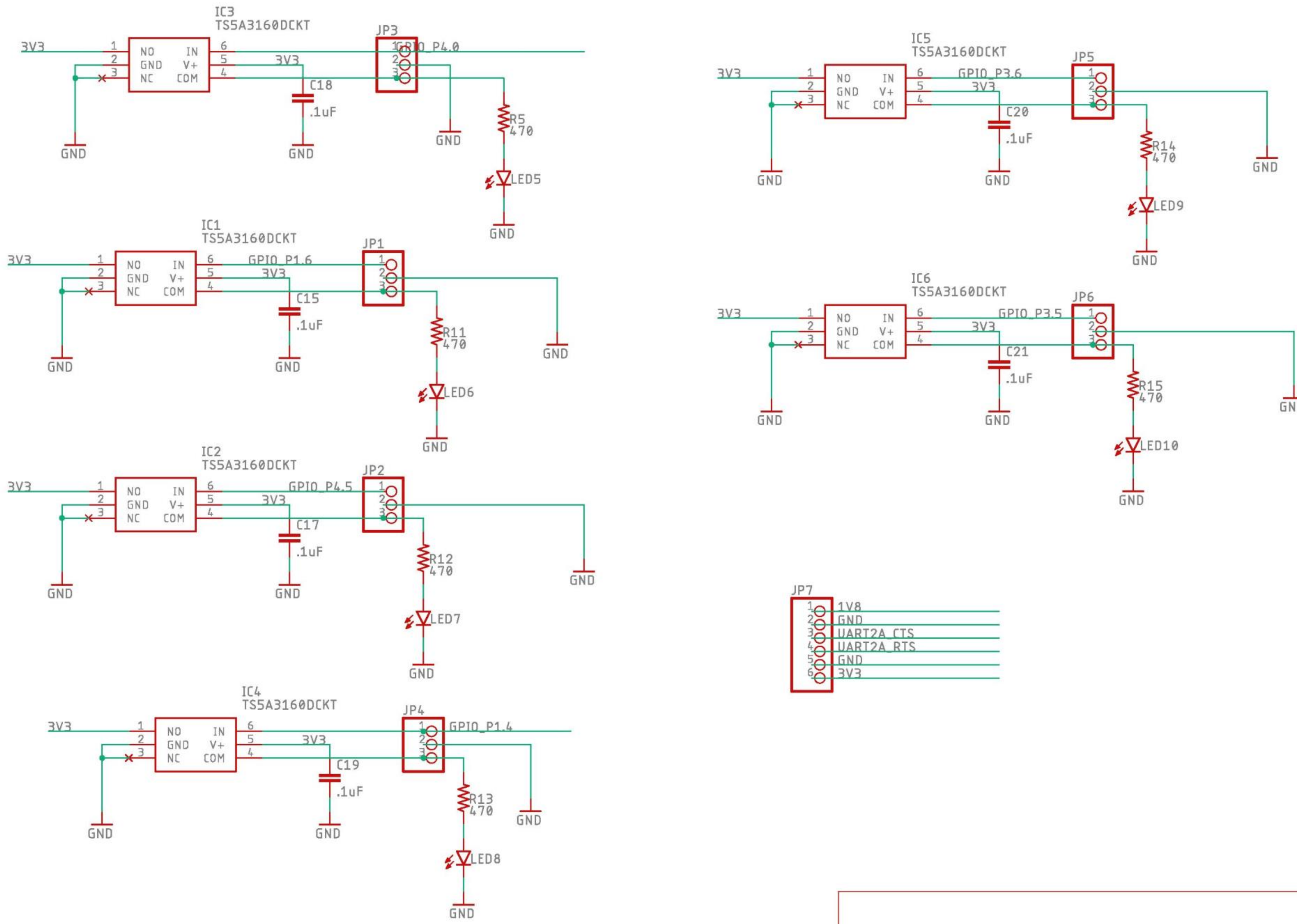
At the end of Senior Design II, FriendlyEyes had undergone a significant number of modifications through testing stages. In essence, the main components such as all of the sensor subsystem as well as the microprocessor remained the same as those selected in the Fall 2021 semester, allowing an overall smooth implementation of the prototype.

Some notable additions to the model are the incorporation of NAND gates used as switches to drive the mechanical feedback features, and the addition of a buzzer to that subsystem. This then permitted to implement a key with combinations of different types of feedback so that the user could determine with certainty where the threat is coming from, and of what type.

In the following pages readers will find visual material on the final implementation of FriendlyEyes, accounting for tables laying out functionality, schematics, final printed circuit board, enclosure, and mounting procedure.


BATTERY CHARGING CIRCUIT
J6
PJ-037A
U3
IN
OUT
PGDL
PG
EPAD
GND
R1 100k
C5 1uF
C7 47nF
C6 22uF
CR1
C8 4.7uF
R8 2k
U2
PROG
VDD
VBAT
VSS
STAT
R2 470
LED2
C9 4.7uF
J8
C10 .1uF
GND
DEVICE ON/OFF SWITCH
S3
CONN
COM
NC
C1 220uF
C2 220uF
VBAT
VBAT TO 5V BOOST
L1
5V
U4
VIN
EN
FAULT
SW
VOUT
C3 4.7UF
C4 4.7UF
VBAT TO 3.3 LDO
3V3
U5
OUT_1
OUT_2
C14 1uF
C16 1uF
R4 33
R3 0
U1
N.C.
C11 .1uF
R7 470
R6 470
R10 470
LED3
LED1
LED4
LOW-BATTERY MONITOR
TITLE: FE_FNL_Home-rev2
Document Number:
REV:
Date: 4/3/2022 10:59 PM
Sheet: 1/3


BOARD-TO-BOARD CONNECTORS
J3
MP1 MP2 MP3 MP4
GPIO_P3.6
GND
GND
3V3
3V3
GND
GND
UART2A_TX
UART2A_RX
GND
GPIO_P4.0
GND
GPIO_P1.4
GND
GPIO_P1.6
GND
UART2A_RTS
UART2A_CTS
GPIO_P3.5
GPIO_P4.5
GND
GND
3V3
3V3
GND
GND
GND
3V3
GND
1V8
J1
SPIM0A_SS
SPIM0A_MISO
R9
SPIM0A_MOSI
GND
SPIM0A_SCK
GND
HWRST
1-WIRE_A1/UART0A_RX
1-WIRE_A0/UART0A_TX
1V8
GPIO_P1.1
1-WIRE_B1/UART0A_RTS
1-WIRE_B0/UART0A_CTS
GND
SWDIO
SWO
SRST
GND
SWDCLK
GND
DAPLINK
J4
1V8
GND
GND
GND
SRST
SWO
SWDCLK
SWDIO
NC_TDI
INS-3330
J9
GND
UART2A_TX
UART2A_RX
GND
GND
J10
5V
5V
GND
GND
GND
GND
URM09
J15
GND
3V3
1-WIRE_B1/UART0A_RTS
C13
.1uF
GND
J16
GND
3V3
GPIO_P1.1
C12
.1uF
GND
URM09 + UTILITY PINS
J2
GND
SPIM0A_SCK
SPIM0A_MOSI
SPIM0A_SS
GND
GND
GND
HWRST
GND
SPIM0A_MISO
J5
1-WIRE_A1/UART0A_RX
1-WIRE_A0/UART0A_TX
GND
1-WIRE_B0/UART0A_CTS
GND
3V3
GND
GND
3V3
GND
J17
GND
VBAT
GND
J11
J14
GND
GND
5V
5V
GND
GND
5V
GND
GND
TITLE: FE_FNL_Home-rev2
Document Number:
REV:
Date: 4/3/2022 10:59 PM
Sheet: 2/3



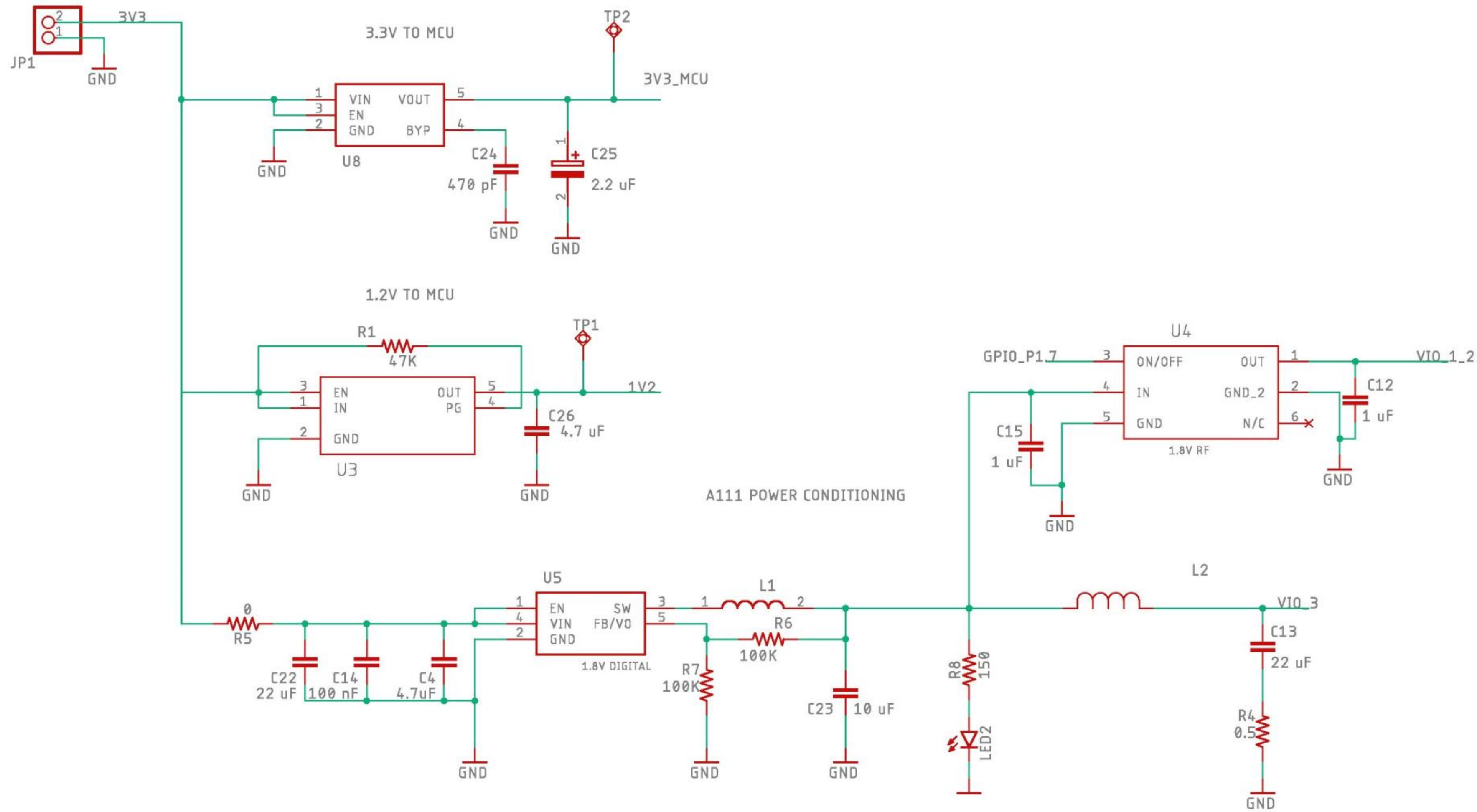
TITLE: FE_FNL_Home-rev2

Document Number:

REV:

Date: 4/3/2022 10:59 PM

Sheet: 3/3



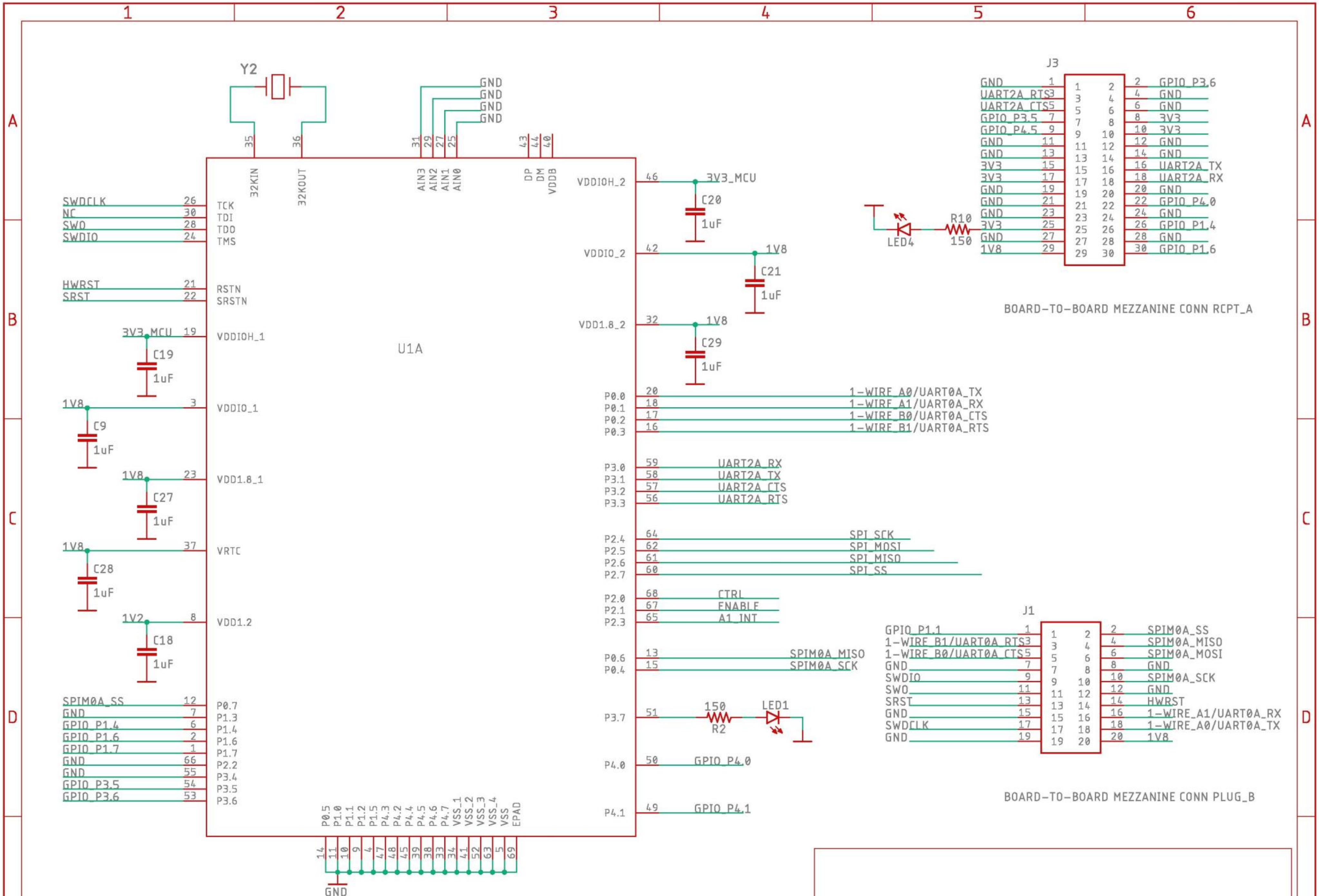
TITLE: FE_FNL_CoreBoard

Document Number:

REV:

Date: 4/23/2022 6:42 PM

Sheet: 1/3



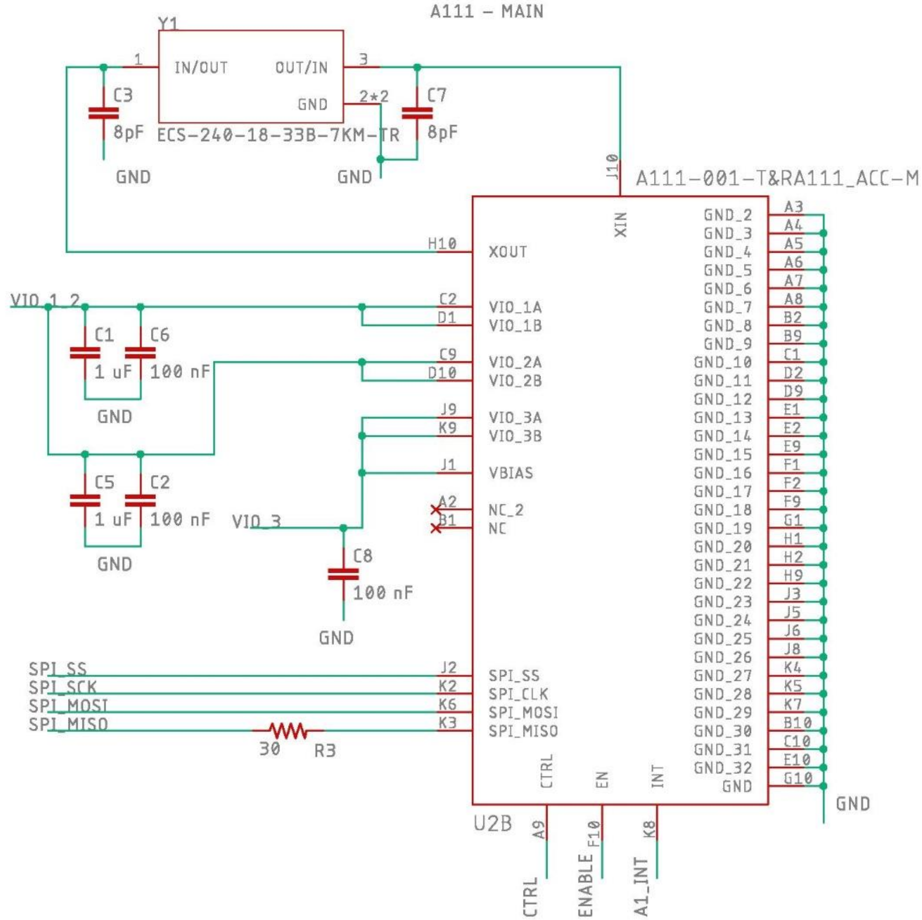
TITLE: FE_FNL_CoreBoard

Document Number:

REV:

Date: 4/23/2022 6:42 PM

Sheet: 2/3



TITLE: FE_FNL_CoreBoard

Document Number:

REV:

Date: 4/23/2022 6:42 PM

Sheet: 3/3

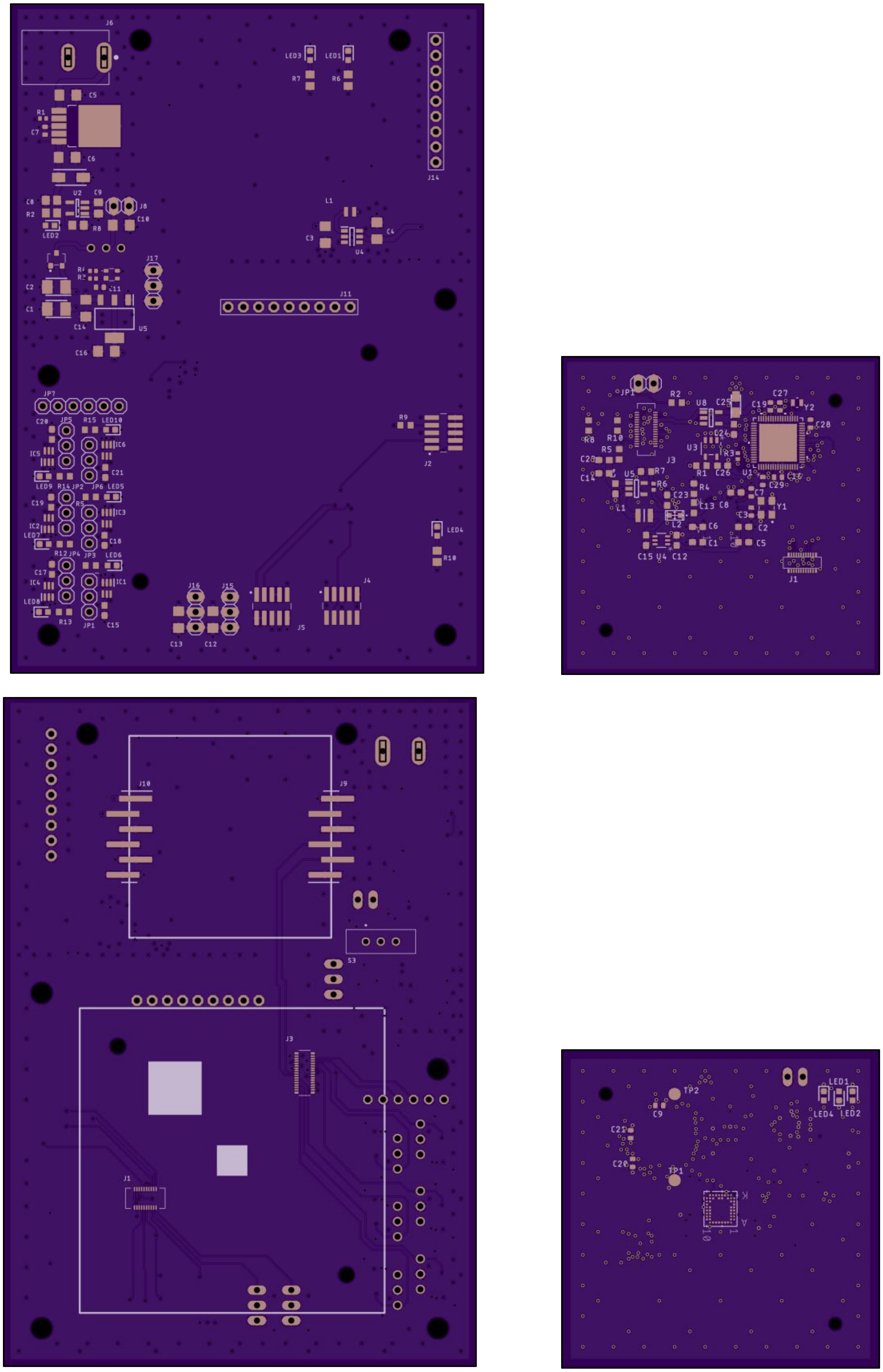


Figure 22: Printed Circuit Boards

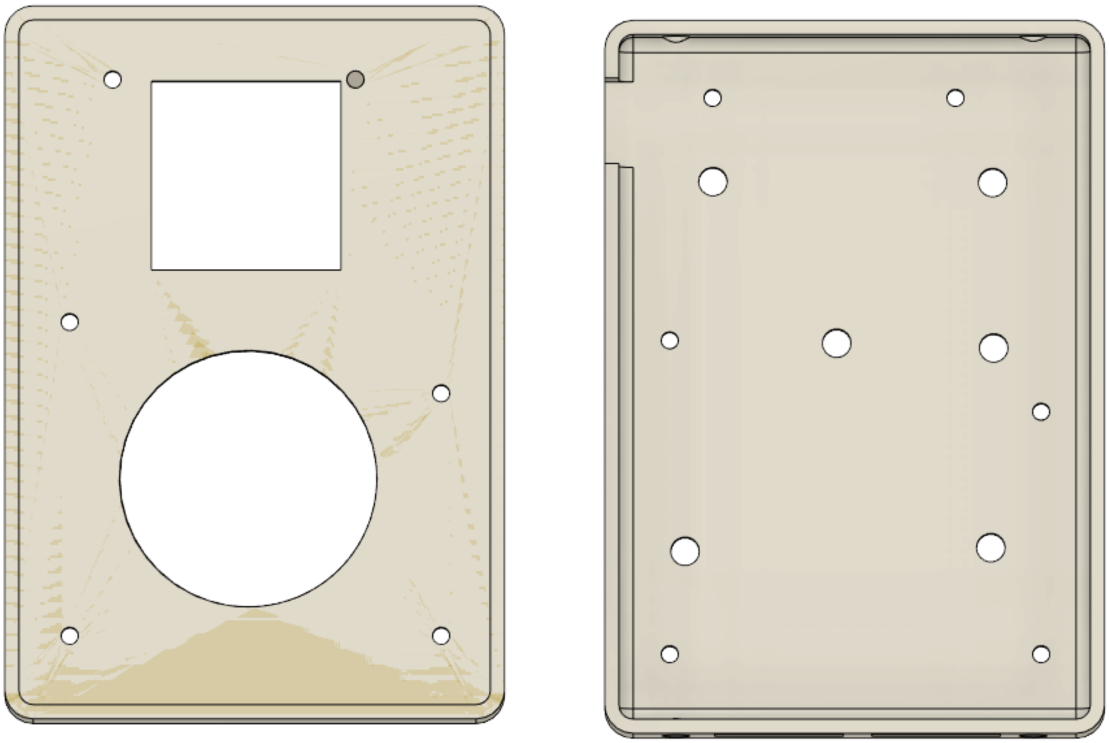


Figure 23: Enclosure

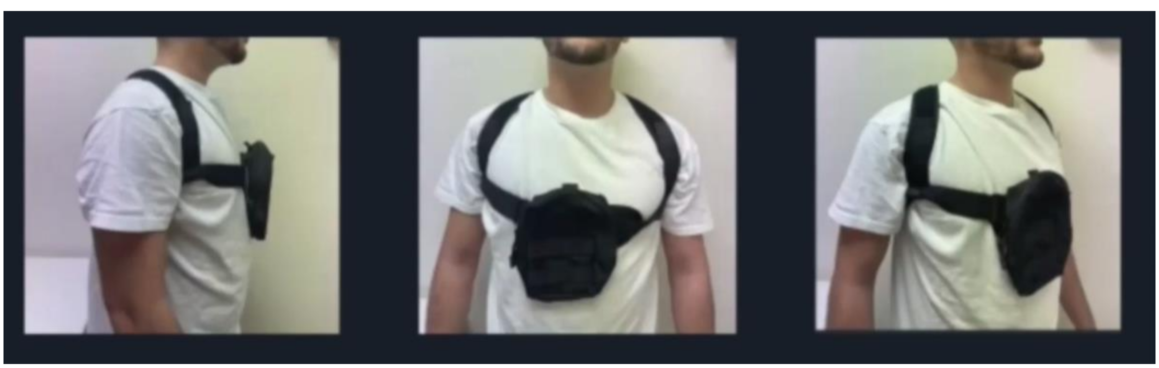


Figure 24: Sack and Strapping system

FEEDBACK KEY
.Main (0.3 – 7 m):
- FRONT: VIB_L AND VIB_R
- SIDES: VIB_L OR VIB_R
.Outer (5 – 9 m):
- FRONT: 2X LEVEL BUZZ
.Depth Tracking:
- SIDES: BUZZ

Table 20: key to different feedback mechanisms and their meaning

Figure 25: Project Logo

7 ADMINISTRATIVE CONSIDERATIONS

What follows is a series of administrative facts and measures on the development of FriendlyEyes.

7.1 Component Manufacturers & Vendors

The current supply-chain shortage added external strain on the feasibility of the project. Integrated circuits that we had singled out for specific purposes such as power management and logic design during our investigation have been out of stock for some time now, and backorders taking up to a year to obtain. Companies that seem to be the most affected have big names like Texas Instruments and NXP. Most of webench power design tool suggested regulators are not being produced, and they are expected to be back up to two years from now, so we have been forced to look at alternative manufacturers, although TI's reach in product lines was too large, going into the depths of special purpose IC design and production.

For as long as the project has run, we have dealt with Digikey, Mouser, and even private companies who ship their own product. Shortages hit these companies in similar levels, but we have been able to work around them with alternates so far.

7.2 PCB Manufacturers

During this time, we have also searched for PCB manufacturers to work with throughout the project. Looking at the quality of their product, their build and shipping times, cost per mm^2, and references obtained from experienced engineers, the list was narrowed to a few contenders, some working for different purposes, to produce our breakout boards we looked at a relatively small area for the PCB, so the Chinese vendor JLCPCB offering bundles for 1 and 2 layer FR-4 PCBs of 100mmx100mm with 1-day build time looks like the best option. This company also leads the race for sourcing the prototypes for our completed system because of their flexibility and low cost, nevertheless for our final revision we may be looking at a sturdier printed circuit board that can withstand impact aside from ensuring reliability of all signals traversing it, added to the possibility of outsourcing the assembly of at least some of the more delicate and difficult to solder components, such as the A111 module itself, so we would prefer to work with a domestic company that provides accessible customer support to minimize issues hailing from production. For that purpose, OSHPARK or 4PCB Advanced Circuits may be worth the higher price tags.

7.3 Budget & Financing

We do not expect to get a sponsor to aid us in financing for this project so the project will be self-funded. For this reason, we hope to keep the project as low budget as possible without interfering with the functionality of the design.

Although we have financed the whole product development so far, we expect to cause an impact with our design, so this has not been an issue this far.

Component	**Budget**
PCB	$20
Sensors	$100
Power Supply	$30
Analog-to-Digital Converter	$10
Microcontroller/microprocessor	$20
USB cable	$2
Input/output interfaces	$30
Passive components	$30
DC-DC converters	$50
Voltage regulators and active components	$50
Vest/Hat	$30
Total	$372

Table 21

So far, we have stocked up on the tens and twenties of each of our components to make sure we are not affected by external factors such as lack of supply later on, so our monetary requirements have inflated as the project moved forward, while we adapted our financing plans as we saw fit, and this is seen with the overall part selection and the cheap cost we found through extensive investigation.

7.4 Decision Matrix

The following diagram shows a tool used by us during the development phase:

	Vest Design	**Vest and Hat Design**
Description	All components will be located on the vest. Vibrating motors on the best will vibrate at different frequencies when sensors pick up that an individual is within a certain range of objects.	The sensors for this project would be located on the hat while the rest of the components would be located on the vest. Vibrating motors on the best will vibrate at different frequencies when sensors pick up that an individual is within a certain range of objects.
Motivation	We want to help the visually impaired by helping them navigate the space around them easier. We also believe this wearable can be used for different purposes from the original intention.	We want to help the visually impaired by helping them navigate the space around them easier. We also believe this wearable can be used for different purposes from the original intention.
Stretch Goals	We would like to attach a braille pad so that individuals will know if there are specific objects in front of them like a chair or a door. We would also like to integrate an induction charger for the battery.	We would like to attach a braille pad so that individuals will know if there are specific objects in front of them like a chair or a door. Bluetooth communication for the sensors. This would enable us to have no wires from the hat to the vest. We would also like to integrate an induction charger for the battery.

Table 22: Decision Matrix

7.5 Project Milestones

Below is the summary of our project milestones in time.

Senior Design 1

Number	Task	Milestone Date	Status
1	Pick Project Idea, Assign roles	8/27/2021	
2	Initial Project Documentation – Divide and Conquer	9/17/2021	
3	Updated Divide and Conquer document	10/01/2021	
4	60 page draft	11/05/2021	
5	100 page draft	11/19/2021	
6	120 page Final Document	12/07/2021	
7	Breadboard testing	12/07/2021	
8	Begin ordering parts	12/07/2021	

Table 23

Senior Design 2

Number	Task	Milestone Date	Status
1	Implementing Note Detection & Test Software	TBD	
2	Finish first draft of drivers	TBD	
3	Testing Parts	TBD	
4	Possible Redesign	03/08/2022	
5	Finalized Design	03/22/2022	
6	Final Prototype working	04/07/2022	
7	SD Showcase	04/20/2022	

Table 24

APPENDIX

A References

[a] Thomson Reuters. (2015, March 18). *Palestinian Students Design Vest to help the blind navigate*. Reuters. Retrieved December 6, 2021, from https://www.reuters.com/article/us-westbank-blind-vest/palestinian-students-design-vest-to-help-the-blind-navigate-idUSKBN0ME11320150318.

[b] *Wearables help the blind walk*. ASME. (n.d.). Retrieved December 6, 2021, from https://www.asme.org/topics-resources/content/wearables-help-the-blind-walk.

[c] Larry Hardesty | MIT News Office. (n.d.). *Wearable system helps visually impaired users navigate*. MIT News | Massachusetts Institute of Technology. Retrieved December 6, 2021, from https://news.mit.edu/2017/wearable-visually-impaired-users-navigate-0531.

[d] Bellan, R. (2021, July 28). *Ashirase, a Honda incubation, reveals Advanced Walking Assistance System for Visually impaired*. TechCrunch. Retrieved December 6, 2021, from https://techcrunch.com/2021/07/28/ashirase-a-honda-incubation-reveals-advanced-walking-assistance-system-for-visually-impaired/.

[1] Wavelength Electronics. (2021, March 25). *Power Supply Basics*. Wavelength Electronics. Retrieved December 6, 2021, from https://www.teamwavelength.com/power-supply-basics/.

[2] Spiegel, D. C. (n.d.). *Power Electronics for Renewable Energy Systems*. Fuel Cell Store. Retrieved December 6, 2021, from https://www.fuelcellstore.com/blog-section/power-electronics-for-renewable-energy-systems.

[3] Industrial Quick Search. (n.d.). *Industrial Quick Search*. What Is It? Where Is It Used? AC vs. DC. Retrieved December 6, 2021, from https://www.iqsdirectory.com/articles/power-supply/dc-power-supply.html.

[4] *Switch Mode Power Supply Basics and switching regulators*. Basic Electronics Tutorials. (2021, August 4). Retrieved December 6, 2021, from https://www.electronics-tutorials.ws/power/switch-mode-power-supply.html.

[5] Granath, E. (2021, April 27). *Advantages of buck-boost converters*. Power & Beyond. Retrieved December 6, 2021, from https://www.power-and-beyond.com/advantages-of-buck-boost-converters-a-910595/.

[6] OpenStax. (n.d.). *17.5 batteries and Fuel Cells*. Chemistry. Retrieved December 6, 2021, from https://opentextbc.ca/chemistry/chapter/17-5-batteries-and-fuel-cells/.

[7] Classification of cells or batteries. (n.d.). Retrieved December 2021, from https://depts.washington.edu/matseed/batteries/MSE/classification.html.

[8] *BU-302: Series and Parallel Battery Configurations*. Battery University. (2021, October 25). Retrieved December 6, 2021, from https://batteryuniversity.com/article/bu-302-series-and-parallel-battery-configurations.

[9] *How do lithium-ion batteries work?* Explain that Stuff. (2020, November 23). Retrieved December 6, 2021, from https://www.explainthatstuff.com/how-lithium-ion-batteries-work.html.

[10] *What is the energy density of a lithium-ion battery?* Home. (n.d.). Retrieved December 6, 2021, from https://www.fluxpower.com/blog/what-is-the-energy-density-of-a-lithium-ion-battery.

[11] HowStuffWorks. (2006, November 14). *How lithium-ion batteries work*. HowStuffWorks. Retrieved December 6, 2021, from https://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery.htm.

[12] *Lithium-ion battery - clean energy institute*. (n.d.). Retrieved December 6, 2021, from https://www.cei.washington.edu/education/science-of-solar/battery-technology/.

[13] Battery University. (2021, December 3). *BU-808: How to prolong lithium-based batteries*. Battery University. Retrieved December 6, 2021, from https://batteryuniversity.com/article/bu-808-how-to-prolong-lithium-based-batteries.

[14] Notes, E. (n.d.). *Lithium Ion Battery Advantages & Disadvantages*. Electronics Notes. Retrieved December 6, 2021, from https://www.electronics-notes.com/articles/electronic_components/battery-technology/li-ion-lithium-ion-advantages-disadvantages.php.

[15] *Nickel-cadmium batteries: Basic theory and maintenance ...* (n.d.). Retrieved December 6, 2021, from https://www.aviationpros.com/engines-components/article/10387569/nickelcadmium-batteries-basic-theory-and-maintenance-procedures.

[16] *Nickel Cadmium Battery*. Nickel Cadmium Battery - an overview | ScienceDirect Topics. (n.d.). Retrieved December 6, 2021, from https://www.sciencedirect.com/topics/engineering/nickel-cadmium-battery.

[17] Battery University. (2021, October 25). *BU-407: Charging nickel-cadmium*. Battery University. Retrieved December 6, 2021, from https://batteryuniversity.com/article/bu-407-charging-nickel-cadmium.

[18] *What the heck is a NICD battery?* BatteryStuff.com. (n.d.). Retrieved December 6, 2021, from https://www.batterystuff.com/kb/articles/battery-articles/what-the-heck-is-a-nicd-battery.html.

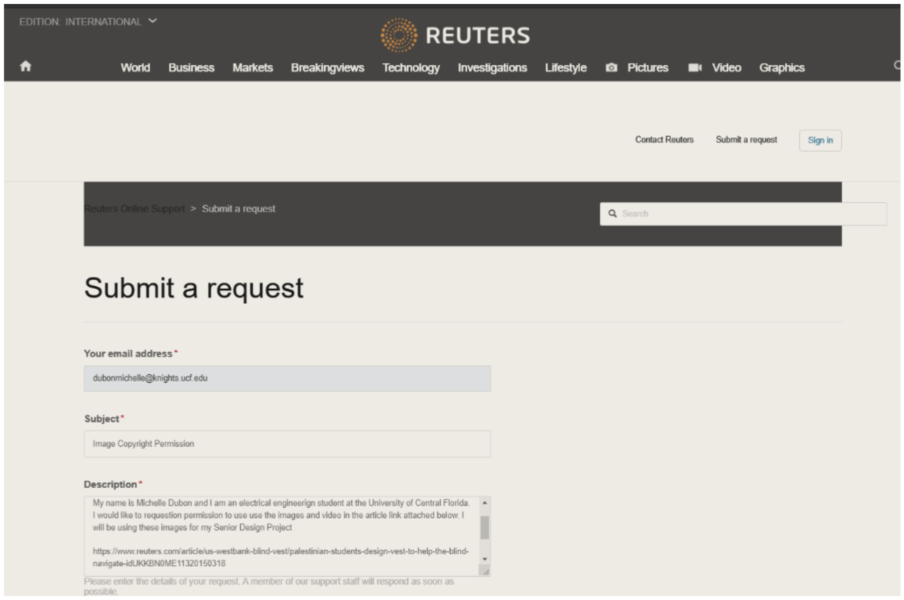
[19] *What is fall detection?: Fall Detection Devices & Systems*. Lively. (n.d.). Retrieved December 6, 2021, from https://www.lively.com/health-and-aging/what-is-fall-detection/.

B Integrated Circuit Datasheets

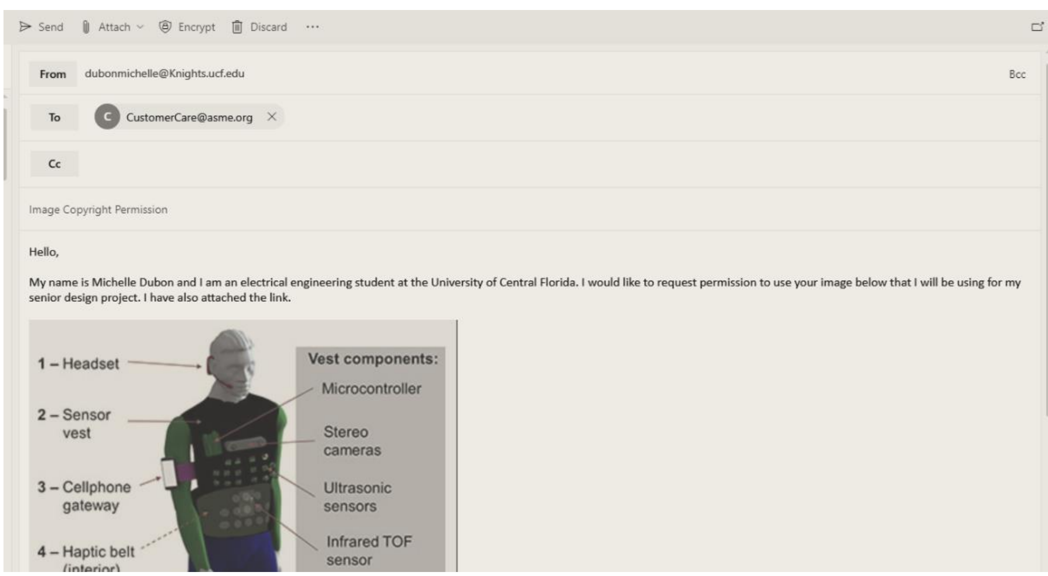
Part Number	Documents
MP2018GZD-33-P	https://www.monolithicpower.com/en/documentview/productdocument/index/version/2/document_type/Datasheet/lang/en/sku/MP2018/document_id/5928/
ST1S12G18R	https://www.st.com/content/ccc/resource/technical/document/datasheet/22/99/6c/42/0d/cc/47/8f/CD00181873.pdf/files/CD00181873.pdf/jcr:content/translations/en.CD00181873.pdf
NCP115ASN180T2G	https://www.mouser.com/datasheet/2/308/1/NCP115_D-2316977.pdf
SIP32431DR3-T1GE3	https://www.mouser.com/datasheet/2/427/VISH_S_A0010847864_1-2571495.pdf
MIC5205-3.3YM5-TR	https://ww1.microchip.com/downloads/en/DeviceDoc/20005785A.pdf
MIC5258-1.2YM5-TR	http://www.microchip.com/mymicrochip/filehandler.aspx?ddocname=en579827
ISL9111AEH50Z-T7A	https://www.ti.com/lit/ds/symlink/tps7a88-q1.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1637831935273
A111	https://media.digikey.com/pdf/Data%20Sheets/Acconeer%20PDFs/A111-001_DS_V2.4.pdf
INS-3330	https://www.innosent.de/index.php?eID=dumpFile&t=f&f=3834&token=608a69dfe58ee8ee27a4769892d40c3ffe194119
SEN0388	https://www.digikey.com/en/products/detail/SEN0388/1738-SEN0388-ND/13688346?itemSeq=384084262
MAX32625ITKL+	https://www.digikey.com/en/products/detail/MAX32625ITKL%2b/MAX32625ITKL%2b-ND/8124092?itemSeq=384085843

C Copyright Information

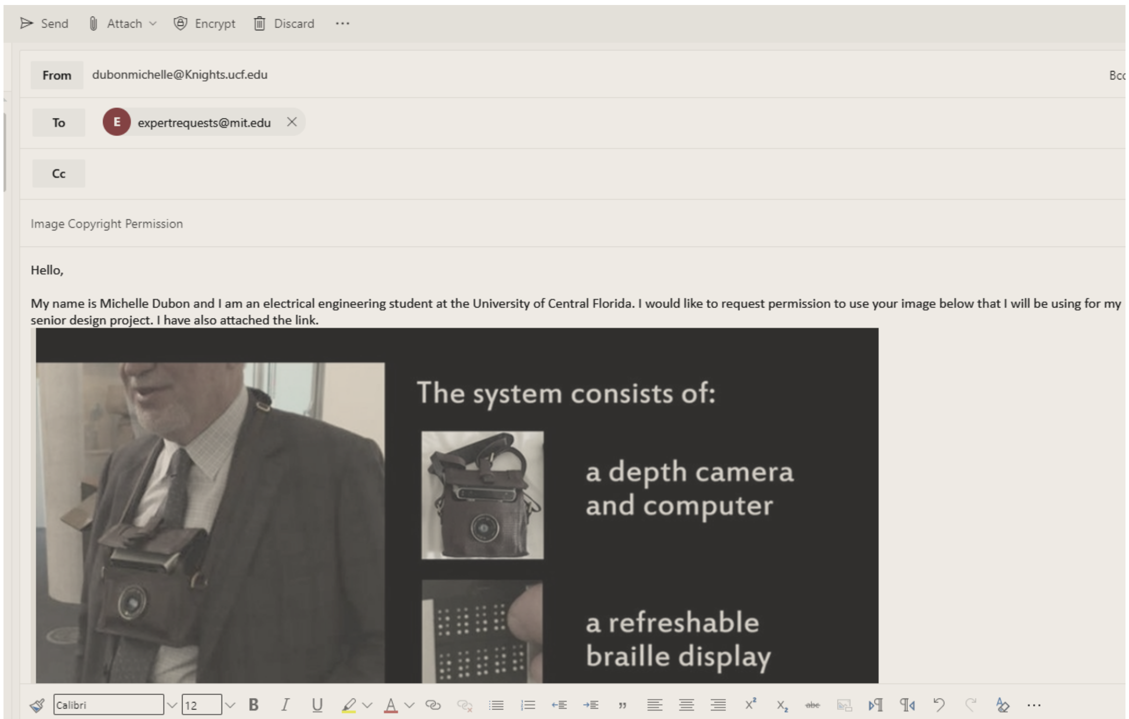
This paper has not gone through revision of copyrighted material included. No copyright infringement is intended.



Copyright (Permission Pending) - Eyeronman



Copyright (Permission Pending) - MIT's Computer Science and Artificial Intelligence



Copyright (Permission Pending) - Honda's "Ashirase"