Remote Area Monitoring

Final Document

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Group 10

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1.0– Executive Summary

Our project aims to reduce the impact of forest fires by providing data to forest management agencies to make informed decisions. While our system is not detecting the forest fires, we are providing information about the environment within the forest. This information consists of weather data with a specific focus on forest management. During our research, we learned about the current methods for resource allocation and planning behind the prevention of forest fires. Those in charge of managing areas prone to forest fires look at much of the same data our system intends to supply. The difference is the data currently available to the interested parties is on a macro scale. This means that the conditions of an area are generalized and averaged. The decisions made rely on historical data and averages that may not be the full picture of the conditions in an area. This has the potential to divert resources for things such as controlled burns and fire breaks away from areas that are in need.

Our system is designed to be placed over a relatively small area of the forest specifically near populated or otherwise at risk areas. Our system covers the area with a mesh network of nodes providing much more granular data for the managing parties to observe. The goal behind this is to clearly show the health and fire risk of areas buffering populated centers. This may aid in the allocation of resources to these areas. In addition, the data our system gathered is stored to provide a historical record of the area. This may be helpful in forecasting future changes to an area once a large enough sample size of data has been collected.

The research into our competitors revealed a sparsely populated space. Our main competitor Dryad takes a similar approach using a mesh network but with a greater focus on detection. While detecting forest fires early is important, equally or of greater importance is preventing them from occurring or spreading in the first place. Beyond this, there are no direct competitors. The current methods for collecting this type of data rely on satellite observation, visual inspections, and sparsely placed weather stations. There are some other methods used by different forest management agencies, though they are not standardized.

We also considered the impacts of our project on the environment. Our system will consist of multiple devices placed throughout a natural environment. We will work to ensure the safety and sustainability of these devices remains a priority through the development lifecycle. One way we will work towards this is by creating a modular system to best fit the needs of each individual customer. This will help to cut down on unnecessary electronic waste. We will also be adhering to applicable standards to increase the compatibility and safety of our system.

As a final note, our system designs will be fully open source. Forest fires are devastating and are only going to increase in frequency and severity as our world warms. We want to do our part to preserve these natural areas and make them safer for those living nearby.

2.0 – Project Overview

2.1 Project Narrative

In recent years, we have seen the devastating consequences of global warming. One such consequence is the measurable uptick in wildfires. In 2020 alone over 10 million acres of land burned destroying nearly 18,000 structures. Our motivation originates from one event in 2016, the Chimney Tops 2 fire. One group member was present at the origin of this wildfire. The short of it is, wildfires are terrifying and have a lifelong impact on those affected.

In the days following the start of the fire, we contacted the fire service to offer any assistance we may provide from a first-person perspective. The investigator we spoke with had an interesting request. He asked for all the photos we took from the day the fire started. His reasoning was that they needed to determine the fuel load of the area. Fuel load is the amount of combustible materials present. For example, dried brush and dead trees. According to the investigator, this information is hard to ascertain once the fire has passed through an area consuming all the fuel. Being of an engineering mindset, this interaction evoked a line of thinking about how we may help this issue in the future.

We began by examining the options currently available. The options include two main methods of detection both with drastically different approaches. The first method to detect fires is by air. Either from airplanes or satellites. The second method is placing a mesh network of sensors across an area of forest. Both methods have positive and negative features. The fundamental issues with the currently available products that we are aiming to solve is cost and availability. The cost of satellite creation or rental is preventative to many potential users. Additionally, the remaining products are not available for purchase.

We realize that reliably detecting fires is an engineering challenge that may quickly exceed the capacity of two semesters. We will not be creating a fire warning system. With consideration of the fire investigator’s insights, we intend to create an open-source monitoring system.

We will focus on monitoring the environmental factors leading up to wildfires. Some of these factors include fuel load, moisture, temperature, volatile compounds in air and wind speed/direction. Our system will consist of a resilient mesh network of nodes. Each node will report its data back to an aggregator node where the data is stored and displayed. All nodes are modular allowing only the necessary sensors be equipped for the specific application of the system. The system will be fault tolerant, maintaining functionality with a minimal number of nodes remaining.

Our hope is that the information gathered by our system will aid those responsible for forest management in the prevention of forest fires by prompting preventative actions. As well as informing movement of assets when actively fighting a fire. Finally, and most importantly, placing the mesh near populated areas may aid emergency management in issuing earlier warnings to residents in the event an evacuation is required.

2.2 – Motivation

There have been a noticeable amount of forest fires happening recently and it happens without prior warning. There are various reasons and circumstances of why those fires happen and sometimes these circumstances tend to be underreported because of a lack of proper technology. While knowing about these certain circumstances, we can learn how to properly gather data and analyze them in order to predict the chances of a forest fire from happening.

Therefore, this is the reason why we are creating the Remote Area Monitoring Device to gather different types of data such as humidity, temperature, wind speed and direction, and moisture of an area of a specific range so that it can transfer that data to users via a web application. In order for the device to gather these types of data, it would contain cameras, sensors, and anemometers to capture specific nodes. This type of data is then analyzed so that we can then determine the threat of the forest fire of the specific area where it is being measured. When we create our design, we want to make sure that it is efficient and easy to use for any user. It is also important that the product is able to withstand natural damage. The device should be able to work with new technology and software such as Arduino and Python.

2.3 – Goals

2.3.1 – Core Goals

In this section, we will list the goals we believe will lead to project success.

- Create a network of sensing nodes capable of off-grid communications and operation
- Collect the data gathered by each node and aggregate the data in a database. This data may be exported or viewed for a historical representation of the area.
- Each sensing node shall adopt a modular design. This is to reduce the overall cost of the system by either: allowing each node to only have the sensors necessary for the application or reducing the number of fully featured nodes in a given monitoring area.
- A minimum set of sensors will be implemented including temperature, humidity, smoke, and an anemometer
- All nodes will run on a combination between solar power and a reserve battery for operation at night or in inclement conditions
- The aggregator shall provide a method to visualize the live data. This may include a map of each node with a color-coded status
- The system maintainer may designate persons to receive notifications when a node is no longer communicating with the aggregator

2.3.2 – Stretch Goals

In this section, we will list the nice to have features that we will implement time and resources permitting.

- Predictive data analysis – Use gathered data in conjunction with outside data to offer suggestions to area maintainers. For example, when the system notices an area is dry and there is no rain predicted in the next few days, the system will recommend the fire danger level is increased
- Fault tolerance in nodes – If a node has a degraded component the system shall automatically shut that component down and continue to function with remaining components where possible
- Preventative Maintenance – The system shall detect a degradation in sensors or batteries of the nodes and suggest preventative actions prior to failure
- Daily or weekly reports with a management friendly layout – Focus on graphics and clear visual representation of the data marked most important by the maintaining agency
- Expand the capacity of the network – Allow for covering much larger areas by increasing the number of nodes the system supports

2.4 – Requirement Specifications

2.4.1 – Hardware Requirement Specifications

When we select our hardware components, we have to keep various specifications in mind. We have to make sure that our Remote Area Monitoring Device is able to properly function in the area where it is being tested given the constraints and that it produces the most accurate results and data possible. Therefore, the hardware components that we select must follow a specific accuracy range in order to give us the best value when measuring nodes such as the humidity, temperature, carbon monoxide level, rain level, and soil moisture. The device itself should be large enough at about 6in x 6in so that it can be able to manage and use different types of nodes properly. Also, the device should be able to measure and analyze forest fire threats at a certain distance and with a reliable camera or viewing device so that it would give more time and space to report data about it while being able to detect it in a much wider area and distance. It would also need to accurately analyze the type of threat that is coming from the area that is being investigated. The device should also be able to be powered from a reasonable amount of time since it is going to be placed outside so that means that the battery of power reserve should be able to stay fully charged for at least 3 days. The components of the device should be strong enough to withstand circumstances such as rain or high amounts of sunlight and should also be disposable, recyclable, and not that expensive so that it can be affordable for the user who buys that product.

Table 2.4.1.1 – Hardware Requirement Specifications

Requirement ID	Specification	Value
001	Range	400 Meters Minimum
002	Visual Camera	2MP Sensor SPI Interface
003	Infrared Camera	2MP Sensor SPI Interface

004	Power Reserve	3 Days on a Fully Charged Battery
005	Charging	3 Watt Minimum PV Panel – Wall charging option
006	Physical Dimensions	6in x 6in
007	Wind Speed and Direction	+- 5% Accuracy
008	Humidity Sensor	Accuracy +- 3%
009	Temperature Sensor	Accuracy +- 0.5C
010	Barometer	Accuracy: +-5kpa
011	TVOC Sensor	Detects 1000ppm change in TVOCs
012	Carbon Monoxide Sensor	Detects 1000ppm change in CO
013	GPS Module	15m Radial Accuracy
014	Soil Moisture Sensor	Detects 1 Drop of Conductive Liquid
015	Rain Level Sensor	0.2794mm per step

2.4.2 – Software Requirement Specifications

For our device, we will be including software components as well. The reason for that is in order to send data that we obtained from the nodes that we are measuring with our Remote Area Monitoring Device; we should use software that presents those values in a web application. When we select our software components, we have to make sure that the components are up-to-date, compatible, and are able to store high amounts of information. The way that the data is going to be presented on the web application is by maps, of-grid networks, and databases. With these methods, it can help the user know which specific areas of the forest have a higher risk of forest fires happening while basing from and including other nodes such as temperature. The software should be able to communicate and send data without relying on cellular networks and that it is able to store a reasonable amount of data.

Table 2.4.2.1 – Software Requirements Specifications

Requirement ID	Specification	Description
016	Application	Web application to display real time and historical data
017	Map View	Show each node on a map with the status of the node
018	Map Overlay	Display a gradient on the map representing the environmental conditions such as temperature

019	Off-Grid Network	Network for communicating to and from the nodes without relying on established networks such as cellular
020	Database	Store a minimum of 5 years of sensor data
021	Number of Nodes	200

2.5 – Prototype Diagrams

2.5.1 – Node Hardware Block Diagram

Diagram 2.5.1.1 outlines the core systems of a node in the network. These nodes are responsible for capturing and relaying sensor data.

Diagram 2.5.1.1 – Node Hardware Block Diagram

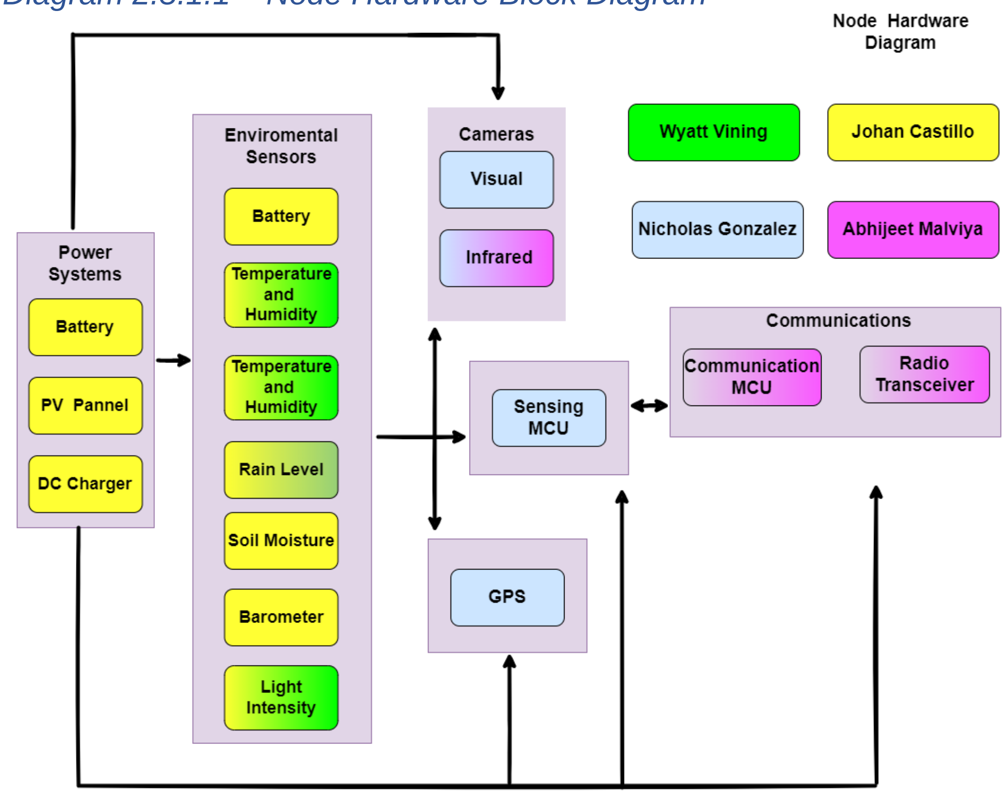
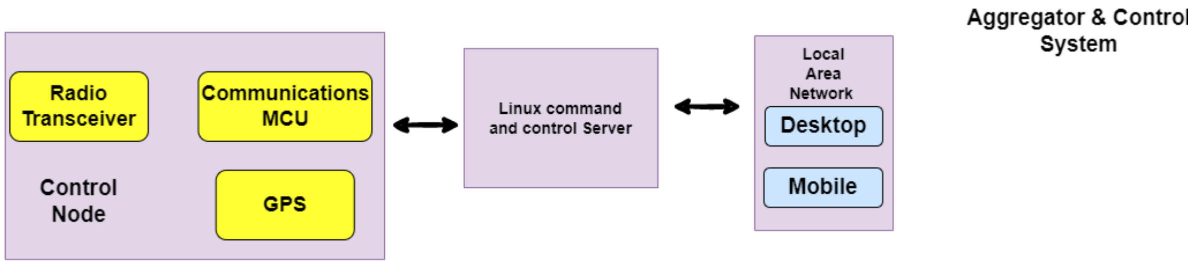


Diagram 2.5.1.2 also describes a node in the network. This is a special node responsible for receiving the data from the wider network and send commands out to all nodes on the network.

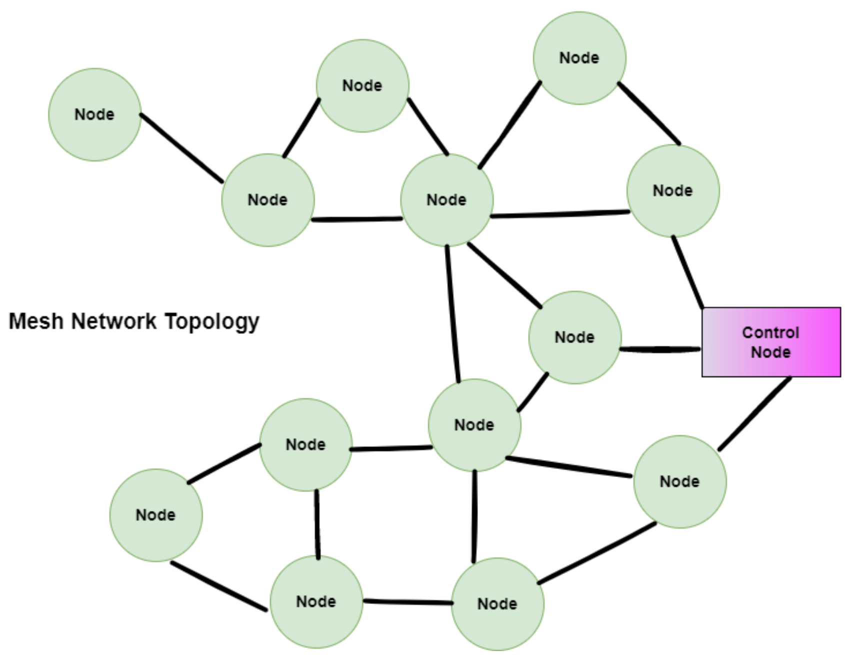
Diagram 2.5.1.2 – Control Node Hardware Block Diagram



2.5.2 – Mesh Network Topology

Diagram 2.5.1.1 describes the network topology. All nodes in the mesh communicate to one another with each having a unique address. The control node listens for data to pass to the aggregator.

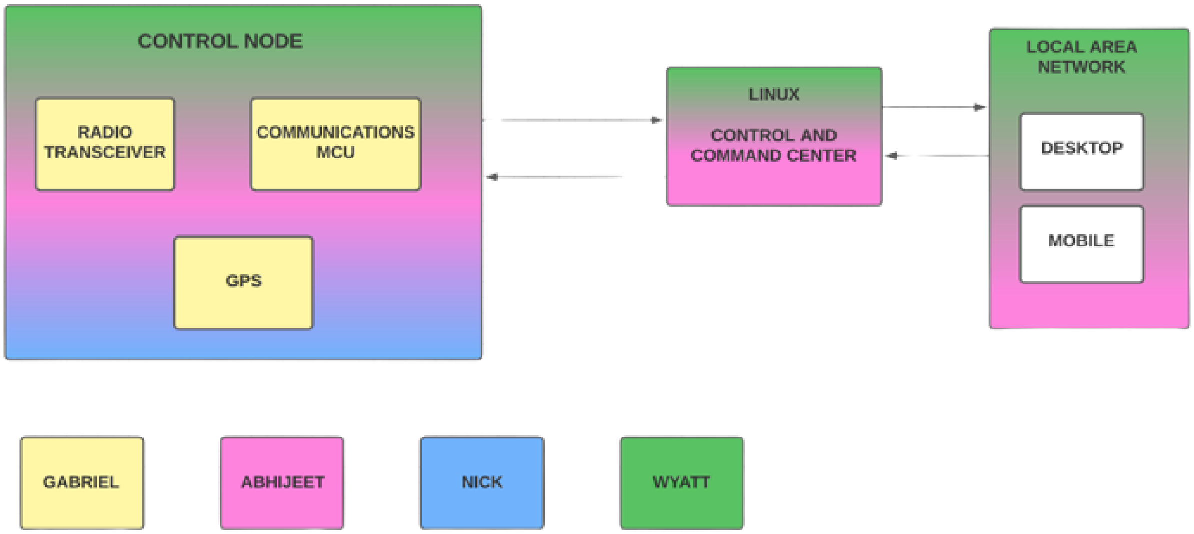
Diagram 2.5.1.1 – Mesh Network Topology



2.5.3 – Command and Control System Block Diagram

Diagram 2.5.3.1 shows the connection between the control node and the server. The server collects the data and passes commands for the network to the control node when needed. The server is also responsible for hosting the user interface.

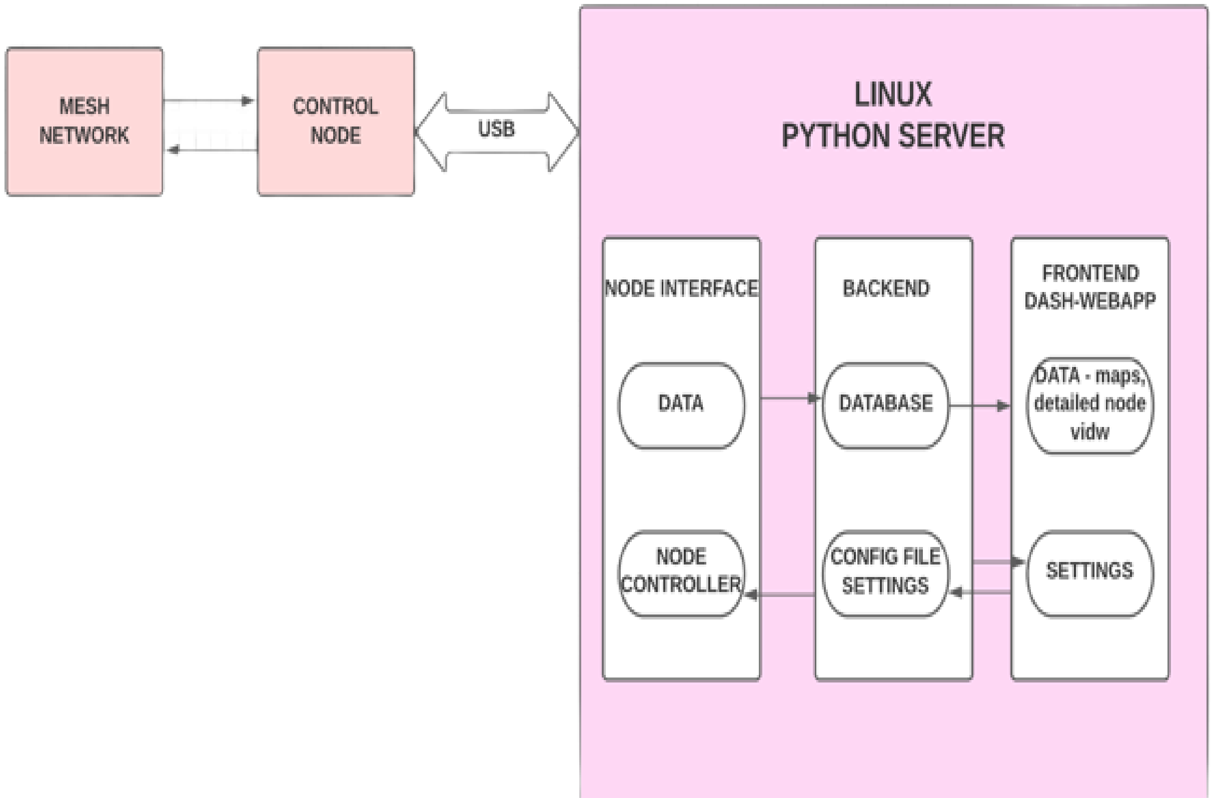
Diagram 2.5.3.1 – Command and Control Software Block Diagram



2.5.4 – Web Server Block Diagram

In this diagram, it shows how the information from the mesh network is transferred to the control node and back to it again. The web server and the control node are responsible for most of the transfer of data in the software. The control node is basically an antenna that is then connected to a USB cable so that it sends that data and other commands from there to the Linux Python Server. Within the Linux Server, it contains three parts called the Node Interface, Backend, and the Frontend Dash-Webapp. The Linux server is responsible for mostly every other action that is happening on the software. In the Node Interface, it contains the data which then stores that information to the database on the backend which it then sends to specific parts of the webapp such as the maps. The database holds collections that contain different data objects in which Python then helps to format them correctly. That interface also sees whether there is garbage from the Mesh Network and the Control Node so that it can take that out and send it to the backend and then to the webapp, which portrays those results visually. The settings on the software can let the user perform certain modifications to the web application such as the type of notifications it receives like updates from the web application. It does this by having the Python backend read the config files so it knows what to do with the settings of the web application. The settings in the frontend then interchanges data with the Configure File Settings from the backend which eventually transfers that information to the Node Controller in the interface. The Linux Server sends back commands to the Control Node so that it knows what exactly to do in the software.

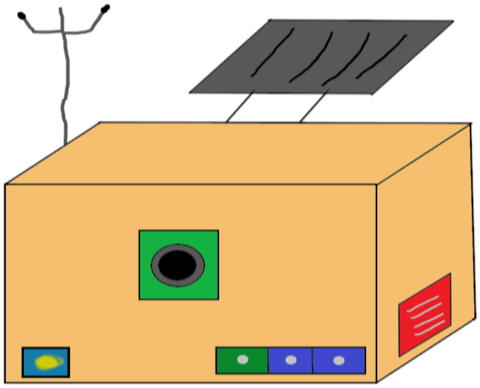
Diagram 2.5.4.1 – Web Server Block Diagram



2.5.5 – Exterior Design Concept

This is how we plan to have the Remote Area Monitoring Device look on the outside. We planned to have all the circuits and components placed inside a cardboard box. Around the box, there would be small holes where we would place the cameras in order to view what is happening outside the environment. It will also contain other holes where it would contain other components from the device that would measure specific nodes such as humidity, temperature, rain, and soil moisture. We plan to place the solar panels on top of the box so that it can properly receive power from the sunlight. There would also be an anemometer on top of the box as well in order to measure the wind speed and direction. All of these nodes would help us know the chances of a forest fire happening in the area being measured and the severity of it.

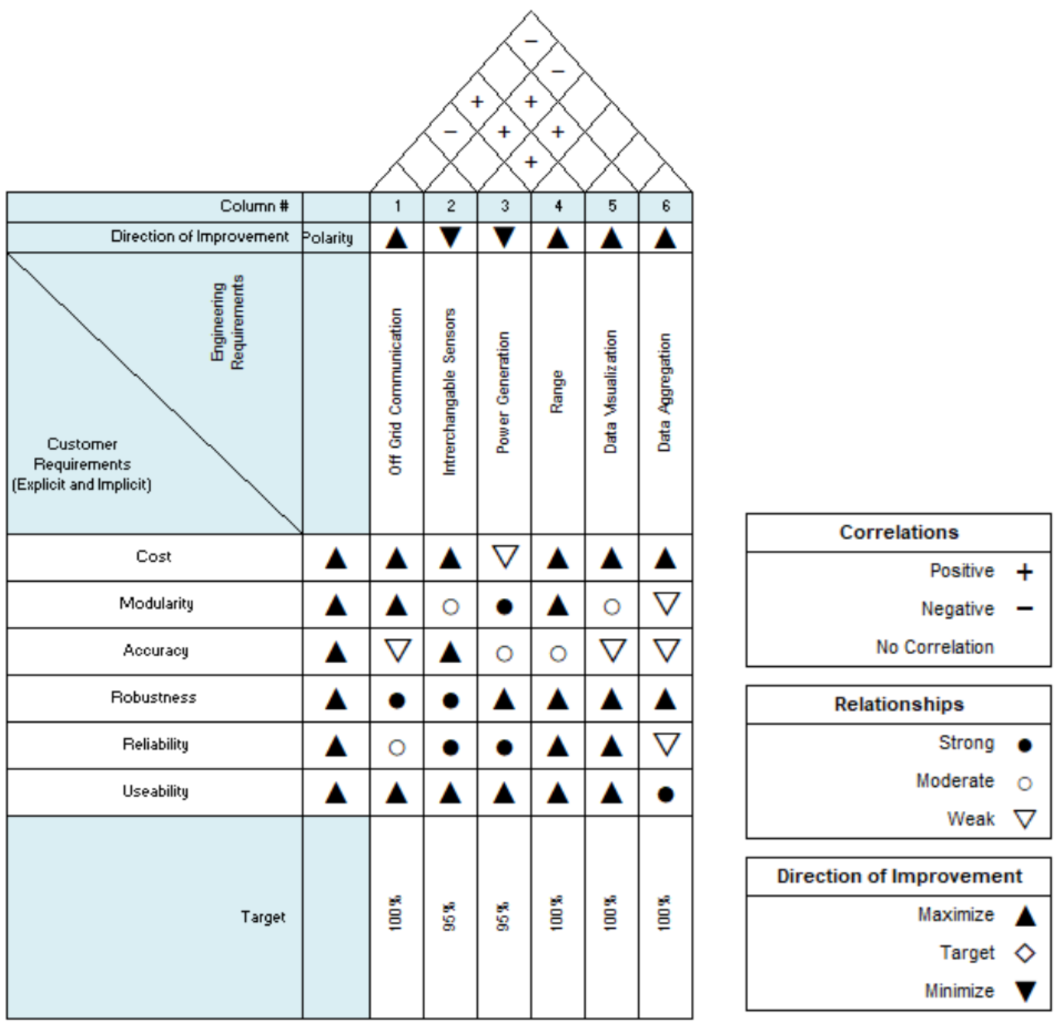
Diagram 2.5.5.1 – Node Exterior Design Concept



2.6 – House of Quality

Our house of quality diagram (Diagram 2.6.0.1) shows our inclination to maximize the value to our customer while minimizing the cost. One of the ways we intend to accomplish this is by using off the shelf parts and making our designs available open-source.

Diagram 2.6.0.1 – House of Quality Diagram



3.0 – Market Research

3.1 – Similar Products

3.1.1 – Dryad

Forest fires are catastrophic not only for the life and environments they devastate, but also because of the lengthy harm they create by emitting large amounts of CO2 while also killing vegetation that absorbs carbon. The United States is experiencing some of the worst wildfire season in decades, while Australia's 2019-2020 wildfire period was the second worst in history, including over 46,050,750 acres burned. Following unprecedented temperatures, western areas of the United States and Canada are now prepared for the yearly wildfire outbreak, which some experts say may set bleak new marks.

Dryad Silvanet employs solar-powered gas sensors in a large-scale IoT sensor network to detect wildfires as early as possible and to monitor forest health and growth. Dryad aims to avoid undesired wildfires, which generate up to 20% of global CO2 emissions and have a significant impact on biodiversity. By 2030, we want to have avoided the burning of one million hectares of forest, saving 400 million tons of CO2.With a large-scale, dispersed sensor network with a central analytics and alerting platform for ultra-early wildfire detection and continuous forest health monitoring. The solar-powered wireless sensors detect forest fires using embedded AI and measure temperature, humidity, and air pressure. Silvanet, which is open to third-party sensors, provides a wireless, solar-powered mesh network architecture for a variety of IoT applications in the forest. Silvanet additionally provides a Cloud Platform for device administration, data analytics, and alerts.

Most options for detecting wildfires rely on optical devices such as cameras or satellites. However, optical techniques might take hours to identify wildfires if they are obstructed by forest canopy or clouds. amera and satellite-based systems, often take many hours or even days to identify a fire since they rely on the smoke plume expanding sufficiently to be noticed from a great distance. This makes it significantly more difficult, if not impossible, for firefighters to put out the fire. Furthermore, developing solutions based on the Narrowband-Internet of Things (NB-IoT) standard are unsuitable for large-scale and isolated woods where the cost of constructing an LTE/4G network is too expensive.

Dryad's Silvanet is focused on identifying wildfires as early as 60 minutes using solar-powered gas sensors put in the forest, detecting wildfires as early as 60 minutes using built-in machine-learning (ML), analyzing gas patterns to consistently detect a fire. Silvanet provides a long-range wireless network (LoRa) that has been enhanced with a patent-pending mesh network design to cover very broad distances because the system cannot rely on mobile network service in the forest. The Silvanet, designed as a general-purpose IoT network infrastructure, can be used by any LoRa compliant 3rd party sensor, enabling health and growth-monitoring applications such as soil-moisture, sap-flow, or tree-growth monitoring, and feeding valuable data into the central Silvanet Cloud Platform, which provides data analytics and alerting services to Dryad's customers.

The Silvanet Mesh Gateway expands the Silvanet Network's reach beyond the conventional single-hop direct connection from sensors and gateways in normal

LoRaWAN networks to massive implementations. The design employs a multi-hop mesh network of Gateways connected using LoRa, with each Gateway acting as a conventional LoRaWAN gateway to Silvanet Wildfire Sensors and third-party sensors. The photovoltaic Powered Mesh Gateways are installed inside the forest, producing a mesh network with an average radius of 2-6 km relying on topological and physical positioning of the Mesh Gateways. The Mesh Gateway only communicates with other Mesh Gateways or a Border Gateway through the LoRa radio. It does not require a direct 4G/LTE radio or Ethernet connection, resulting in low power usage, which is backed by the integrated solar panel.

Figure 3.1.1.1 – Dryad Silvanet Mesh Gateway

Some of features could be futher implemented of the mesh gateway are, Improve LoRaWAN networks to cover a larger region Solar-powered, no-maintenance Any LoRaWAN-compliant sensor can be used. Network setup that is done automatically Mesh network with self-healing and auto fail-over Over-the-Air Firmware Update (FUOTA)

Figure 3.1.1.2 – Dryad Mesh Network

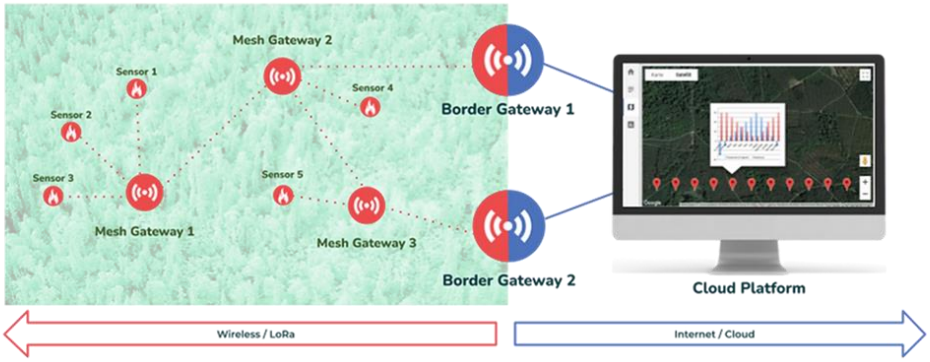


Table 3.1.1.1 – Dryad General Specifications

Maintenance	Maintenance-free (10-15 yr)
Mesh Gateway to Border Gateway (Ratio)	Typically, 20 Mesh Gateways are required for each Border Gateway.
maximum distance between Mesh Gateways.	2-6 kilometers, depending on topography and Gateway placement
Mesh Gateway to Sensor (Ratio)	Typically, 100 sensors per Gateway, depending on topology
Max distance between Mesh Gateways	2-6 km, depending on topology and placement of Gateways
Power source	Solar-powered, battery-free
Energy Storage	Supercapacitors
Installation	Mounted on pole or attached to a tree

SILVANET WILDFIRE SENSOR

Time is of the importance when it comes to wildfires. Silvanet detects smoke, hydrogen, and other gases released by pyrolysis in the beginning phases of a wildfire, providing firefighters critical time and the opportunity to smother the fire before it gets out of control.

The Silvanet Wildfire Sensor is intended to identify forest fires in their early phases (even during the smoking phase, during the first 60 min) and to manage the microclimate by detecting temperature, humidity, and air pressure. The sensor combines ultra-low-power Air Quality detection with a very accurate gas sensing mode. It identifies Hydrogen, Carbon Monoxide, Carbon Dioxide, and other gases at the 0.0001% or parts per million level using built-in machine learning to reliably identify a fire and eliminate false positives. The sensor transmits data wirelessly via LoRaWAN communications and may operate without batteries for 10-15 years, reducing the usage of lithium and other harmful elements.

Figure 3.1.1.3 – Dryad Silvanet Wildlife Sensor

Table 3.1.1.2 – General Specifications Dryad Silvanet Wildlife Sensor

Maintenance	Maintenance-free (10-15 yr)
Mesh Gateway to Border Gateway (Ratio)	Normally, 20 Mesh Gateways are required for each Border Gateway.
maximum distance between Mesh Gateways.	100m radius for 60min detection of 2x2m fire
Mesh Gateway to Sensor (Ratio)	Typically, 100 sensors per Gateway, depending on topology
Power source	Solar-powered, battery-free
Energy Storage	Supercapacitors
Installation	Mounted tree (3m height recommended)

SILVANET BORDER GATEWAY

The Silvanet Border Gateway is often installed towards the edge of the target forest area, such as in a forest home or near a settlement. The Silvanet Cloud Platform interfaces with the Border Gateway, which relays messages from Forest fire Sensors (directly or indirectly via Mesh Gateways). Wireless connectivity is offered via the installed LTE radio (using 4G/LTE-M with 2G/GPRS fallback) or via a wired Internet connection via the built-in Ethernet adapter. The Silva net Border Gateway features built-in functionality for satellite uplink utilizing the SWARM satellite system for distant locations in which there is no mobile data service and no accessibility to mains power. It may be used with either mains electricity or a solar cell.

Figure 3.1.1.4 – Dryad Border Gateway

Table 3.1.1.3 – Dryad Border Gateway General Specifications

Maintenance	Maintenance-free (10-15 yr)
Mesh Gateway to Border Gateway (Ratio)	Normally, 20 Mesh Gateways are required for each Border Gateway.
maximum distance between Mesh Gateways.	2-6 kilometers, depending on topography and Gateway placement
Mesh Gateway to Sensor (Ratio)	Typically, 100 sensors per Gateway, depending on topology
Max distance between Mesh Gateways	2-6 km, depending on topology and placement of Gateways
Power source	Mains powered (PoE) or Solar-powered, battery-free
Energy Storage	Supercapacitors
Installation	Mounted on pole or attached to a tree

3.2 – Area Management Policies and Programs

A fire spreads through radiation when the heat travels through electromagnetic waves in the air. Fire spreads are so dangerous and can cause so much damage so quickly to open lands. A fire can literally occur anywhere at any time, so you always have to be mindful of your surroundings and what you need to do to avoid it. So, this is why it is imperative to understand the guidelines that safety hazards and officials issue. NPS or National Park Service is one such organization that tries to main their environment and ensure that areas are safe from fire hazards.

NPS works with interagency partners in an effort to prevent unwanted dangerous human-caused hazardous fires. We humans, who have been existing on this planet from ever since the dinosaurs were destroyed by unfortunate and unforeseen circumstances, are responsible for causing approximately 90% of the wildfire in open lands. The key component to stop these scenarios is education and outreach. There are other procedures and precautions taken by park managers as well, including implementing the fire restrictions during times of very high or extreme fire dangers. So, how exactly does a wildfire start? Common causes of wildfire include lightning, human carelessness, arson, volcano eruption, pyroclastic cloud from active volcano. Heat waves, droughts, and cyclical climate changes such as El Nino can also have a dramatic effect on the risk of wildfires. But, according to weatherwizkids, four out of five wildfires are caused by people.

3.2.1 – Environmental Impacts

Fires are adverse and unpredictable events with tangible costs for property and human life. The immediate and direct costs of the fire provide a metric for understanding the economic impact it has on the environment. In addition to the physical costs, fires have a range of less immediate and obvious adverse consequences on the natural environment. These include air contamination from the fire plume (whose deposition is likely to subsequently include land and water contamination). The amount of gas which contains a lot of toxic chemicals mixes with the oxygen in the air which harms all living species that have been existing on this planet for 4.65 billion years. Fire is an important element that is used by a lot of us for different day to day lives, but we don’t understand the impact it has on the environment if we use it incorrectly. There are many beautiful national forests in this country which have been harmed because of the carelessness of people in general.

So, we should understand the fire effects on this environment. It is evident that wildfire is part of our nature. It is sporadic and can cause havoc with anything in its path. Scientists with the Pacific Northwest Research Station are conducting a range of studies pertaining to fire effects on the environment in multiple fields of study, from meteorology to ecology. The range of studies include: Fire Behavior, Fire and Climate Change, Fire Ecology, Fire Preparedness, Fire and Smoke, Fuel Treatments, Fire and Weather.

A fire behavior is heavily depicted by the way the fire’s intensity and the rate of the speed that it is moving at. Scientists who study fire behaviors are keened in factors that influence the fire intensity and the speed of fire such as fuel types, weather and topography.

We already know how the climate change is in full effect at the moment. It has been stated that the change in temperature and weather has already occurred in various regions of this world. The average temperature is increasing slightly per year. Places that are warm are getting warmer while cold places don't see snow anymore. Climate change is in effect and the spread of wildfire is another contributing factor to this. Antarctica is melting slowly. This is because the spread of wildfire mixes with the atmosphere and disrupts the ecosystem. All the toxic particles move through the air towards various locations which alters the ecosystem. As this becomes a phenomenon in the world, farmers won't have much food to grow, aquatic animals won't have a place to live in, etc.

3.3 – Current Standards and Equipment

In this project we will be facing various different types of standards and constraints. These aspects are necessary since they set guidelines on how to build and implement our forest fire detection alarm system properly to limit creating errors and to help us determine the scale and limitations of our design. Standards are crucial due to the fact that it helps to make sure that the device is safe and efficient. There are many different types of standards that we can follow based on the project or device being created, so we need to choose which ones should be the most appropriate for our design, how we plan to deliver it to the customers, and whether or not it is safe in the environment where it's going to be used.

Constraints are set up to determine the limitations of a design. They are necessary because it will help us focus on more specific aspects of the project, let us know whether or not extra nodes or features are needed to be created and if we're not wasting too much money on resources. This is one of the reasons why we have to set up a reasonable budget for our project.

3.3.1 – Standards

Engineering standards are used to set up rules and guidelines of how to build, implement, and test a design in order to make sure that it is functioning properly and efficiently with regards to economics and the health and safety of the users and the environment. Understanding and knowing which standards are going to be used is an important aspect in an engineering design project, if we decide to not follow standards, it can cause difficulty and confusion in building the project and there can be risks of having it malfunction.

Depending on the part or product being manufactured, there can be different types of standards that need to be implemented. For this project, we are going to be abiding by the IEEE, PCB, ANSI, and Python language standards. The IEEE standards are necessary since they can be used to test the functionality of the design such as the communication between the hardware and software aspects of the project. The PCB and ANSI standards are going to be used to build and manufacture the hardware aspects such as the circuits which control the alarm system. We are also going to follow local and federal environmental ordinances since our product is going to be used in outdoor areas such as forests.

3.3.2 – Fire Danger Rating System

Forest fires can happen at any moment and how dangerous it can end up being depends on certain circumstances. There is a system put in place called the National Fire Danger Rating System (NFDRS) and that was created so that there are more efficient and scientifically-based standards to detect forest fires which can be applied anywhere and is cost-effective. There are various organizations that use these standards to control fires around their respective areas. These standards help determine the possible locations where these fires might occur and the previous activities within those locations.

To determine the severity of fires, NFDRS takes the fuels, weather, topography and risks into account to determine the type of rating it should give in a selected area. While looking at those aspects, NFDRS can finally give a Fire Danger level ranging from Low to Moderate, High, Very High, and Extreme. When the threat is Low, it means that you need to have extremely flammable heat sources to cause fires and it can be easily controlled. When it's moderate, it means that fires can easily be caused in that area by man-made accidents but it would spread really slowly or not at all. When it's High, it means that the fires can be dangerous but it can be put out if it's still small. When it's Very High, it means that any flammable object can cause a severe fire that is hard to stop; and when it's Extreme, it means that the fires can last several days and it's very hard to extinguish.

While cooperating with weather stations, they can help us to transfer information and guidelines to analyze different types of inclement weather that can cause forest fires. One of these methods is by determining how prevalent lightning strikes are in an area since when they strike a dry object, they can produce flame due to the amount of heat they produce. When determining the lightning activity level, it is rated in six levels. The lowest level (LAL 1) means that there is no cumulus cloud in that area, which means there isn't a possibility of lightning-producing thunderstorms to happen while when it is at LAL 2, it means that some cumulus clouds are present but the threat is still low. When it’s at LAL 3, cumulus clouds are common and some lightning may happen. At LAL 4, lightning is way more frequent and thunderstorms cover 30% of the sky. When it's at LAL 5, lightning and thunderstorms are very intense and in LAL 6 is where there’s a “dry lightning” which means that precipitation evaporates before it reaches the ground in a lightning storm. When that happens, it increases the likelihood of a fire happening since there is less water and moisture to stop it.

NFDRS is also composed of three parts which are Scientific Basis, User Controlled Site Descriptors, and Data. To determine how threatening fires can be, scientific models that take environmental aspects such as moisture into account to see if the chances of starting a forest fire are high. User Controlled Site Descriptors take account of the area where it's being researched and the plants around it to see how flammable they can be. It also looks at the area’s terrain and climate such as how much rainfall it receives as well. Then, Data is gathered from the controlled site descriptors to calculate the appropriate rating for a location such as the type of vegetation in the area and rain quantity.

When gathering data, there are two variable that we need to focus on to determine the fire danger rating: weather observations and other parameters that user finds to calculate the rating such as the vegetation state or the shrub type code. When gathering weather data, it should be made sure that the data is recent or is able to predict the weather for the next day, and it could be gathered via weather stations. When a user is going by their own parameters, he should notice that changes can happen in the environment that's being researched such as trees freezing or drying up or the fuels that it may leave out.

Seasonal changes can also affect how information regarding about fire prevention is obtained. So therefore, we should focus and analyze the different seasons and the greenness factor, which represent the conditions of the environment.

Table 3.3.2.1 – Season Codes and Greenness Factor

Growth Phase	Season	Season Code	Greenness Factor
Plants are dormant	Winter	1	0
Plants begin to grow again	Spring	2	Increase the factor to 20 for each plant
Plant growth is complete	Summer	3	Change the factor based on each plant's growth
Plants are dormant	Fall	4	Decrease the factor to 0 for each plant

While abiding by the NFDRS standards, there are certain equations that should be used to perform calculations to help determine how flammable a tree or plant is within the area where it's being tested. One of those equations is the Equilibrium Moisture Content formula. There are three main variations of using that formula:

Equation 3.3.2.1 – Relative Humidity Less Than 10 Percent

$$EMC = 0.03229 + 0.281073 \times RH - 0.000578 \times TEMP \times RH$$

Equation 3.3.2.2 – Relative Humidity Equal to or Greater Than 10 Percent but Less Than 50 Percent

$$EMC = 2.22749 + 0.160107 \times RH - 0.014784 \times TEMP$$

Equation 3.3.3.3 – Relative Humidity Equal to or Greater Than 50 Percent

$$EMC = 21.0606 + 0.005565 \times RH \times 2 - 0.00035 \times RH \times TEMP - 0.483199 \times RH$$

In these equations above, RH represents the relative humidity and TEMP represents the dry bulb temperature, which is the air temperature measured from the environment being tested. While getting the EMC values, they can be used to get the observation time, maximum temperature, minimum relative humidity time, and minimum temperature-maximum relative humidity time.

Also, while calculating the relative humidity, it is also important to take the Dry and Wet bulb temperature for the moisture variable into account. To calculate these variables, you have to get the saturation vapor pressure values. Then to get the elevation of the area being tested, you calculate the CORR value.

Equation 3.3.3.4 – CORR Value Calculations

$$SATVPD = EXP\left(1.81 + (TMPOBS \times 17.27 - 4717.31)/(TMPOBS - 35.86)\right)$$

$$SATVPW = EXP\left(1.81 + (TMPWET \times 17.27 - 4717.31)/(TMPWET - 35.86)\right)$$

CORR=6.6*10**-4.*(1.0+(0.00115*(TMPWET-273.16))*TMPOBS TMPWET)*(1013.09/EXP(ELEV/25,000.0))

In these equations above, SATVPS and SATVPW represent the saturation vapor pressure for dry bulb and wet bulb temperature respectively. EXP represents the exponential function of the equation that is selected by the parentheses. TMPOBS represent the dry bulb temperature and TMPWET is the wet bulb temperature. CORR represents the difference between SATVPW and ambient vapor pressure and ELEV is the elevation.

3.3.3 – Natural Resource Management

In our project, we plan to follow federal ordinances such as the National Park Service's Natural Resource Management standards. These guidelines also explain how a researched area might be affected by natural phenomena and how to properly take action and use resources efficiently while also cooperating with other similar standards and laws created as well. There are various reasons for why such a phenomenon might happen and it can cause changes to the environment that is being tested, so therefore we can see how certain aspects of the forest such as plants and trees can be restored and whether or not some parts should be replaced or moved to a different location. These standards also focus on the non-living aspects of an environment as well. By looking at this, we can see what can we do when a fire is being detected with our alarm system.

Also, these standards state that in case that something wrong happens in the environment that we are testing our design such as getting injured or having resources get damaged, then that management service can cooperate with other authorities in order to provide compensation and new resources to take care of the damage being done. It also analyzes different areas within the experiment such as the cost, scientific research from other colleges and organizations, park ordinances, and safety in order to find the best way to approach the experiment. In order for these standards to work, we should analyze the products that we buy for our design and make sure that it doesn't cause that much damage to the environment and whether it's economical. When researching the tested environment, we also have to make sure that soil is sustainable which helps with determining climate regulation.

3.3.4 – NFPA 1143 Standard for Wildland Fire Management

A standard that we plan to abide by would be the NFPA 1143 Standard for Wildland Fire Management. These standards tell us how to deal and manage forest fires and by working with other resources and organizations and also provide different types of training and equipment. It also tells us what we should do to prevent those fires from happening again in our area, such as coming up with plans beforehand based on analyzing fire seasons and patterns over the years. NFPA 1143 takes into account many different areas such as fire department apparatus and divisions and also works with other standards such as the Standard on Emergency Services Incident Management System and the National Fire Danger Rating System.

While working with NFPA 1143, it also recommends cooperating with local fire departments using mandates from the respective local government to combat these disasters. This standard advises that in a case where you are working with any instruments or laboratories that hasn't been officially sanctioned yet for safety, NFPA doesn't bear the responsibility to approve it. Instead, we should always abide by the federal or state mandates or fire departments to have jurisdiction for these fields. It also requires people who are working within those fields to have proper training in first aid and safety and be familiar to agencies that require those guidelines. Programs are established to help people to train and get further knowledge about those fires.

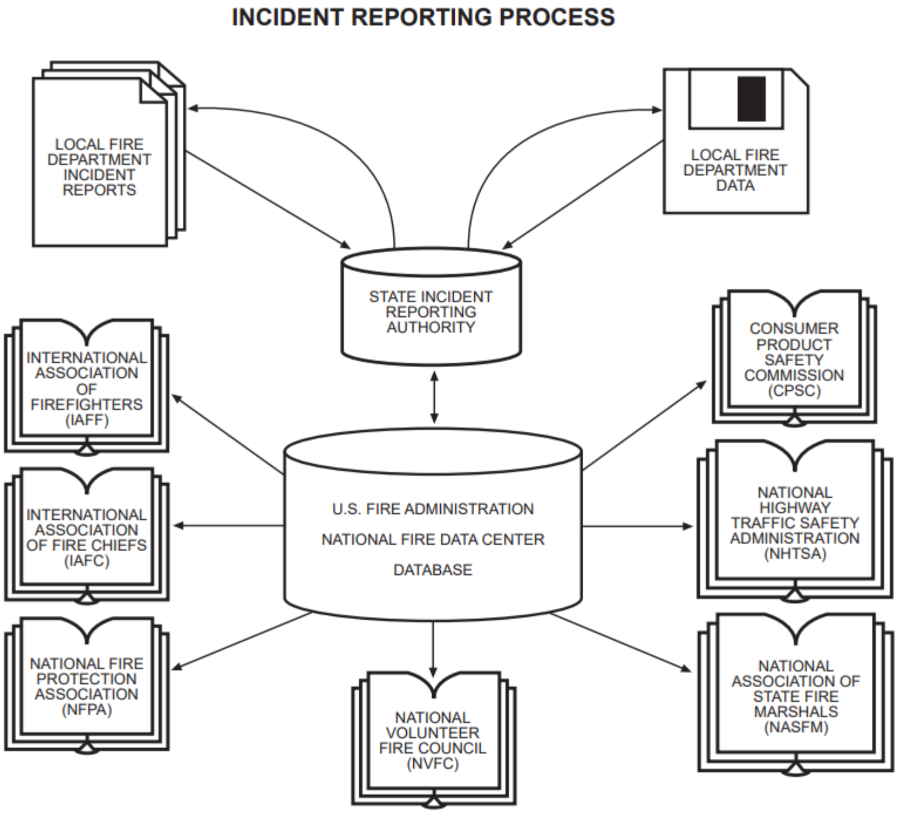
The variables that NFPA 1143 looks at to prevent forest fires include Risks, Hazards, and Values. By taking risks into account, it looks at how fast fire can spread and it does that by comparing that separately to how much fire can burn. It also determines whether or not the fires were man-made or caused by natural disasters such as lightning storms and by how recently have they occurred. When looking at hazards, it looks at what can cause such fires to happen and how hard it can be to control it. Finally, when looking at the values, it analyzes what areas of a forest should be taken in the highest consideration to avoid it being burned and how to protect it. After that, we can determine how to implement fire protection programs and prioritize that specific place compared to other areas.

In order to stop and combat those fires, there are three variables that should be known: Education, Engineering, and Enforcement. Knowledge should be spread as much as possible informing people about fire prevention. Proper engineering can be used to stop those fires from happening by removing fuel or other combustible material in a forest. By cooperating with law enforcement, they can find an inexpensive way to administer laws on forests that restrict fire activity and have close contact with fire departments so they can stop those fires from happening immediately. It is recommended that in each area where the environment is being researched to have at least five well trained firefighters in case of an emergency happening. Fire chiefs and law enforcement and the first types of people that we should contact in those situations and they plan and improve communication tactics and relief crews.

3.3.5 – NFPA 1143 Standard for Wildland Fire Management

NFIRS is a type of fire reporting system that responds to incidents and also analyzes the type of fire disaster that is happening. It also tells us the type of resources that we should use to combat fires. The way they report incidents is by gathering data and incident reports from local fire departments and interchanging them with the state incident reporting authority. Then, the authority passes over that information to the U.S Fire Administration National Fire Data Center Database which it then sends to different governmental agencies such as the IAFF, IAFC, NFPA, NVFC, NASFM, NHTSA, and CPSC.

Figure 3.3.5.1 – Incident Reporting Process Diagram [2]



When identifying the type of incident happening regarding a fire, it requires us to select a range of codes to describe it. Some examples that we plan to use are 100 which means that there is a fire happening, 200 means that there is an explosion or overheat but no fire, 300 means rescue and emergency medical service, 700 means that there is a false alarm, 800 means that there is a severe or inclement weather, and 900 means that there is a special incident. When a fire is happening, the level of severity is determined as numbers from a range of 1 to 5, with 1 being the less severe and 5 being the most severe. A level of U is given when the fire threat is undetermined.

Not only does it determine the severity of fires, but it can also identify causes of why it happens. One of the reasons is because certain fuels are found in important aspects in forests such as tree or plants and they can be flammable. Therefore, NFIRS utilizes a data element called Fuel Model at Origin which analyzes these types of vegetative fuels that appear after a plant is being burned at the point of origin and predicts how dangerous a forest fire can be. This model is divided into different subsections that describe that type of vegetation that is being affected such as Fuel Model A representing annual grasses, Fuel Model B representing mature 6 feet tall brushes, and Fuel Model C representing open pine with grass. Fuel moisture can be classified to different time lag classes such as 1 hour, which represents fuel from dried plants with a diameter less than a quarter inch; 10 hour, which are dried wood with a ¾ to 1 inch diameter; 100 hour, which are plants with a 1-to-3-inch diameter and tend to be the most common one; and 1000 hour, which are plants with a 3-to-6-inch diameter. The fuel moisture levels can also be seen on greenness maps made by the Normalized Difference Vegetation Index data.

3.3.6 – Humidity Standards

Humidity plays an important role in detecting and preventing forest fires from happening. A type of humidity that is important to measure of ecosystems where it is being examined is relative humidity, which measures the amount of moisture there is in the air at the same temperature and pressure. When the air is warm, it means that it is more humid since it contains more moisture. Relative humidity is measured by weather stations or by using wet and dry bulb readings. By having more humid air, it could mean that the chances of having a forest fire would be lesser because since it contains water, it prevents fire from spreading. If relative humidity is low, then forest fires become more likely to happen because the fuels released from forest vegetation become drier.

3.3.7 – NWGC Standards for Fire Weather Stations

NWCG is a group that was formed to promote training and standards that other firefighting agencies can apply with to prevent forest fires. They also promote standards that exist for fire weather stations and they also work with other standards such as NFDRS since we can cooperate with weather stations on assigning ratings to forests to analyze the threat of those fires.

3.3.8 – Fire Watch Towers

One way of detecting forest fires from far away is by looking from Fire Watch Towers. They are usually placed in high areas within the location where the fires and smoke are being detected to get a much clearer view of them, since if someone were to view it at ground level, they might not get a clear outlook since it would be covered by trees and other types of terrain. These towers are meant to view areas from a 20-mile radius. While spotting fires over, there should be a way to have some sort of communication to send information to other places. Therefore, fire watch towers should contain radios to transfer data. By viewing a selected area over a high elevation, it can be easier to locate and map the affected area and pass that information to other sources via satellite so that there can be an accurate view of the situation and what places to avoid.

3.3.9 – Satellite Imagery

Not only can an environment be tested for possible forest fires up close, but it can also be detected from different faraway places by the use of satellite imagery. Satellite energy can help us map different parts depending on whether the threat is high by assigning different colors to those areas depending on the threat level. With that data, it could be sent to different users with that software. However, satellites can be expensive to use so we have to find more economic ways to detect fires.

Many maps require the use of satellite imagery to properly view an area being researched and what precautions we can take to prevent such incidents. We can view the fuel moisture levels maps through greenness maps made by the Normalized Difference Vegetation Index data. From these maps, we can see what areas have the healthiest vegetation since it is shaded green.

Other types of maps from satellite imagery that we can use is the Keetch-Byram Drought Index (KBDI) which can detect which places have been suffering from drought. Drought can play an important part in preventing forest fires since we can tell that if a forest hasn't been receiving too much rain, it might dry up and since there is little to no moisture, then it would be harder to control flames. By viewing those maps, you can see the KBDI levels which signify the amount of rain those areas will need to be healthy. When the KBDI value is 0–200, it means that soil and fuel moisture are still high; when it is at 200–400, it means that it is starting to become somewhat dry; when it is at 400–600, it means that there are drier and duff layers; and when it is at 600–800, it means that the drought is severe. Since at lower levels means that it has more moisture, the chance of a forest fire or similar phenomena to happen would be less severe compared to when a KBDI value is high.

3.4 – History of Forest Management and Fire Fighting

Forest fires have existed since the start of human history and can have significant and mostly impacts to the environment such as causing problems to ecosystems, people's health such as getting severely injured or death, and the production of resources. It is also considered to be the biggest threat regarding the destruction of forests. It wasn't until the 1800s in the United States when two people named Franklin Hough and Bernhard Fernow decided that they should find ways to finally control them. They were concerned that forest fires were damaging too many trees and therefore disrupting timber production so they decided to ask the United States Government to set up the US Forest Service. By doing this, it set up standards and made certain areas of land to be protected by the government such as how to control fire, how fire behaves, and how it affects the forest.

However, they still needed to find a way to suppress forest fires. In 1910, there were a series of massive forest fires occurring in three states happening in just two days. The amount of damage that was done was significant and the US Forest Service had to find ways to stop that. They realized that they needed to have more men and equipment with proper training and backing from that service and they then created standards that would help them prepare for those types of situations. It also allowed cooperation from different regions in the United States that are usually far away from each other to manage and transfer data about those types of situations so that other places can know what is happening earlier.

In 1916, scientists like Coert DuBois began to research the causes of forest fires and how to control them and determined that they can be caused by weather hazards. By doing this, they divided up forests into different sections based on the weather they had to determine such causes of those hazards for happening. Then, they began to look at different methods on how to prevent forest fires from happening again.

One tactic that they created was light burning. This meant that small fires should be added around a forest fire to prevent it from spreading and it also improved land conditions. Many people believed that if some plants were burned earlier, then it would help the trees from the forest to be safe from fire outbreaks and it would reduce the chances of that area to burn again. However, this proved to be somewhat ineffective because it still destroyed most of the vegetation around that area. So, another method was planned and this time it stated that other nodes should be created such as better communication systems, fire watch towers, and roads to help detect forest fires earlier.

In the 1930s, the Civilian Conservation Corps was created. This organization provided new methods to combat forest fires such as allowing more volunteers to help stop fires themselves. They also adopted new technologies such as smokejumpers and fire suppression chemicals to combat these fires anywhere and any place. Better documentation was then created to locate when these fires can happen next in a more accurate and faster amount of time.

Later on, more advanced methods and standards were thought of to understand forest fire control. They decided to split up to different research stations and analyze more specific and different forest areas in the country. They also began to evaluate resources and determine what causes forest fires to happen. While doing that, they began to examine how to control these fires in a more economical manner. Local agencies began to promote better training to firefighters and other people responsible to look out for forest fires. Newer technologies such as radar and infrared sensors were adopted to detect when cumulus clouds are near.

3.4.1 – Response Times

Fire Response times help provide information of when and how resources from a fire station can be reached to an area affected by a forest fire and how far away they are. If a station is far away from an affected area or if they use all of their resources just on that area, then the response time would be longer since it would take more time to carry all other resources to other areas where it needs to be treated. Therefore, response times should be made sure that it is low most of the time.

Fire response times can be broken into three rating components: Availability, Capability, and Performance. The availability measures which equipment is ready to use during a fire incident, the capability measures the equipment's ability to stop the fires, and the performance measures how effective the equipment is to combat the fires.

There is a standard that shows how to report fire response times and it is called NFPA 1710. NFPA establishes a criterion of the recommended response times needed for an emergency. Some of the recommended times by this standard include that the alarm answering time should be around 15 to 40 seconds, the alarm processing time should be around 64-106 seconds, the turnout time should be about 80 seconds for fire responses, the First Engine Arrive on Scene Time should be about 240 seconds, the Second Company Arrive on Scene Time should be about 360 seconds, the initial full alarm for low to medium hazards should be about 480 seconds, and for high hazards, it should be about 610 seconds. Also, response times are divided into three subsections called Call processing time, which is the time when the call is sent to a firefighting unit; Turnout time, which is the time when firefighters begin to prepare for action, and Travel time, which is the time of when the unit arrives from the station to the area affected from a forest fire.

3.4.2 – How Often are Fires Reported

Here in the United States, fires weren't reported that much until the mid to late 1800s. That is because at that time, there wasn’t that much technology that allowed data to be shared to other places at a fast rate about where and when a forest fire happened. Most of the reporting was done by asking people who heard about those fires second hand. Later around that time, it has been reported that in the state of Idaho that fires happen at least once every four years. The chief of the Division of Forestry, Gifford Pinchot, created a method to analyze and report the occurrence of forest fires better. He cooperated with different agencies to determine the cause of those fires in different states by collecting and analyzing newspaper reports based on those respective areas. By the early 1900s, there was a decrease of forest fires due to having better safety regulations in the lumber industry.

Over the years, fire response times might have an effect on how many times fire incidents have been reported. It has been seen that each year, the number of times incidents have been reported has been increased. This is because there has been more advanced technology that has been able to report those fires at a faster rate and data regarding those incidents can be transferred to other far away areas quickly.

3.4.2 – What Are the Causes of how Fires are Spread?

Forest fires can be started in different ways. One of these is by human activity such as accidentally leaving the fire from a barbecue, burning bushes to clear up land, or playing with matches and other flammable devices. These actions cause these fires to spread to other areas uncontrollably. However, weather such as lightning storms and rain can have a huge impact as well. In an area where there is inadequate rain, it can cause trees to dry up because they need water to survive. Since those trees don’t contain too much water anymore, they have a higher chance to be flammable so when a forest fire happens, they can spread much faster. During thunderstorms, lightning can end up striking those trees and ignite fires. However, rain can have positive effects as well and can actually prevent and control fires from spreading because water is able to put down flames. Therefore, our design should include features that detect how much rainfall an area is getting and the chances of how much lighting it will get when a thunderstorm happens.

4.0 – Research and Part Selection

4.1 – Hardware Technologies Research

Sensors

We start this section responding to the most basic of the question, what is a sensor? A sensor is a device that transforms a physical quantity to an electrical signal, therefore providing a voltage or current or causing a resistance change. In general, the sensor's impedance, which includes capacitive and inductive sensors, may alter. As a result, we are tasked with measuring one of these electrical values. bellow we will explain in further details the subsets of analog sensors. since this is most heavily used technology in our project, the following sections will sever as the groundwork for explanation of the most used machinery of in our module.

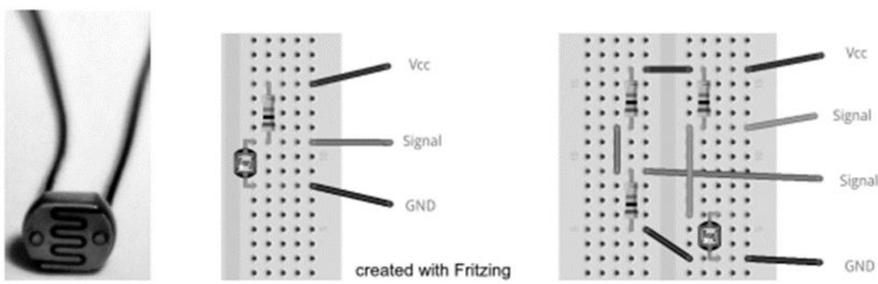
Analog Sensors

Analog sensors are devices that generate analog output in relation to the amount being computed. These sensors also monitor changes in environmental elements such as light intensity, wind speed, and sun radiation, among others. And the output voltage varies from 0 to 5 volts.

Resistance Base Sensors

The first resistance-based sensor we'll look at is a light-dependent resistance (LDR), which is seen bellow. Its resistance varies depending on how much light it is exposed to. The variation range varies on the device and normally runs from 100 Ω to MΩ. This sensor schematic needs to be explained in detail since it's the basis of our moisture sensor which will be explained in detail in the further sections

Figure 4.1.1 - voltage divider between the source voltage and ground



The figure above produces a voltage divider between the source voltage and ground, we connect a photoresistor in series with a resistor gives the voltage Vs on the signal terminal. As a result, as the LDR is illuminated, its resistance RLDR changes, and the signal voltage fluctuates accordingly. We must place the resistor R0 in the middle of the RLDR range. As a result, the voltage we measure is about one-half of the supply voltage. As a result, we must also utilize a voltmeter in that voltage range.

Very slight fluctuations in light intensity become difficult to resolve and may require amplification. This difficulty can be alleviated by using a Wheatstone bridge. Wheatstone bridge is an electrical circuit that is used to determine the unknown electrical resistance by balancing two legs of a bridge circuit, one of which contains the unknown component which compares the voltages in two resistor dividers, as illustrated on the right.

Resistance-based temperature detectors (RTD), such as the PT100 temperature sensor, are another type of resistance-based sensor. It is a platinum-based calibrated sensor with a resistance of precisely 100 at 0 oC. It is based on the fact that the resistance of a highly pure metal is governed only by the scattering of electrons in the conduction band with phonons, which are vibrations of the ions that comprise the metal's crystal lattice.

Temperatures generate greater vibrations of the lattice, resulting in increased resistance. At greater temperatures, one may expect the crystal ions to oscillate with bigger amplitudes, producing a larger target for the electrons to scatter and therefore hindering their mobility. Because this is a material attribute, calibration measurements of resistance as a function of temperature are universally valid for all sensors made of the same metal, provided the metal is highly pure and devoid of defects. Platinum wire coiled on a ceramic support body is a common material used in commercial sensors.

Voltage Base Sensors

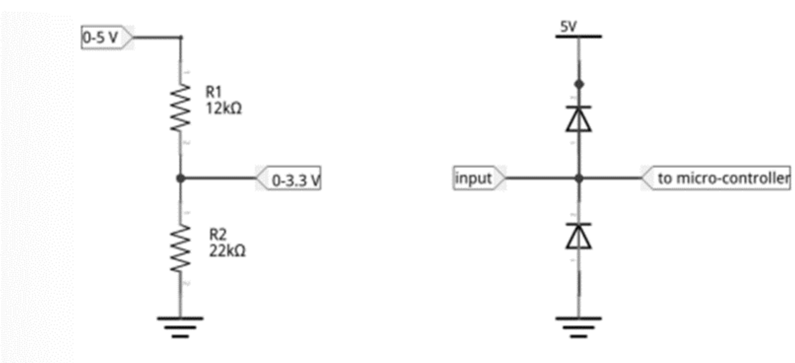
Voltage-based sensor is type of sensor that directly produces a voltage at its output pin. The LM35 temperature sensor is a common example of this type of sensors. The operation is based on the passage of familiar currents. For the sake of familiarity, we will name these currents With With current densities   across the age drop. The voltage differential varies in direct proportion to the temperature. This is explained by inverting the current–voltage curve for the base-emitter junction diode.

One of the components that is good to make remarks of voltage-based sensors are Thermocouples. Thermocouples are temperature sensors that use the effects of temperature and temperature gradient on conductors composed of various materials to detect temperature. The Peltier effect (When an electric current is maintained in a circuit with two different conductors, one junction cools and the other heats; the effect is significantly stronger in circuits including dissimilar semiconductors) creates a temperature-dependent current at the junction of the conductors. As a result of rearranging charges inside their crystal structure, certain crystals and ceramics react to external stressors by creating a piezoelectric voltage between opposite surfaces of the material.

Current Base Sensors

A current base sensor is a type of sensor, usually a Pin diode, which is a diode having a large, undoped intrinsic semiconductor area situated between a p-type and an n-type semiconductor region. that generates a current of up to 100 nA. Charge-coupled devices, or CCDs, are sensors used in imaging applications such as cameras. They are comparable to a pin diode linked to a tiny capacitor, one for each pixel of the camera. When exposed to light, a tiny charge is transferred to the capacitor.

Figure 4.1.2 – Current Sensor



On the left is a voltage divider that reduces the input voltage from 0 to 5 volts to 0-3.3 volts. The right design demonstrates the usage of clamping diodes to protect the microcontroller input from being between ground and 5 V. Solar cells function similarly to photodiodes in photovoltaic mode, providing a voltage to a load. They are, however, tailored to absorb as much of the spectrum as feasible while simultaneously having a wide absorbent surface to maximize the electric power available to the load.

Analog to Digital Conversion

With the previously mentioned sensors we normally, we wish to convert analog signals to digital format so that they may be processed on a computer. This feat is accomplished through an analog-to-digital converter (ADC), which may be thought of conceptually as an extremely fast measuring voltmeter. It is made up of a sample-and-hold circuit, which keeps the voltage steady for a brief period while it is measured and digitized. Several digitizing processes are used, and we will go through a few of them. ADC The voltmeter is built using a huge number of comparators that compare the voltage against a series of voltages produced from a resistor ladder. An extra circuit encodes the comparator output into a binary form. ADCs are frequently incorporated into microcontrollers and sensors having digital interfaces, such as those detailed in subsequent sections. Following our examination of the ADC, the workhorse of digital data-acquisition systems, we now turn our attention to the problem of powering our circuits.

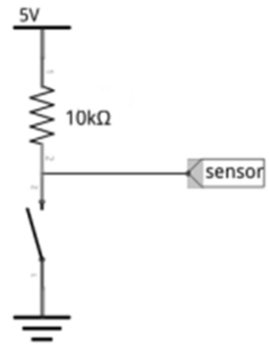
Supply Voltage for Sensors

Our sensors and microcontroller require power to function, and in our case, we will have a mixture of both, conventional as well as alternative sources. (Explained in later sections) This is generally supplied by a power source. A transformer is used in a typical kind of power supply to scale down the 220 V or 120 V AC voltage from the wall to a regularly used voltage range of roughly 5 to 20 V**.** Batteries or rechargeable batteries can also be used to power an electrical circuit. Lithium-ion or lithium-polymer (Explained in later sections) rechargeable batteries, which will be implemented on this mesh, are of relevance because they can supply very high currents to a circuit, which is especially significant for devices that demand high currents, such as WLAN circuits or motors. Because of their high inherent energy density, lithium-ion cells deliver voltages in multiples of approximately 3.7 V and require sophisticated dis- and recharging circuitry to prevent under- and overcharging, as well as physically injuring the battery. We can utilize electricity from the USB port to power electrical circuits that are used near a computer. Many RS-232-to-serial converter circuits offer up to 500 mA, which is frequently enough for tiny circuits. We may also utilize solar cells and so-called supercapacitors as temporary power sources to make circuits highly portable in the field. After examining analog sensors, analog-to-digital converters, and power supply, we now move on to sensors that create digital signals directly.

Digital Sensors

We are now will refer to sensors that do not require an external ADC and instead send their measurement information directly to the microcontroller in digital form. Some sensors already have an ADC built in, whereas others do not. We will start with the latter, of those which buttons and switches are the most visible examples. The most basic digital sensor is either a switch that is either closed or open, or a button whose open or close state is only momentarily triggered. These words are used interchangeably. Our objective is to reliably sense their status, which is often accomplished with a pull-up resistor coupled to the supply voltage.

Figure 4.1.3 - pull-up resistor that is connected to the supply voltage with a switch



The supply voltage may be accurately detected via the microcontroller's sensing pin. The voltage on the pin drops to zero or ground level only when the switch is pushed. When the switch is open, the voltage potential on the pin is undefined and dictated by stray capacitances in the system. As a result, when sensing the state of a switch, it is usually recommended to employ a pull-up resistor. When the resistor and switch positions are reversed, the resistor works as a pull-down resistor, and the sensing level is 0 unless the switch is closed. Now we'll look at sensors that directly report their measurement data in digital form, beginning with I2C devices.

I2C Devices

devices need to be break down into their intrinsic form before discussing later further device types (barometric pressure sensor and humidity sensor) which will be break down into detail in further sections. With this being stated let’s start laying the groundwork of this section. Language is used when individuals need to communicate with one another. When two individuals speak the same language, they can chat about whatever they desire. Communication is tough if they do not speak the same language. Similarly, electrical components must communicate, and each had their own languages too. Thereare a few commonly spoken languages. TTL Serial, SPI,, I2S, 1Wire, and Parallel are the most prevalent. Barometric pressure sensors include the BMP085, as well as subsequent variants BMP180 and BMP280.

They are based on using a piezoresistive strain gauge to measure the strain induced by the deformation of a membrane that separates an evacuated test-volume from the outside air pressure. The complete system is constructed directly onto a silicon substrate, and the strain gauge is formed by doping a tiny part appropriately. Because the semiconductor-based strain gauge is temperature dependent, a temperature sensor is integrated.

Air Quality Sensors

Air quality sensors are devices used to detect contaminants in the air. This includes dangerous pollutants and noxious gases that may be harmful to human health. They are used in various applications like air quality monitoring, various gas detection that can harm the environment in very disastrous ways affecting the environment, combustion controllers and oxygen generators. So, our air quality sensors will be placed on our product while activating the mesh network. As the mesh network is activated, the air quality will detect the air and try to obtain all the data it can and display it on the web interface when the user hovers over the different nodes as they please. The air quality will be able to measure the how much oxygen and carbon dioxide are released in the air including other toxic chemicals which will help to give a better idea on how clean the air and/or the environment is. All of that information will help in detecting the possible hazardous conditions on the land, also fire hazards.

Other Sensors

Aside from the defined protocols, there are a variety of communication standards developed by device makers. The relative humidity sensor, DHT22, and the DHT11 are two examples of such devices; the latter is depicted on the right in Figure. The temperature must be known to calculate the relative humidity, which is done via a thermistor. A capacitive humidity sensor is used to measure the humidity. The operating idea is based on the use of a tiny capacitor with an exposed dielectric that has a high affinity for attracting water, causing a substantial shift in the relative dielectric constant r and capacitance. The density of tiny particles floating in air can be used to measure air quality. Two examples of such sensors are shown above. A PPD42NS particle sensor may be seen on the left.A resistor within this detector warms the air, causing the air containing suspended dust particles to rise and pass through the light generated by an infrared diode. The dust particles scatter the light onto a phototransistor, which causes an output pin to be pulled to a low potential. A cleaned-up signal is provided after signal conditioning and amplification. When particles scatter light, it is low; otherwise, it is high. The sensor has been calibrated such that the time at low signal to total time ratio may be converted to particles per liter. The GP2Y1010AU0F, seen on the right, operates in a similar manner. It detects light dispersed off dust particles as well, but it regularly turns on the infrared diode and integrates the signal from the phototransistor, and the output value must be sampled 0.28 ms after the LED was switched on. The difference between the signal with and without the LED offers enough rejection of ambient light. Both dust sensors' effectiveness may be increased by placing them in the airstream formed by a fan, which must be turned on and off.

Several additional sensors, frequently linked to environmental factors like as humidity or barometric pressure, also report temperature as a byproduct since it is required internally to calibrate the given primary measurement result.

Biological and Chemical Sensors

For many years, researchers have been working on detecting very minute amounts of chemical and biological substances. Carbon monoxide detection for environmental applications, biological and biomedical monitoring, missile fuel leakage detection, and security applications all require high-sensitivity sensors that can quantify chemical or biological agents at low parts per billion (ppb) or parts per million (ppm). The recent advancement of microelectronic technology has created an excellent opportunity for the manufacturing of a sensor and an interface circuit on a single chip. The sensor and interface circuit are manufactured on a single chip, resulting in improved resolution, greater accuracy, and lower-noise signal conditioning and amplification. Furthermore, improved control over sensor working conditions such as temperature and linearity may be offered. When the sensor is near to the interface circuit, removing lengthy wire capacitance and the electromagnetic interface results in increased sensitivity and reduced noise. The array of sensors may be constructed on a single chip to reduce false alarms and increase sensor selectivity. Biochips are biosensors that contain transducers based on integrated circuits. A biochip is often made up of an array of biosensors that may be monitored separately and utilized to analyze numerous analytes. The interplay between the analyte and the bioreceptor is intended to have a quantifiable impact. A transducer is a device that turns a quantifiable impact into a signal (typically electrical) that can be monitored and recorded. Antibody/antigen interactions, nucleic acid contacts, enzymatic interactions, cellular interactions (microorganisms, proteins), and interactions employing biomimetic materials are the most prevalent biosensors (synthetic bioreceptor).

4.1.1 – Microcontrollers

The microcontroller unit or MCU will be the brains of each node. The MCU can be thought of as a miniature computer with all of the sensors being its peripherals. There is a wide variety for microcontrollers available for use in today’s modern electronics. There are also application specific and general purpose microcontrollers. For our purposes, we will focus on the feature set of general purpose microcontrollers.

These general purpose MCUs have a wide array of functionality with a shared set of core features. The central feature of an MCU is the processor. The processor will be single or multiple cores and is responsible for reacting to the inputs and outputs. The inputs and outputs will be handled in two ways. The first is general purpose input output or GPIO pins. These GPIO pins are capable of producing or accepting analog and digital signals. Not all GPIO pins are created equal, some are unidirectional or may only handle digital signal processing. The second way the inputs and outputs are handled is through the use of widely accepted peripheral interfaces. Some of the most notable standards are Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C), and Serial. These interfaces may overlap with the same pins used for GPIO operations or have their own dedicated pins. We dive deeper into these interfaces in other sections of our research. The presence of these interfaces is important to this application as many of the sensors rely on one of these common interfaces for communication. Though, the interfaces themselves are well documented and may be implemented separately, having them built into the MCU reduces complexity and increases reliability of the system.

We may also consider the software development flow for the MCU. When creating programs to run on our microcontroller, we will be using an Integrated Development Environment or IDE. The IDE is responsible for multiple functions in the software development flow. The first is, accepting the high-level programming language such as C, C++, or MicroPython. Then translating our chosen high-level language into the lower-level operations needed for the microcontroller. Beyond just translating higher level language, many microprocessors also offer human readable constructs to interact with the hardware components. An example of this is, the Wire functionality offered by Arduino for interacting with devices connected to the I2C bus. The prevalence and syntax for these features is unique to the family of microcontroller boards. The next step in the programming flow is actually loading the program onto the microprocessor's local storage. This may be included in the IDE or may require external tools. Lastly, each IDE may have a resource for communicating with the device and debugging code at execution time. This ranges from a basic serial console to a detailed range of tools for viewing the contents of registers or power consumption.

SB Development Board 32. E.s. P 32 is a low-cost system in the chip series made by Espressif Systems, a Shanghai-based Chinese startup, which is fabricated by TSMC using their 40 nm technology. Their Microcontroller has the ability of Wi-Fi and Bluetooth, which makes it chip all that is rounded for the development of our mesh network. When it comes to chip characteristics, it features a dual-core CPU, which means it has two processors. It also has Wi-Fi and Bluetooth. And you don't have to plug in the B Dongle every time you want to utilize Wi-Fi or receive a module. This came very useful for our mesh setup since Wi-Fi and Bluetooth where necessary requirements for our communication layout between nodes. The chip also executes a 32-bit application The clock frequency of this board may reach 240 megahertz, and it has 512 kilobytes with 30 or 36 rounds, 15 in each row. It also has a variety of extensions available, including such capacitive touch sensors and digital converters, Universelle digital analogue converter, asynchronous series communication modules, SPI, ice squirty, and others. the dual-core processor It has 2.4 GHz, 802.11 b/g/n WiFi, and 40 MHz of bandwidth support built in. It has Bluetooth Low Energy 5.0 connection and is capable of long-range communication of up to 1 kilometer via the coded PHY layer.

With 2 Mbps transfer capabilities, it also provides faster transmission speeds and data throughput. The ESP32-S3 has a superior RF performance even at high temperatures, which is an outstanding characteristic for our implementation since it could be expose to the high heats of the forests. he chips has an ultra-low-power (ULP) core that enables a variety of low-power modes. Because it supports AES-XTS-based flash encryption, RSA-based secure boot, digital signature, and HMAC, the ESP32-S3 is extremely safe, this feature has been from the most help since we are making our modular network restricted from a conventional power source from substantial period. Vector instructions have been added to the Xtensa LX7 core. Vector instructions are a type of instruction that allows for simultaneous processing of AI datasets, enhancing performance and power efficiency.

These instructions Will used and leveraged once we get to the part of Image processing for early fire detection with the camera module. Espressif developers are actively working on upgrades to the ESP-WHO face detection library and the ESP-Skai net speech recognition library Our team plans to constantly es committed to use to most updated library to improve usability and efficiency of our module.

4.1.2 – Anemometers

An anemometer is an instrument used to measure wind conditions. Specifically, anemometers may measure wind speed or direction or both. The anemometer is a core component to our project as the state of the wind is a critical factor in predicting fire propagation. With that, we are going to look at each of the available types of anemometers.

First up is the most basic type of anemometer, the cup anemometer. These are one of the first variations of anemometer ever created. They were invented by Dr. John Thomas Rodney Robinson in the year 1845 at the Armagh Observatory in Northern Ireland. The operating principle of this type of anemometer is to capture the wind in cups whose openings are placed perpendicular to the wind direction vector. The cups are mounted to a central hub and the apparatus generally contains three cups. As the wind speed changes, the cups interface with the wind to create an acceleration or deceleration of the angular velocity at the hub. The number of rotations of the hub is measured providing a means to extrapolate wind speed. The rotational rate of the hub is directly correlated to the measurement of wind speed. As a result, it is important to consider the frictional or other forces contributing to the arrest of this motion. There are two main ways to reduce external forces on the system. The first is to utilize low friction bearings for the hub. The bearings are similar to the ones used in hard disk drives. The second method is to use a sensor for the speed that does not mechanically interface with the hub. A common method to record the number of rotations per time period is by using a hall effect sensor. Hall effect sensors function in the presence of a sufficiently intense magnetic field. The sensor itself is composed of semiconductor material that allows the flow of current only in the presence of magnetic flux generated by the magnetic field. The Hall effect sensor is placed near the hub of the anemometer. A magnet is then attached to the hub itself. In this configuration, the magnet passes the sensor once per revolution of the anemometer hub. As the magnet passes the Hall effect sensor, current is allowed to flow through the sensor and a brief pulse of voltage is measured. A microcontroller may observe the frequency of these voltage pulses. The anemometer may be calibrated by directing a set of wind events with a known speed over the anemometer. We may characterize the frequency of pulses as wind speed. With a set of known pulse values, unknown wind speeds may then be extrapolated mathematically.

The cup anemometer measures wind speed only. To measure wind direction, we may consider the next type of anemometer, the wind vane. In its most basic form, the wind vane has been around for thousands of years. The first recorded wind vane was created by Greek astronomer Andronicus in the year 48 B.C. The basic design still remains in modern versions of the wind vane. The wind vane uses a vertical rudder to align its axis with the direction of the wind. The rudder is often mounted to a nacelle with the center of the nacelle attached to a fixed vertical axle. The mechanical mate between the nacelle and the axle is important to the functionality of the wind vane. Reducing the friction and other arresting forces at this connection point increases the potential accuracy and precision of the system. For example, at low wind speed the force of the wind moving over the rudder may not overcome the force required to move the nacelle. This would cause the system to register an incorrect measurement. We may obtain the wind direction by measuring the position of the nacelle in relation to the fixed axle. There are two main methods for measuring the position of a wind vane. The first is a mechanical connection between the nacelle and a continuous positional sensor. A continuous positional sensor is also referred to as a continuous potentiometer. As the input shaft to the potentiometer rotates, the resistance changes. This change is a result of an internal wiper connected to one output moving over a conductive carbon surface connected to another output. The resistance between these outputs may be measured by observing the output voltage with a known input voltage. When the wiper moves in one rotational direction, the voltage increases. In the other rotational direction, the voltage decreases. The input shaft has a continuous range of motion allowing this voltage to represent the absolute position of the input shaft. A microcontroller may be used to translate the voltage into positional information. This is possible by using an analog to digital converter (ADC) input to read the voltage of the continuous potentiometer. The ADC counts may be correlated to the physical position of the sensor by choosing a fixed reference point then, rotating the input shaft 360 degrees. The second method for measuring the direction of the nacelle is by using magnetic sensors. Either by measuring the position of the nacelle in relation to the fixed axle or by measuring the earth's magnetic field to attain a compass azimuth. For measuring the compass azimuth, we may use a microelectromechanical (MEMS) magnetic field sensor. The basic function of this type of sensor is to supply an output representing the direction of the magnetic field lines passing through the device. It is important to note that magnets elsewhere in the system may cause interference when attempting to measure the earth's magnetic field. We may also consider measuring the position of the nacelle itself. This is possible by attaching a diametral magnetized magnet to the center point of the nacelle. The magnetic field produced may then be measured to produce a 0-to-360-degree angle output.

The next type of anemometer is the windmill style. The functionality and principles of the cup anemometer carry over to this style. Where the two diverge is in the implementation of the mechanical interface between the anemometer and the wind. The cups are replaced with a propeller. The propeller is mounted with the hub parallel to the wind direction vector creating a rotation axis around the wind vector. The shape of a windmill anemometer is akin to a propeller airplane with only the tail fin. The tail fin serves an important purpose in this case as the effectiveness of the propeller depends on the face pointing into the wind. For example, if the wind blows across in the same direction the blades extend out from the hub, the blades will not effectively catch the wind. The result is a slower than actual wins speed. A propeller anemometer may also work through the use of a Hall effect sensor. This is to retain the same properties of low impedance to the rotational motion of the propeller. The tail fin of a windmill style anemometer also provides another measurement, wind direction. The tail fin keeps the nacelle pointed into the wind. As a result, measuring the position of the nacelle allows the measurement of wind direction. This direction measurement is conducted in the same way the vane type operates.

Another type of anemometer is the hot wire style. The hot wire anemometer works by heating up a thin piece of wire and placing it in the path of airflow. As the air passes over the wire, the wire is cooled. There are two ways to translate this cooling into a measurement of airflow. First, is the constant current method. This method passes a constant current through the wire and measures the change in temperature. The change in temperature may then be used to find the airflow. The second method is the constant temperature method. This method relies on the electrical property that when a wire is heated, the resistance decreases. The objective of this method is to maintain the temperature and resistance of the wire. The current needed for this is the measurement that may be translated to airflow.

The final type of anemometer we will be investigating is the ultrasonic anemometer. An ultrasonic anemometer uses sound waves to measure both the wind speed and direction. This is accomplished through the use of the Doppler Effect. The Doppler effect describes the behavior of sound waves as an emitter moves towards or away from an observer. In this case, the wind is the acting motion, and the transmitter and observers are stationary. An ultrasonic emitter is placed at the center three equally spaced receivers. All four transducers are faced towards a flat surface acting as a reflector. As wind passes between the transducer housing and the reflector, the frequency seen by each receiver shifts. As the wind pushes the sound waves, the receiver that is downwind observes a frequency increase. While the receiver that is downwind observes a frequency decrease. In this system, the wind acts as the motive force which emulates the movement of the transmitter in relation to the receivers. This is the Doppler effect in action. An important consideration for this system is the sensitivity of the measurements and the related potential interference.

A final note, there are a few types of anemometers that were not mentioned in this section. We did briefly investigate these types, but they were ruled out for cost, complexity, or being analog only with no means to translate to a digital readout.

4.1.4 – Humidity Sensors

The quantity of water vapor in the air is referred to as humidity. The quantity of water vapor in the air in relation to the maximum amount of water that the air can retain is referred to as relative humidity. When determining the fire hazard of a location, humidity is a crucial aspect to consider. There are 3 different types of humidity sensors when it comes to humidity detecting technology: capacitive, resistive, and thermal conductivity humidity sensors.

Capacitive Humidity Sensors

In industrial, commercial, and weather telemetry applications, capacitive humidity sensors (CHS) are commonly utilized. CHSs are made up of a substrate and a thin layer of polymer or metal oxide placed between two conducting electrodes. To protect the sensing surface from contaminants and moisture, it is covered with a porous metal electrode. The substrate is usually made of glass, ceramic, or silicon. The fluctuations in a CHS's dielectric constant are nearly precisely proportional to the surrounding environment's relative humidity (RH).

Advantages: Able to function in high-temperature environments (up to 200 °C), near linear voltage output, wide RH range, high condensation tolerance, reasonable resistance to chemical vapors and contaminants, minimal long-term drift, high accuracy, small size, and low cost.

Disadvantages: Limited sensing distance and sensor interface can be tedious and difficult

Resistive Humidity Sensors

Resistive humidity sensors (RHS) detect changes in the electrical impedance of a hygroscopic material such as conductive polymer, salt, or a treated substrate. These sensors are appropriate for use in industrial, commercial, and home control and display equipment. RHS is made up of noble metal electrodes that are either photoresist-deposited on a substrate or wire-wound on a plastic or glass cylinder.

Advantages: include a faster reaction time than CHS, near linear voltage output, great precision, a compact size, low cost, and a wide RH range.

Disadvantages: Lower working temperature than CHS, susceptible to chemical vapors, low contamination tolerance, and low condensation tolerance.

Thermal Conductivity Humidity Sensors

Thermal conductivity humidity sensors (TCHS) calculate absolute humidity by comparing the thermal conductivity of dry air to that of air containing water evaporates sensors are appropriate for applications such as wood drying kilns, textile, paper, and chemical solids drying machinery, pharmaceutical manufacture, cookery, and food dehydration. The TCHS is made up of two matched negative temperature coefficient (NTC) thermistor components in a bridge circuit, one of which is hermetically sealed in dry nitrogen and the other which is exposed to the atmosphere.

Advantages: Extremely long service life, ability to function in high-temperature conditions (up to 600°C), great resistance to numerous chemical and physical impurities, high precision, and high condensation tolerance.

Disadvantages: Respond to any gas with thermal characteristics other than dry nitrogen; this will impact readings.

4.1.4 – Temperature Sensors

Temperature Sensing

In the field of sensors, temperature sensing technology is one of the most extensively utilized sensing technologies. It enables temperature measuring in a variety of applications and protects against extreme temperature excursions. There are five distinct types of temperature sensors on the market. Each temperature sensor family has benefits and downsides. One sensor may be more suited to a certain application than the other.

Thermocouples

A thermocouple is a connection made by two wires of different metals. The voltage generated by the point of contact between the wires is proportional to the temperature. Thermocouples can measure across a wide temperature range, up to 2300 °C. They are less appropriate for instances where smaller temperature variations must be measured precisely. Thermistors and resistance temperature detectors (RTDs) are better suited for such applications. Temperature is one application. Kilns, gas turbine exhaust, diesel engines, and other industrial operations are all measured.

Advantages: include a wide temperature range (200 °C–1300 °C), a low cost, good accuracy, little long-term drift, and a quick reaction time.

Disadvantages: The relationship between temperature and thermocouple output signal is not linear, the output signal (mV) is low, thermocouples are susceptible to corrosion, and thermocouple calibration is time-consuming and complicated.

Resistance Temperature Detectors

RTD's are widely utilized in a variety of industrial applications, including air conditioning, food processing, textile manufacturing, plastics processing, microelectronics, and exhaust gas temperature measuring. RTDs are essentially temperature-sensitive resistors. Temperature causes an increase in resistance. The majority of RTD elements are made up of a length of fine-coiled wire wrapped around a ceramic or glass core.

Advantages: Linear throughout a large temperature range, moderately accurate, strong stability and repeatability at high temperatures (65 °C–700 °C).

Disadvantages include low sensitivity, higher cost than thermocouples, and susceptibility to stress and vibration.

Thermistors

Thermistors, like RTDs, are temperature-dependent resistor devices. Thermistors are not as precise or reliable as RTDs, but they are easier to wire, cost less, and are directly accepted by practically all automation panels. Thermistors are built of semiconductor materials having a temperature-sensitive resistance.

Advantages: include high sensitivity, low cost, accuracy over a narrow temperature range, and good stability.

Disadvantages: Nonlinear resistance temperature characteristics, self-heating, and a restricted temperature working range are disadvantages.

Integrated Circuit Temperature Sensors

Most of the sensors mentioned previously are either costly or need the use of extra circuits or components in low-cost applications. Integrated circuit (IC) temperature sensors, on the other hand, are entire silicon-based sensing circuits with either analog or digital output. IC temperature sensors are frequently utilized in applications with minimal precision requirements.

Advantages: low cost, high linearity, and easy-to-read output.

Disadvantages: a limited temperature range, self-heating, fragility, and being somewhat less precise than other varieties.

4.1.5 – Barometers

Atmospheric Pressure

One standard atmosphere of pressure equals 1.01325 105 Pa (N/m2) (14.6960 pounds per square inch, 1.01325 bars, 1013.25 mbars, 760.00 mm Hg, or 29.920 in. Hg). This is the mean atmospheric pressure at sea level. At sea level, atmospheric pressure normally deviates from one standard atmosphere by little more than 5%. With increasing altitude, atmospheric pressure falls. Air pressure measuring equipment known as altimeters are used in airplanes to determine altitude. At roughly 5500 m (18,000 ft), the air pressure is half that of sea level. The following instruments are used to measure atmospheric pressure.

Mercury Manometer

Barometric pressure was originally measured with a mercury manometer. This is a 1 m long tube filled with mercury and inverted into an open dish of mercury. The height of the column of mercury maintained in the tube by the external pressure is a measure of the external air pressure. As a result, one standard atmosphere equals 760 mm Hg. While accurate, this gadget is cumbersome and has been phased out for common usage.

Aneroid Barometer

It is made out of a partly evacuated chamber that may expand and contract in response to changes in external pressure. The evacuated chamber is frequently a set of bellows, with expansion and contraction occurring in only one dimension. The most basic aneroid barometers, which are still in use, contain a mechanical connection to a pointer that provides a reading on a dial calibrated to read air pressure. Mechanical barometers of high grade can attain an accuracy of 0.1 percent of full scale. Aneroid barometers can also have an electronic readout, removing the need for a mechanical connection; this is more common for serious meteorological measurements. A magnet attached to the free end of the bellows is placed near a Hall effect probe in one way. The output of the Hall probe is proportional to the distance between the magnet and the Hall probe. An aneroid apparatus, which consists of a stiff cylindrical chamber with a flexible diaphragm at one end, is also used to measure barometric pressure. A capacitor is made by attaching one fixed plate adjacent to the diaphragm and another plate to the diaphragm. The capacitance varies when the diaphragm expands or shrinks. Calibration establishes the pressure associated with each capacitance value. For ground-based measurements, a typical range of 800 to 1060 mbars with an accuracy of 0.3 mbars is used. This type of equipment is manufactured by Setra Corporation for the National Weather Service ASOS network, which is manufactured by AAI Systems Management Incorporated. The ASOS network will be explained more below. Pressure measurement is also covered in other sections of this chapter.

4.1.6 – Air Quality Sensor

Air quality sensors are devices used to detect contaminants in the air. This includes dangerous pollutants and noxious gases that may be harmful to human health. They are used in various applications like air quality monitoring, various gas detection that can harm the environment in very disastrous ways affecting the environment, combustion controllers and oxygen generators. So our air quality sensors will be placed on our product while activating the mesh network. As the mesh network is activated, the air quality will detect the air and try to obtain all the data it can and display it on the web interface when the user hovers over the different nodes as they please. The air quality will be able to measure the how much oxygen and carbon dioxide are released in the air including other toxic chemicals which will help to give a better idea on how clean the air and/or the environment is. All of that information will help in detecting the possible hazardous conditions on the land, also fire hazards.

4.1.7 – Visual Cameras

Cameras provide the machine with the ability to see. Cameras are particularly common exteroceptive sensors for detecting the outside environment, especially in mobile and stationary systems. The camera's picture is processed to extract elements of the environment and identify things. The gear used to process pictures has become extremely low-cost, quick, and tiny in size. This has made integrating cameras in robotic systems relatively simple and cost-effective   Based on the output signal, there are two types of cameras: analog and digital. Digital cameras are available with a variety of interfaces, including USB, FireWire (IEEE 1394), TCP/IP, and SmartLink. Cameras with built-in RF wireless transmitters are very common and may be found on autonomous flying vehicles such as Quadrotors and rescue robots.

4.1.8 – Compass

A digital compass sensor determines the bearing and direction of a robot or autonomous mobility platform. The four cardinal (N, E, S, W) and four intermediate (NE, NW, SE, SW) directions are frequently measured. These sensors are critical for robots that must negotiate unfamiliar terrain. For inclination adjustment, it employs a magnetic field sensor and a tilt sensor.

Tilt Sensor

A tilt sensor or inclinometer measures inclination, i.e., slope (or tilt) angles on a single or dual axis. It determines an object's elevation or inclination with regard to gravity. Inclines (positive slopes as seen by an observer looking upward) and declines (negative slopes as seen by an observer looking below) are both measured using inclinometers. Tilt meters, slope gauges, gradient meters, gradiometers, level gauges, declinometers, and pitch and roll indicators are some of the other names for it. These sensors can provide analog signals or serial digital data as output. MEMS, accelerometer, liquid capacitive, electrolytic, gas bubble in liquid, and other sensor technologies are often used in inclinometers as well as pendulum

4.1.9 – Soil Moisture Sensors

Excess moisture is undesirable in agriculture, housing, textiles, packaging materials, electrical gadgets, dry food processing, and other industries. Moisture detection is useful in a variety of scenarios. Soil moisture assessment, for example, is beneficial for reducing the quantity of irrigation water used to grow plants and maximizing plant development. Excess moisture also causes "wet feet" in plants, which kills them. Because the moisture content of materials is so important, numerous ways for measuring it have been devised. This section describes a variety of soil moisture sensing technologies that are now available on the market, as well as their benefits and drawbacks.

Frequency Domain Reflectometry Soil Moisture Sensor

Frequency domain reflectometry (FDR) is also known as a capacitance sensor. The FDR technique of soil moisture measurement employs an oscillator to create an electromagnetic signal that is carried through the unit and into the soil. The dirt will reflect some of this signal back to the device. The FDR probe measures the reflected wave and reports the water content of the soil to the user.

Advantages: Highly accurate, quick reaction time, and low cost.

Disadvantages: They must be calibrated for the type of soil in which they will be buried.

Time Domain Reflectometry Soil Moisture Sensor

TDR sensors send a pulse down a line into the soil, which is terminated at the end by a probe equipped with wave guides. TDR devices evaluate soil water content by monitoring how long it takes for the pulse to return.

Advantages: Extremely precise and quick reaction.

Disadvantages: Calibration can be time-consuming, complicated, and costly.

Gypsum Blocks

Gypsum blocks employ two electrodes put inside a tiny block of gypsum to monitor soil water tension. The electrodes' wires are attached to either a portable handheld reader or a data logger.The electrical resistance between the two electrodes within the gypsum block determines the quantity of water in the soil. More water in the soil reduces resistance, whereas less water increases resistance.

Advantages: Low cost and simple installation.

Disadvantages: Must be replaced on a regular basis and are sensitive to the salty content of water.

Neutron Probes

Another method for measuring soil moisture content is to use neutron probes. A probe put into the earth emits neutrons, which are low-level radiation. These neutrons clash with the hydrogen atoms in water, which the probe detects. The more water there is in the soil, the more neutrons are reflected back to the apparatus.

Advantages: Extremely precise and quick reaction.

Disadvantages: Expensive, and users must be registered with the government owing to the usage of radioactive materials to release neutrons.

4.1.9 – Photovoltaic Panels

Energy is often regarded as the driving force behind economic progress across the world. Global energy resources are divided into three categories: fossil energy (oil, gas, coal, etc.), nuclear energy, and sustainable sources (wind, solar, geothermal, air power, biomass, hydrogen, ocean, etc).

Wind power is now the primary source of new renewable energy. Over the previous 10 years, global wind power capacity has increased at a pace of 30 percent on average. In 2007, around 20 GW of additional capacity was built, increasing the global total for that year to 94 GW. This yearly expenditure by a sector that employs 200 000 people and serves the electrical demands of 25 million consumers amounts to around 25 billion euros. This significant development has drawn investment from major manufacturers such as General Electric, Siemens, ABB, and Shell, as well as various electrical providers, most notably E.ON and Scottish Power. Wind power has a promising future over the next two decades.

Today's energy pathway is heavily reliant on fossil fuels, and the repercussions in terms of climate change and energy security are already dire. Since the 1970s, solar cells have been recognized as a significant alternative energy source. Solar cells are also promise as a carbon-free energy source capable of mitigating global warming. A solar cell's power conversion efficiency is well characterized as the ratio of electric power generated by the cell to incident sunlight energy per unit of time. Now, the greatest documented cell efficiencies in labs are over 40%, whereas thermal power production power conversion efficiencies can surpass 50%. This, however, does not imply any advantage for thermal generating, as its supplies, such as fossil fuels, are finite, but solar energy is basically inexhaustible.

There is global consensus on the need to reduce carbon emissions, and various policies are being developed both globally and locally to accomplish this. The European Commission unveiled an Energy Package on January 10, 2007, which was approved by the European Council. The EU's greenhouse gas emissions were to be cut by 30% by 2020 if a worldwide agreement is reached, or by 20% unilaterally. The objective to offer a 20% share of energy from renewable energy (RE) sources in the total EU energy mix is a critical component in achieving this goal.

Governments all around the globe have worked to enhance the percentage of renewable green energy in electricity generation. Because of the seriousness of global warming, there is a growing interest in solar energy research. As an alternative energy source, converting sunlight into electricity is critical. Solar energy is regarded as the finest renewable energy source since it is limitless and clean.

Solar radiation may be captured and turned into many types of energy without polluting the environment. Solar collectors, such as solar cells, are required to convert solar radiation. The primary concerns have been energy security, rising carbon-based energy pricing, and mitigating global warming. Global shipping contributes significantly to global greenhouse gas (GHG) emissions, accounting for around 3% of total CO_2 emissions. 1, 2, 3 The International Maritime Organization is presently trying to establish GHG laws for global shipping, and it is under pressure from the EU and the United Nations Framework Convention on Climate Change, among others, to implement measures that will have a significant influence on emissions.

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We will begin our study of PV technology with a brief history of solar energy. Humans were already employing magnifying glasses to focus sunlight and so generate fire around the seventh century BCE. Later, focusing mirrors were used for the same reason by the ancient Greeks and Romans. Horace-Bénédict de Saussure, a Swiss scientist, invented heat traps, which are similar to small greenhouses, in the 18th century. He built hot boxes that consisted of a glass box within another larger glass box, with a total of up to five boxes.

Alexandre-Edmond Becquerel, a 19-year-old French scientist, developed the photovoltaic phenomenon in 1839. This phenomenon was found in an electrolytic cell composed of two platinum electrodes immersed in an electrolyte. An electrolyte is a solution that conducts electricity; Becquerel used silver chloride dissolved in an acidic solution. When he exposed his setup to sunshine, he saw that the current of the cell increased.

The true invention of solar cells as we know them now began in the United States at Bell Laboratories. Daryl M. Chapin, Calvin S. Fuller, and Gerald L. Pearson, three of their scientists, created a silicon-based solar cell with an effectiveness of roughly 6% in 1954 [43]. They are seen in Figure 11.2 in their laboratory. D. C. Reynolds et al. reported on the photoelectric cell of cadmium sulphide (CdS), an II-VI semiconductor, the same year.

Zhores Alferov, a Soviet researcher, invented solar cells based on a gallium arsenide heterojunction in 1970. This was the first solar cell to use III-V semiconductor materials, as discussed in Section 13.2. Dave E. Carlson and Chris R. Carlson founded the company in 1976.Wronski pioneered the use of amorphous silicon in thin-film solar systems while working at RCA Laboratories.The first solar cell was developed by the firms SHARP and Tokyo Electronic Application Laboratory. On the market, there are a variety of battery-powered calculators.

The public's interest in photovoltaic devices for terrestrial applications surged throughout the 1970s as a result of the oil crisis, which resulted in drastically rising oil costs. PV technology was transitioning from a specialty technology for space purposes to a technology appropriate for terrestrial uses at the time. Many businesses began developing PV modules and systems for terrestrial applications in the late 1970s and early

1980s. Solar cells remain vital for space applications, as seen in Figure 11.3, which depicts a solar panel array on the International Space Station (ISS).

The first thin-film photovoltaic arrays based on a copper-sulphide/cadmium-sulphide junction with a conversion efficiency more than 10% were demonstrated at the University of Delaware in 1980. At the University of New South Wales in Australia, crystalline silicon solar cells with efficiency more than 20% were shown in 1985.

The Chinese government has been significantly investing in their PV business since around 2008. As a result, for some years now, China has been the main PV module manufacturer. In 2012, global solar energy capacity exceeded the magical 100 GWp threshold. Thus, between 1999 and 2012, installed PV capacity increased by a factor of 100. In other words, the average annual growth rate of installed PV capacity over the previous 13 years has been over 40%.

For ages, solar energy was already utilized to create heat for decades. Since Gerald Pearson, Daryl Chapin, and Calvin Fuller invented the crystalline silicon solar cell in 1954, solar cells have now become a highly important choice for large-scale solar power production. Photovoltaic power already accounts for 1% of worldwide electricity output in 2015. According to the 2014 IEA Roadmaps for Solar Photovoltaic and Solar Thermal Energy, solar photovoltaic and solar thermal power will account for 27 percent of worldwide electricity output by 2050.

Solar energy is already employed in rural regions to provide tiny amounts of power and heat, helping to the economic growth of these communities. Millions of tiny photovoltaic systems are in use, supplying energy for things like lights and telecommunications. Solar energy systems may be extremely successfully integrated into the physical environment and are actively contributing to the phenomenal development in solar energy use that we are seeing today. Solar energy may be utilized to generate electricity on a large scale in power plants using flat plate and concentrator photovoltaic (PV) systems, as well as thermal concentrated solar power (CSP) systems.

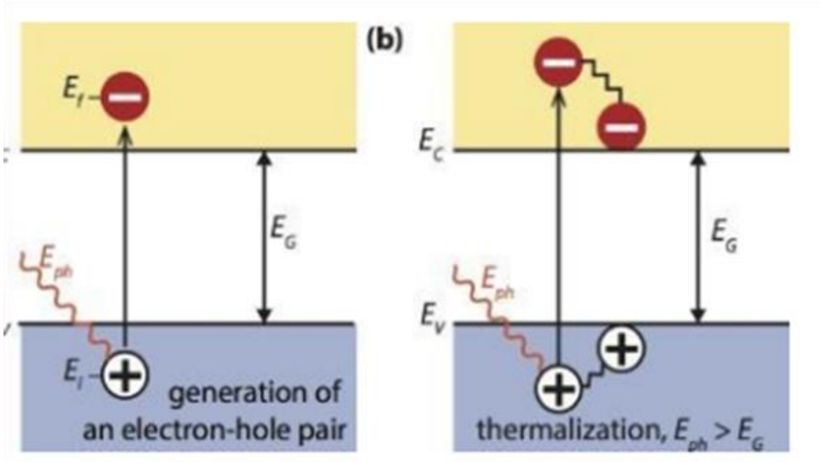
The photovoltaic effect, or the development of a voltage differential at the junction of two distinct materials in response to electromagnetic radiation, underpins the operation of solar cells. The photovoltaic effect is like the photoelectric effect in that electrons are released from a substance that has absorbed light with a frequency greater than a material-dependent cutoff frequency. Albert Einstein realized in 1905 that this phenomenon may be described by assuming that light is made up of well-defined energy quanta known as photons. The energy of a photon of this kind is given by

$$E = Hv$$

where h is Planck's constant and v is light frequency in 1921, Einstein was awarded the Nobel Prize in Physics for his explanation of the photoelectric phenomenon.

When a photon absorbs in a material, its energy is utilized to accelerate the electrons from an initial energy level to a higher energy levelE_f, as shown in Figure.Photons can be absorbed only if the electron energy values $E_i\ and\ E_f$ are present in such a way that the difference between them matches the photon energy,$hv = E_f - E_i$. Electrons in an ideal semiconductor can inhabit energy levels below the valence band edge, E_V, and above the conduction band edge, E_C . There are no permissible energy levels that can be occupied by electrons between those two bands. As a result, this energy differential is known as the bandgap, $E_G = E_C - E_V$.

Figure 4.1.9.2 – PV Panel Functionality [42]



A photon's absorption in a semiconductor with bandgap E_G. is depicted. A photon with the energy is depicted. A photon with the energy $E_ph = hv$ excites an electron from E_i to E_f. A hole is formed at E_i A portion of the energy is thermalized $if\ E_ph > E_G$

The peak power P_{max} , short circuit current density Jsc, open circuit voltage V_{oc}, and fill factor FF are the major characteristics used to characterize the performance of solar cells. These values are calculated using the lighted characteristic. These characteristics can be used to Fsec calculate conversion efficiency.

4.1.10 – Batteries

The term "Lithium Battery" refers to a lot of lithium that are synchronized and connected electrically. Similar to other batteries, lithium battery cells has a negative electro-node, positive electro-node, a separator, and an electrolyte solution. Atoms or molecules with a net electric charge or ions are moved from a positive electrode to a negative electrode through an electrolyte solution. The lithium cells contain and release power by converting potential energy into electrical energy using lithium ions. Electrolyte solutions parse ions to flow between the electrolyte between the electrodes in a free state.

Lithium-ion batteries utilize lithium in ionic forms instead of lithium in solidified form. These forms are usually rechargeable and most of the time don't need to be moved away from a device. These batteries power devices like daily use of computers, laptops, cameras, phones, power tools, etc.

The lithium-metal batteries most of the time contain lithium-metal electrodes and are non-rechargeable. These batteries are generally used to power day to day devices like flashlights, watches, calculators, car-keys, etc.

We have seen the positive outcomes while using these batteries, but they also come with a lot of dangerous hazards. Lithium batteries are generally very safe and will not fail most of the times, however they cannot be without defects for a very long time. When these batteries fail to operate in a safely manner or are damaged, then they can cause a fire or very explosive conditions. Also, with improper use or bad handling can, storing, or charging it may cause these batteries to perform poorly. It is very important and essential to test batteries, chargers and other equipment in use with these to follow appropriate and safe testing standards, for example: UL 2054, NERT certification, product redistribution and aid identifying other defects in design, quality of material and manufacture. The best way to dispose or throw out Lithium batteries is by recycling them because it may just end up in a landfill and it may cause a lot of harm to the environment due to the toxic elements that it may have stored in itself. Even though it is recyclable, the procedure of doing that is a little complicated. Since lithium is a highly reactive element, it cannot be mixed with other types of batteries discussed above also including elements when it is sent to a recycling facility. Since recycling material requires usage of heat to melt the material, it would not be advisable to work with lithium batteries because they can be flammable.

It doesn't take a long period of time to damage lithium batteries from physical impact, exposure to a specific range of temperatures and improper charging conditions:

- Some physical impacts that can crush the lithium batteries are through dropping, punching, and crushing it.
- Lithium batteries can be badly damaged when temperatures too high (exceeding 130 F). Heat sources like heaters, open flames, matches, etc can also intensify the failure rate in cells with damages from other causes.
- Lithium batteries can be badly damages when temperatures are too low as well (low below 32 F) during the process of charging. Charging batteries in sub 0 degrees Celcius can lead to lifelong metallic lithium buildup on the anode which increases failure significantly.
- It is important to follow the manufacturer's instructions as charging the battery blindly can cause damage to rechargeable lithium-ion batteries. For instance, if some manufacturer-authorized chargers will cycle the power of the battery to be on/off before it is completely charged to disallow overcharging. Since ultra-fast chargers may not cycle power too much, it is important to not use them unless the manufacturer's instructions includes an option to do so.

It is important to be safe from the injuries causes by damaging the battery or battery defects of lithium as they can be preventable with the help of some of safety guidelines: 100% know that lithium batteries, chargers and associated equipment are tested in accordance with appropriate testing standard (UL 2054) as it is applicable and certified by the NRTL or Nationally recognized testing laboratory while changing the batteries and chargers for the specified electronic device that the user uses. Ensure that these devices are specifically designed and approved for safety and are ready to be purchased from the device's other manufacturer. It is imperative to remove lithium powered devices and batteries from the charger once it is 100% charged and ready to use. If these batteries are used in generalized day to day product or in our product for the project then it is imperative and crucial to inspect them for signs of damage, for instance hissing, leaking, budging, cracking, temperature rise, and any leakage of smoke. It is important to immediately remove a device or battery from the service and put it in an area far away from flammable materials when these circumstances rise. The methods mentioned will prevent fire and/or fire hazardous situations in any environment or surrounding.

NiMh batteries are utilized in over 95% of HEVs and other major manufacturers have so far invested a lot in the past ten years. The major advantage from a manufacturing perception is the safety and injury-free environment of NiMh batteries compared to lithium batteries, and, so far, no incidents have occurred or been reported in the press before. NiMh batteries are preferred in the real-world or industry and consumer applications rise due to their design flexibility (like raning from 40 mAh to 250 mAh), environmental acceptability, very low maintenance, high strong power and energy densities, cost and importantly: the safety (discharge and in-charge modes, most especially at high voltages). NiMh batteries are currently prices at an amount of $250 to $1500 per kWh, so the total price of the battery pack provided for a hybrid (Toyota Prius, though the newer the models use 5.2kWh lithium battery packs) varies between $600 and $4000 per vehicle. The NiMh batteries was patented in 1986 by Stanford Ovshinksky who is the founder of Ovonics, when recharging hydrogen storage models. Ovshinsky also described NiMh battery as the hydrogen ion or protonic battery by an analogy with Lithium atteries as the NiMh electrochemical reaction involves the transfer and insertion of H+. The major components of NiMh batteries consist of anode of hydrogen absorbing alloys or MH, a cathode of nickel hydroxide or NiOH2 and a potassium hydroxide or KOH electrolye Nickel-metal hydride batteries as in most aspects of their manufacture and design, the manufacturing procedure is similar to the NiCd batteries. The key difference is the change of placings of the negative cadmium based electrode with an electrode using a hydrogen storing metal alloy. Nearly all NiMH batteries operating in this field in these times emply a very rare earth Mischmetal called the nickel based metal allow (MmNi5-type) with some chunks of cobalt, manganese and aluminum. The statements in the previous aspect of nickel-based substances including the hazardous risks of the chaotic electrolyte can also apply for the NiMH system. The absence of the cadmium makes recycling process of spent products. The soft-chemical process of Ni-MH batteries have also been studied. The chemical composition of the recovered material from the large-format NiMH cell is provided to show how it can be recyclable.

Nickel Cadmium or NiCd battery cells are completely instilled with electrolytes and often need to be handled, stored and moved with vents facing north or upwards. It is important to avoid using the NiCd batteries in direct sunlight, high temperature, high humidity and dry conditions. The NiCd batteries can be stored in a cool and dry area where temperature can range form 10 degrees Celsius to 30 degrees Celsius which is 50 to 86 degrees Fahrenheit and with a humidity between 44% and 86%. Ensure that one does not connect a positive terminal to a negative terminal with electrically conductive materials. Always store and operate the Nickel-Cadmium batteries in separate rooms where the lead-acidic batteries can be stored and used. Also, keep NiCd batteries away from water in cooling areas with well-ventilated conditions. Do not put any other materials of use on the top of the batteries as given the features of any specific battery type and how it can be performed, that certain battery can be beneficial for our product as it will perform efficiently and last longer in any circumstances comparted to the usage of Lithium batteries.

4.1.11 – Battery Charge Controllers

Battery charge controllers are vital to ensure that our batteries work desirably for long hours so that the product is effective in full use. Battery charge controllers or charge regulators or battery regulators are mainly used to charge a solar deep cycle battery safely at the accurate charge rates and to protect the battery from overcharging or it might overheat and destroy itself. If it does destroy itself then the battery won't be able to function properly which won't help the product in any situation at all. There are a significant variety of solar charge controllers available such as: AC chargers, solar lighting controllers, etc.

Solar charge controllers are used to optimize the charge from solar panels, regulate the charge and protect the batteries overall located in the solar power systems. The solar lighting controllers comprise of both a solar charge controller and a lighting controller which is actually programmable in one unit Direct charge or DC lights are run directly off the solar lighting controller at accurate scheduled period of times which potentially eliminates the requirement of a load controller or an alternative timer. Alternative current or AC battery chargers use an AC source. An AC source like a wall outlet which is used to directly charge a direct current or DC battery bank. There are a lot of different versions available which allow fast charging, or an input/output of different voltages. The load controllers are significantly capable of being solar charge controller or a direct current (DC) load controller, or a diversion load controller. It will be key to determine which load controller does it want to operate as, but since our battery will be charged through the beams of the sun rays directly falling on the solar panel, then it will beneficial for the direct current load controller to enact like a solar charge controller, because the more power it contains, the product can perform its tasks for the users for longer durations. In order to make sure that the battery charge controllers work properly, then the low voltage disconnect or the LVD is an important voltage that allows one to connect to a DC source load which is the same voltage as the battery bank which allows the controller to turn it off when the battery bank power is low. This process allows the battery bank to be protected from the battery becoming completely drained which is also known as deep discharging.

4.1.12 – Power Regulation

A power or a voltage regulator is a circuit that maintains a fixed output voltage, even though it doesn't matter how the input voltage or load conditions change. The way this works, is where a voltage regulator maintains the voltages from a power supply within a range that is compatible with other electrical units. Voltage regulators are often used for DC/DC power conversions, AC/AC or AC/DC can perform conversions too. There are two types of voltage regulators: Linear and Switching. Both of these types of regulators control or regulate a system's voltage, however linear regulators operate with very low efficiency whereas switching regulators operate with very high efficiency. All if not most of the input power gets transferred into the output without dissipation.

Linear regulators use devices such as BJT or MOSFET which are active pass and is controlled by a high gain amplifier which is operational. In order to maintain a constant output voltage, the linear regulator will modify the pass device resistance by comparing the internal voltage reference to the sampled output voltage. This drives the error to zero. It is important to notice that linear regulators are step-down converters, so the output voltage is always below the input voltage by definition. There are a few regulators that give a few advantages which are generally simpler to design, cost-efficient, and offer low noise as well as low output voltage ripple. MP2018, which is a linear regulator, requires an input and output capacitor to operate. Their simplicity and reliability make them intuitive and simple devices for engineers.

Some of the known parameters to know when we use voltage regulators are the input voltage, output voltage and output current. There are other parameters to be considered but it depends on the application. Some of these parameters include: quiescent current, switching current, thermal resistance, and feedback voltage. We would use quiescent current when the efficiency needs to be increase during the light-load or standby modes. Feedback voltage is another parameter that needs to be considered importantly because it finds out the lowest output voltage that the voltage regulator can support.

In order to get the right results, the right voltage regulator needs to be selected for the design. So, to select the right voltage, the designer is first understood the key parameters used. The key parameters consist of Vin, Vout, I,out, etc. There are other system priorities considered to such as: performance, efficiency, cost, power good indication and/or enable control. Once these problems or requirements are defined, a parametric search table is used to find the best device to meet the requirements which will make things simpler in functioning. The parametric search table is nothing but a valuable tool for designers. This tool provides different features and packages to meet the required parameters.

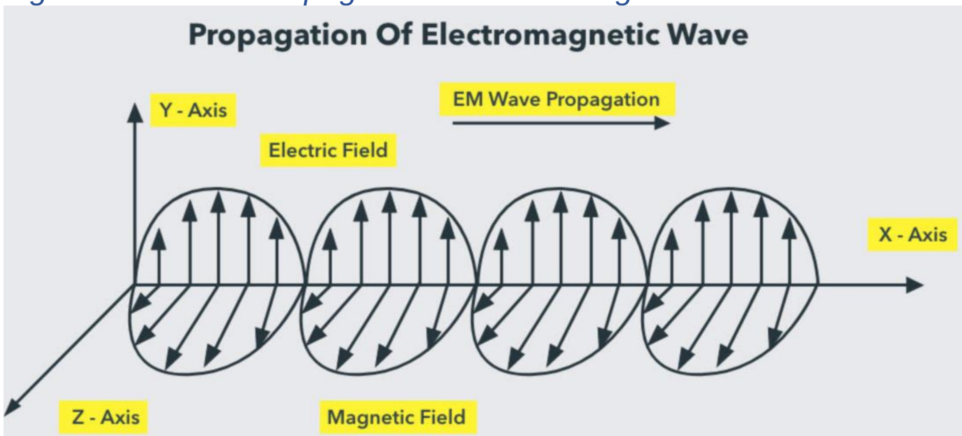
4.1.13 – Wireless Communications

As evident from recent advances in technology in our world, wireless communication has been the fastest growing and expanding technology over several networks and nodes in this world. It is one of the most vibrant technological areas in regarding the communication field. Wireless communication is a process of transmitting information from one point to another without utilizing any direct connection through wires, cables or any other physical mediums. This sort of communication is seen through the use of Bluetooth available in portable devices such as mobile phones, portable computers such as laptops, tablets, iPads, etc. Usually, information is transmitted from one transmitter to a receiver which are placed over a limited distance. With the aid of a wireless communication, the transmitted and receiver can be stored anywhere between a particular amount of distance which could range anywhere from a few meters to a thousand kilometers. In today's world, communication is key. It has always been key regardless of any century we live in. Without proper communication, no tasks can be done. So, communication is highly important to thrive in today's society regardless of the career that one works in. Due to which, wireless communication has integrated into our lives as a key component.

Any type of communication system, wired or unwired, can be guided or unguided. When wired communication is examined, the medium is a physical path such as cables, optic fiber links, axial cables, etc. These materials are used to guide the signal to spread from one point to another. This already seems like a lot of work and can lead to serious conjunctions in terms of wiring and connecting devices to function properly. So, wireless communication is the optical way to ensure proper connection between two devices. The mesh networks will use wireless connection in order to connect the circuit board which collects different data points of the particular area, which then gets stored into a database, and that will display the information onto the webapp for the users. There won't be any physical medium used. The circuit board will have its own wiring and functioning done for the different components which will be connected to a database wirelessly. The signals from one device to another are propagated through space. Space only permits for signal transmission without any guidance, the medium used in these sorts of wireless communications, or any wireless communications is called the unguided medium. But how do these signals travel through space?

Even though there are no cables or any other physical mediums to send signals, antennas are used to accomplish the transmission and reception of signals. Antennas are nothing but electrical devices that transform the signals acquired from electrical to radio in the form of Electromagnetic or EM waves and vice versa. These electromagnetic waves propagate through empty space. So, both the receiver and transmitter consists of an antenna. The electromagnetic waves are important because they transport the electromagnetic energy of the electromagnetic field through empty space. Electromagnetic waves consists of Gamma Rays (y-rays), X-rays, Visible light, ultraviolet rays, microwave rays, infrared rays, and radio waves. Electromagnetic waves are also called radio waves which are also used in wireless communication to transport the signals. These electromagnetic waves consist of both electric and magnetic fields in the form of time varying sine waves or sinusoidal waves. Both of these fields are oscillating perpendicular to each other and direction of the propagation of the electromagnetic wave is perpendicular to both of these fields. Scientifically or mathematically, an electromagnetic wave can be explained using Maxwell's equations. These equations will be extremely helpful to use the waves effectively when we connect the nodes in our mesh network to accurately display the retrieved data from the system.

Figure 4.1.13.1 – Propagation of Electromagnetic Waves



The picture displayed above, Figure 4.1.13.1 shows a better idea of the type of calculations which may be used to attribute for the electromagnetic waves to ensure better signals while connecting devices.

Wireless communication helps in mobility. Other than mobility, wireless communication helps in offering flexibility and ease of use, which makes it increasingly better day by day. Wireless communication like mobile telephony can be created anywhere and at any instance with a considerable high performance. Another important point to consider is infrastructure when it comes to wired communication systems. The installation and setup of infrastructure can be cost a lot of money and can also be very time consuming. Whereas the infrastructure for wireless communication can be installed very easily and comes with a low cost. Wireless communication can be a viable option when it emergency situations arise. The setup of wired communications can be time consuming and tough to untangle whereas there isn't much to worry about when it comes to wireless communication.

4.1.14 - GPS

The GPS or a Global Positioning System is a satellite-based navigation system consisting of at the very least 24 satellites. GPS constructs in any weather conditions, anywhere in the world and operates every second of the day without any additional setup. The satellites were placed into orbits for military use by the US gov initially but then civilians were able to use in the 1980s and beyond.

GPS satellites circle or revolve around our planet Earth twice a day in a precise orbit. Each of the satellite transmits a signal and orbital parameters that ensures that GPS devices are able to compute and decode any accurate location of the satellite orbiting. Then, the GPS receivers utilize this information to calculate the user's precise location. Eventually, the GPS receiver is able to measure the distance from one point to each satellite by the amount of time it takes to receive a transmitted signal. With more measurements from more satellites, the receiver can determine a user's position and show the results electronically to measure any running route, finding the way back to home or any adventure anywhere.

First the 2-D position is calculated (the latitude and longitude) and that tracks the movement which is a GPS receiver must be locked to a particular signal of at least 3-4 satellites. If there are 4 or more satellites then the receiver can tell one's 3-D position (latitude, longitude and altitude). Usually, a GPS receiver does track 8 or more satellites, but it all depends on the time of the day where one is located. In today's world, GPS systems are very accurate due to their multi-channel designs. The receivers are quick to lock onto satellites when it is turned on. It maintains a decent tracking lock in dense tree surroundings or in urban settings with tall buildings. What and how is the signal sent? The gps satellites transmit at least 2-3 low-power radio signals. The signals move by line of sight wherein it will pass through cloud, glasses, and plastic, however it will not go through the most solid objects, such as buildings and mountains. There are three types of information that a GPS signal gives: Pseudorandom code, Ephemeris data, almanac data. Pseudorandom code is an ID code that finds out which satellite is transmitting information. The ephemeris data is needed to determine if a satellite's position and shows important information about the health of a satellite, current data and time. There are many factors that affect the GPS signal and accuracy include: Lonosphere and troposphere delays where satellite signals slow as they pass through the atmosphere and then gps system uses a built-in model to partially correct for any errors that arise. The signal multipath is another factor that affect the GPS signal and accuracy where the GPS signal may reflect off objects like tall buildings or very large rock surfaces before it would reach the receiver which will improve and increase the travel time of the signal and may create errors. Receiving clock errors is another factor which may affect the GPS signal and accuracy where a receiver's built-in clock may have a little off timing errors because it less than usual accurate than the atomic clocks on the GPS satellites. Another factor to consider is the number of satellite visible where the more satellites a GPS receiver can perceive the better the accuracy is. When the signal gets blocked, there might be position errors or potentially no position reading at all. GPS units will usually not work underwater or underground, but there are new high-sensitivity receiver can track some signals when inside buildings. Satellite signals are more effective though when satellites are placed at wider angles relative to each other.

We intend to place a GPS system into our product as well. The nodes are essentially pinpoints on the map depicting different cities. The GPS system will be able to track all the information that is gathered from that specific node and then all the information will transfer into a data server which was discussed earlier. The data server will be made through the use of python. GPS system is important because it is reliable in terms of delivering accurate information to a specific server. So, if we are able to place a GPS then the users will have a convenient and easy interface to use it.

4.2 – Part Selection

4.2.1 – Microcontroller

We need an MCU that has a good selection of both digital and analog general purpose input output (GPIO) pins. Next, we must consider the communications standards the MCU supports. The most common of these being SPI, I2C, and Serial. We may also consider the wireless communication standard, this may be built-in or external. We may also take note of the processor memory and speed as this may be important as we temporarily store sensor data or participate in the mesh communication. Lastly, we need to consider the programming language and supporting software. The native language to each of the microcontrollers we research may allow different features. Some examples of these features are object oriented design, code portability between microcontrollers of the same family and faster prototyping in certain languages. As for the supporting software, we need to consider the ease of development. This project has a limited scope in terms of time and budget. With this, a family of MCUs with an easy to use software suite delivers a strong value proposition. Ease of use is subjective though we may apply some basic ground rules. First, the IDE should be capable of compiling and uploading the code to the device with minimal steps and do so reliably. Second, there should be support for external libraries. These libraries may allow us to interface with sensors without the need to develop our own low level code. Lastly, the development environment should be stable and simple to set up.

Our initial design concept used two separate microcontrollers. One microcontroller handled communications while the other handled the sensors. We expected this to be the best option under the assumption that each sensor would need its own set of pins to communicate with the microcontroller. Further research has revealed that many of the sensors are capable of sharing the inter integrates circuit bus. As a result, we began to search for a single microprocessor to handle all of the functions for a node.

We quickly selected the ESP32 system on a chip as the heart of our nodes. There are a few key reasons for this. First, the ESP32 integrates wireless communications into the same package as the microcontroller. This allows us simple access using a library of functions provided by the manufacturer of the ESP32. The second reason is the amount of general purpose input output pins. The ESP32 provides more pins that we expect to use by a wide enough margin to allow for potential feature creep given the time and budget. The third reason is the performance. The ESP32 offers a dual core processor with 512k bytes of memory space. These two specifications are important when we are communicating across the mesh network and gathering sensor data simultaneously. The fourth reason is the availability of both development boards and raw modules for programming. Development boards are widely available for creating our system prototypes. When it is time to deploy our system, the ESP32 module may be purchase on its own. Additionally, there are external programmers available allowing us to avoid adding the complexity and cost of on board programming to our design. The fifth and final reason we selected the ESP32 is its compatibility with the Arduino family of boards. The Arduino IDE is simple and reliable. Also, the Arduino family of boards has a wide user base with extensive documentation and libraries. All of these factors combined to alleviate some stress points during the early development and the late stage deployment of our project.

4.2.2 – Anemometer

While investigating each sensor in our design, we must consider the build versus buy framework. Our project is self-funded by our group members requiring cost to be an important consideration. We also have a finite window of time for development of the subsystems and the project as a whole. These previsions give us strong arguments for both sides of the build versus buy proposition. In the case of the anemometer, it quickly became clear that we need to investigate the probability of building the sensor ourselves. The cost for an anemometer of any applicable type starts as the most expensive single component and goes up to well above our budget from there. As a result, we will be investing the time to develop our own lower cost anemometer.

As we begin the development process, we need reflect on our research and select the most likely candidate for purposes. We may immediately eliminate one option, the hot wire anemometer. This type of anemometer has a few insurmountable challenges when considering our design requirements. The first is that the core functionality of this type of anemometer requires the heating of a wire for detection of airflow. Heating is a generally energy intensive process. Additionally, there is a requirement for a mechanical design to prevent the generated heat from propagating to other components of the device. The final issue is that the measurement range of the hot wire anemometer does not scale linearly. This means that the device may be capable of measuring very fine variation in a light breeze then become overwhelmed in a strong gale. For this reason alone, the hot wire anemometer is not a good fit for highly variable natural weather conditions.

The elimination of the hot wire anemometer leaves us with two diverging paths. The first is the tried and true mechanical design consisting of a wind vane for detecting direction and a spinning apparatus for detecting speed. This path consists of both the cup style and the windmill style as the electrical implementation of both styles is similar. The second path we may consider is the ultrasonic anemometer. This path has a few key benefits over the other. First, the mechanical design is much simpler. There are no dynamic elements or forces to consider. The mechanical design is also relatively simple and compatible with rapid iteration using 3D printing. This leads into the second benefit, the ultrasonic anemometer has no moving parts. Our system will be deployed in areas that may hinder regular preventative maintenance. Reducing the complexity and need for preventative maintenance is an important consideration. A further benefit to the ultrasonic anemometer is that a single apparatus provides both wind speed and direction measurements. This is not a common trait of anemometers, there are typically multiple sensors needed to give both measurements. Lastly, the components to construct an ultrasonic anemometer are inexpensive. Costing only a few dollars compared to tens or hundreds of dollars for an off the shelf offering. These benefits combined necessitate further investigation.

Ultrasonic Anemometer Investigation

As we begin our investigations into the specific methods for building an ultrasonic anemometer it may be beneficial to first visualize how this subsystem works.

Figure 4.2.2.1 – Ultrasonic Anemometer Functionality

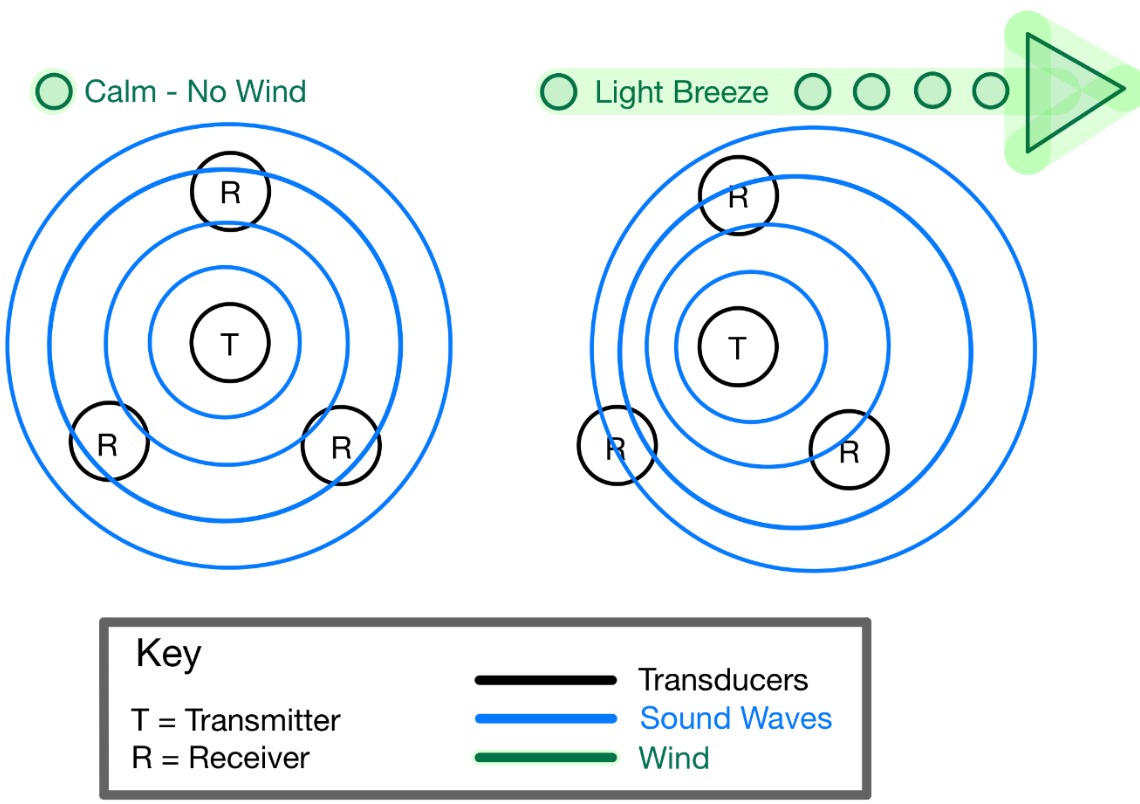
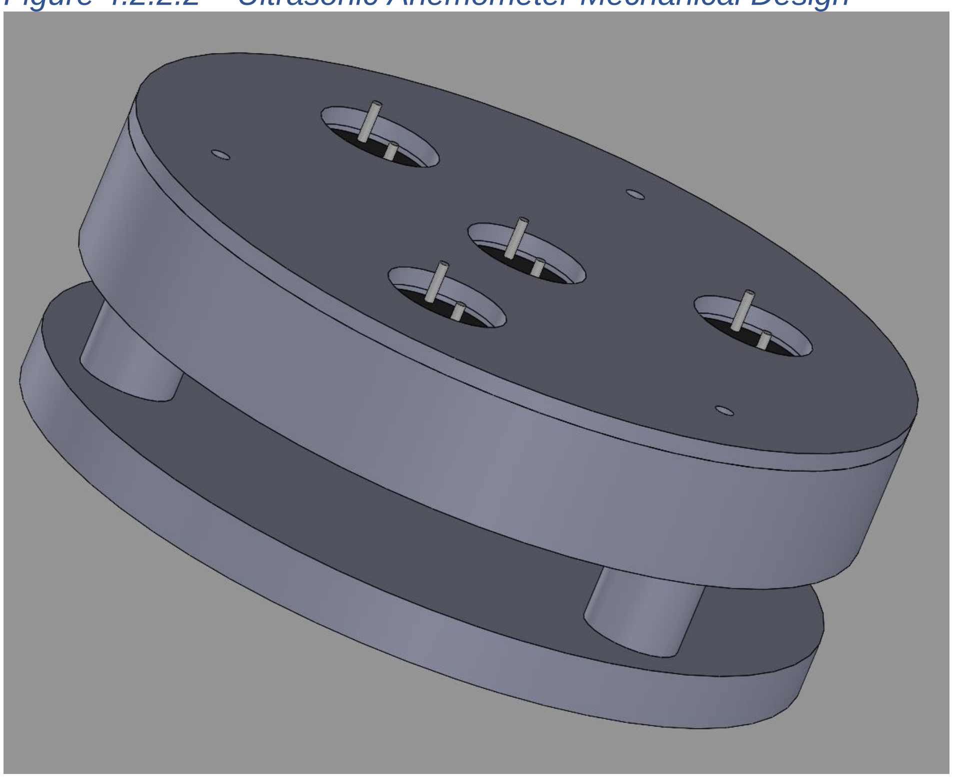


Diagram 4.2.2.1 shows how the wind passing through the anemometer affects the sound waves. The diagram depicts two different wind conditions. On the left, we see the conditions in a calm environment. There are no distortions or changes to the form of the sound waves. On the right, there is a light breeze propagating from the left of the sensor array to the right. In this condition, we may observe the sound waves become compressed when observed from the far left receiver. In contrast, the waves are expanded when observed from the far right receiver. This is a representation of the core functional mechanism of this anemometer, the Doppler effect.

Now that we have a visual idea of the effects the sensor will experience, we need to consider a means to measure these effects. As we begin to investigate the specific methods for interpreting this data, it is apparent that the available information on this subject is limited. There is a single readily available resource for a complete solution. Beyond this single source, there are a handful of research documents and available off the shelf components that may be used for reference. Keeping in mind one of our core design limitations the timeframe, we will attempt to build a proof of concept using the single source. This will supply us with an in-depth understanding of the feasibility of this anemometer design.

Figure 4.2.2.2 – Ultrasonic Anemometer Mechanical Design

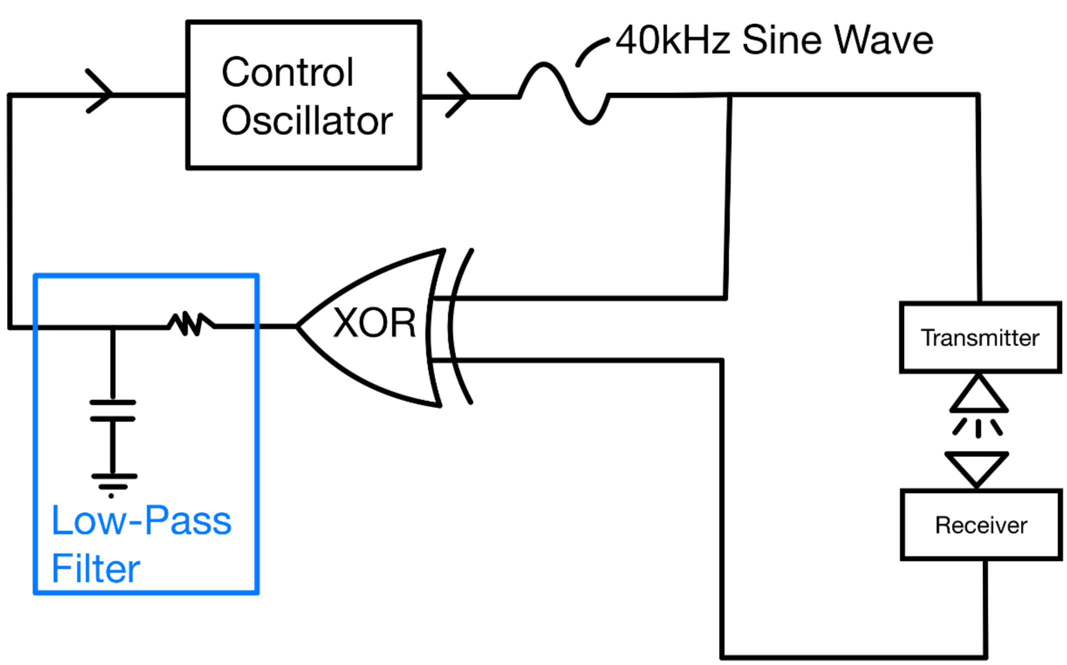


The functionality of the ultrasonic anemometer depends on the reflection of sound in a uniform manner from the transmitter to the three receivers. This will require a planar reflection surface. Additionally, the reflection surface must be the correct distance from the transducers. If the reflector is too far and the sound energy may escape the system before it is properly measured. If the reflector is too close and the sound energy may overpower the wind reducing the sensitivity of the system. In an attempt to reduce the impact of these and other mechanical factors as we build this prototype, we started by creating a computerized model of the mechanical design. A preview of this design may be seen if Figure 4.2.2.2 as a capture from within the Solidworks design program.

The first step in the mechanical design was to carefully measure and model the transducers themselves. With this model created, we may then create the arrangement of the four transducers. The transmitter is placed in the center of the design. We may then use the transmitter as the reference point for the three receivers. The center of each receiver is placed 25mm from the center of the receiver. Each receiver is placed equidistant along a circular path centered on the transmitter. Once the transducers are all in place, we may design a housing to retain them. This housing is comprised of three pieces, the body holding the transducers in the center, the reflector on the bottom and the retaining lid on the top. The assembly is designed with 3D printing in mind. This consideration maintains that we conceptualize the model to be created one layer at a time. Now that we have a mechanical design, we can change our focus to the electrical functionality.

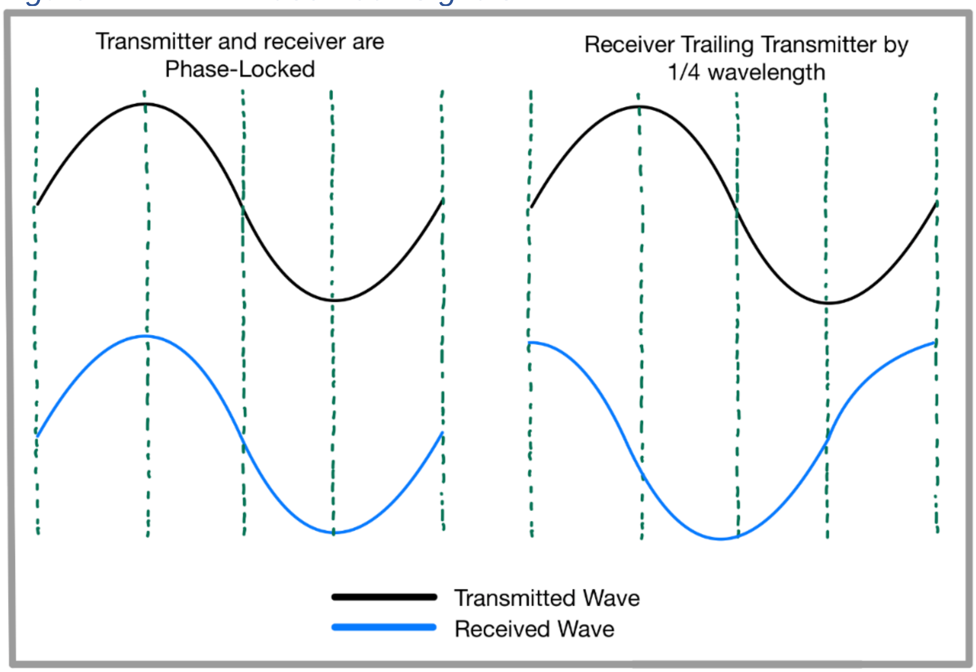
For the ultrasonic anemometer to function, there needs to be a stable emission of 40kHz from the emitter transducer. The 40kHz specification is important as that is the frequency these transducers are tuned to and where they work best. The stability is important as we will be measuring small changes as a result of wind flowing through the sensor. If the transmitter has a fluctuating signal itself, errors may be introduced into the system. There are a few methods to generate the output signal, for this prototype we are going to implement a phase-locked loop. A basic example of this loop mat be observed in Figure 4.2.2.3.

Figure 4.2.2.3 – Phase-Locked Loop



A phase-locked loop consists of three basic components. The main component is the control oscillator. This oscillator takes a direct current voltage as its input. This DC voltage is the control voltage and contributes to setting the output oscillation. The output of the oscillator is tuned by its inputs to be a set frequency. In our case, the target frequency is 40kHz. The output oscillation is used to create a feedback loop that has a high propensity to resist any deviation from the tuned frequency. The output is used to drive the transmit transducer. The output is also fed into one side of an exclusive or gate. One of the three receiver transducers is connected to the other side of the exclusive or. This creates the output for the feedback to the control oscillator.

Figure 4.2.2.4 – Phase-Lock Signals



The sine two sets of sine waves depicted in Figure 4.2.2.4 show the action of the phase-lock loop. On the left is the stable condition where the loop is locked in phase between the output and the input. In this condition, the output of the exclusive or gate is zero because both waves match each other. The right shows the transmission always stays stable at the preset frequency even if the received wave has shifted in phase or frequency. When the condition on the left happens, the output of the exclusive or gate begins to periodically transition from zero to one. This is a result of the waves being out of phase. This is the mechanism we use to adjust the control voltage to the voltage controlled oscillator. We may observe an example of the real exclusive or output in Figure 4.2.2.5. The output of the exclusive or is then passed through a low pass filer with the result being an average volage between the voltage input and reference. This average increases and decreases with the time the square wave is high and low respectively.

Figure 4.2.2.5 – Output of the Exclusive Or

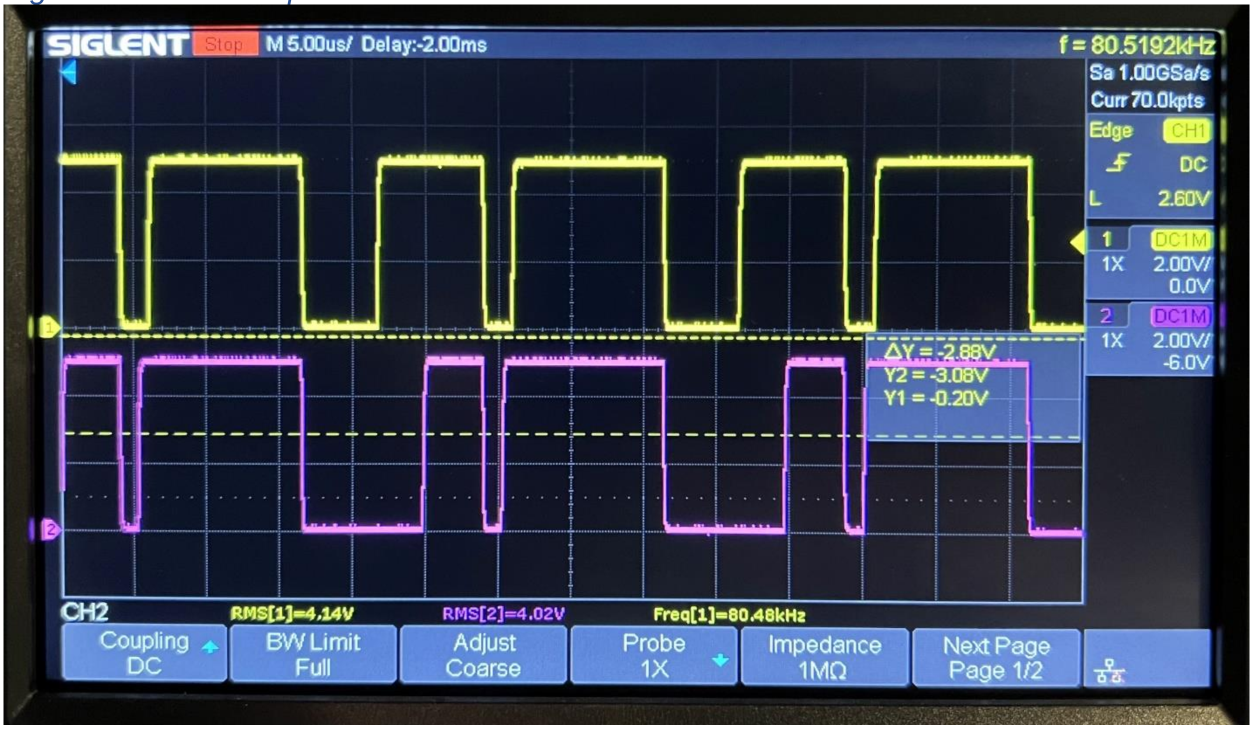
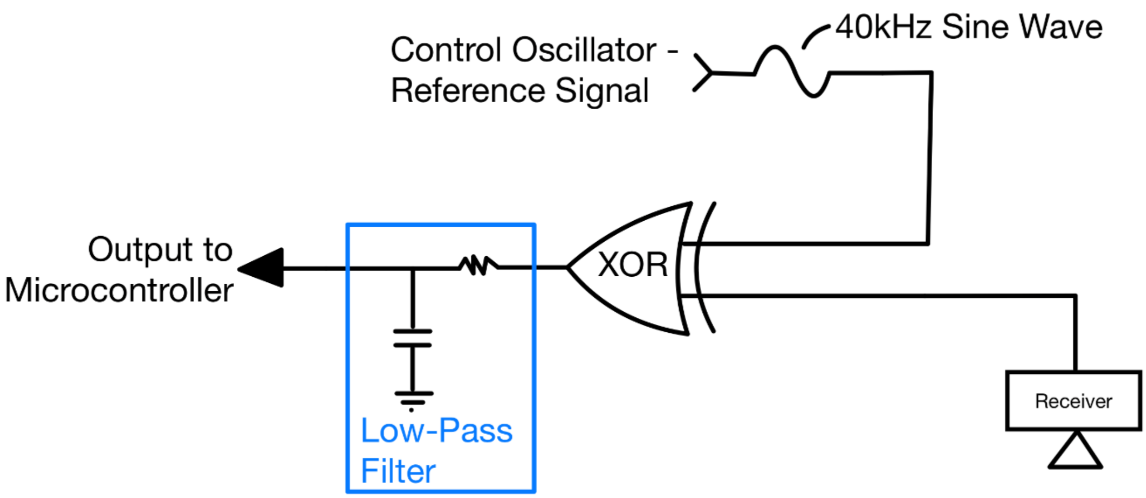


Figure 4.2.2.6 – Ultrasonic Anemometer Receiver



The phase-locked loop uses one of the three receivers as the feedback to maintain the 40kHz signal. That leaves the other two receiving transducers to use as inputs to the microcontroller. Figure 4.2.2.6 shows how each of the inputs to the microcontroller is generated. The same basic principle applies from the input to the feedback loop. The 40kHz signal becomes one side of the exclusive or gate. The other side of the exclusive or gate is the exclusive or gate is the receiver. When passed through the gate together, the resultant signal is a square wave. This wave is fed through a low pass filter. The filter removes the alternating current component and supplies a direct current voltage to the microcontroller. This direct current voltage is the average of the square wave. This voltage may be measured by the analog to digital converter present in the microcontroller. This measurement may then be used to extrapolate the wind conditions.

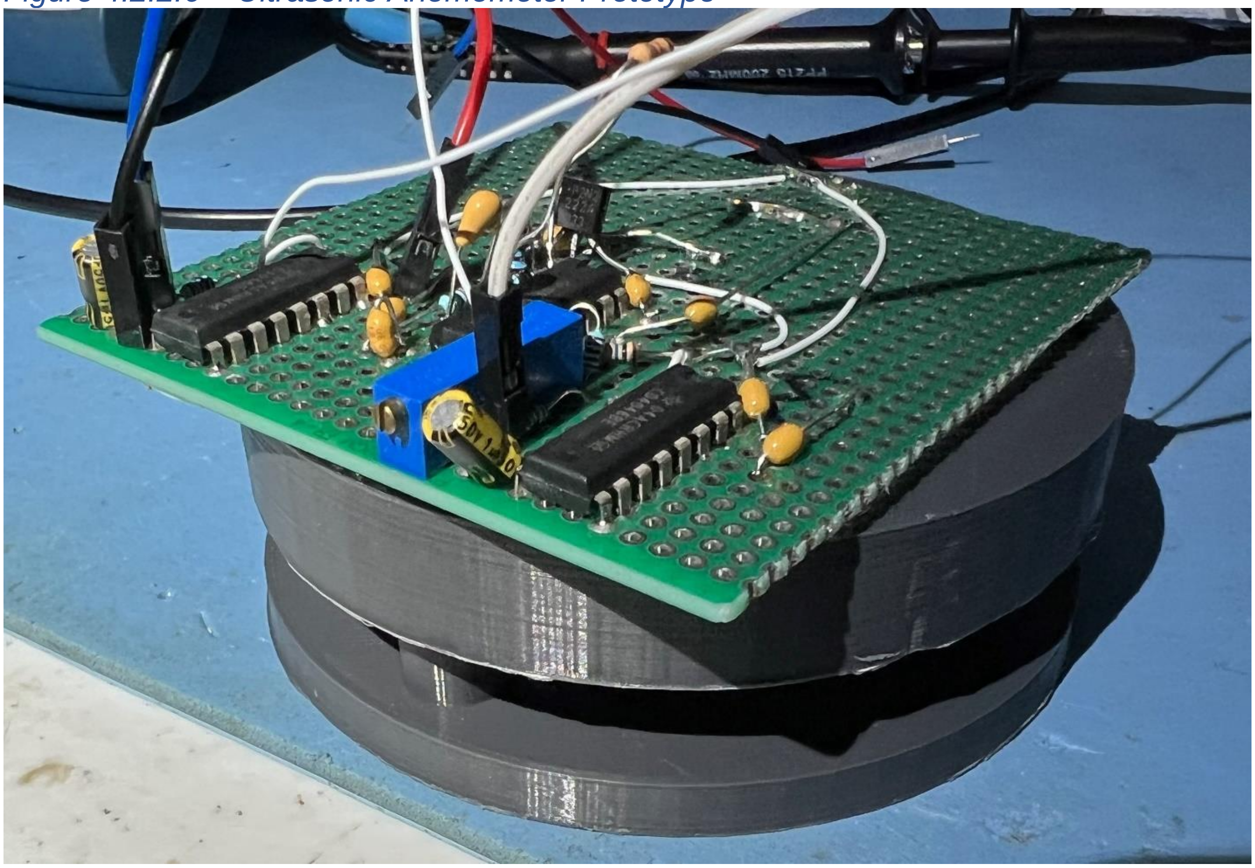


Figure 4.2.2.6 – Ultrasonic Anemometer Prototype

Before we are able to connect our prototype ultrasonic anemometer to an actual microcontroller, there are few challenges we must attempt to overcome. The first is that the reference circuit is designed to work with a five volt logic level microcontroller. The microcontroller we are using has a maximum typical input of 3.3v and is not 5v tolerant. With some reading of the datasheet for the CD4046B phase-lock loop integrated circuit, we may begin to adjust the input voltages. This is accomplished by adjusting external capacitors and resistors. These components are used to set the frequency of the phase-locked loop. This also means that the input voltage and voltage reference must remain stable during measurements. This is an important factor should we decide to use this anemometer. We adjusted the component values to reach an input voltage of 5 volts with an output of roughly 3 volts on both output lines. During the adjustment and investigations we located a second challenge, the variability of the output is well beyond what we expected. The measurements we are attempting to make in this system are microscopic. The changes in voltage we expected is in the order of tens of millivolts. Instead, we were seeing a minimum and maximum voltage readout with a delta of three quarters of a volt. This was also resulting in the maximum reading of our output exceeding the maximum of our microcontroller. These measurements were taken using the minimum and maximum function on our digital volt meter and are visible in Figure 4.2.2.7.

Figure 4.2.2.7 – DC Output Voltage of Ultrasonic Anemometer

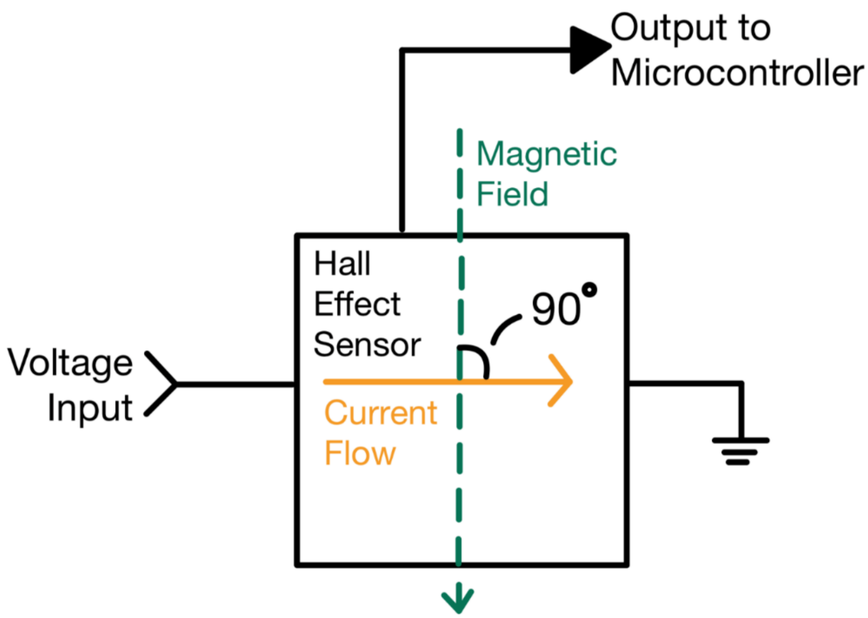
At this point, we must step back and consider the timeframe design constraints. We believe that this design has the potential to function properly with more tuning of the component values. We could also use the given values that may cut back on the variation in the signal. This introduces much more complexity to the design with the need for analog line level translation and a 7 volt supply. These issues compounded to lead us to the decision to move toward another solution for the anemometer.

Cup Anemometer and Wind Vane Investigation

The next style of anemometer we investigated is the cup type with a wind vane. We are investigating both types of wind sensor because the cup style gives us the wind speed and the wind vane gives us direction. The first sensor we will focus on is the cup style wind speed sensor.

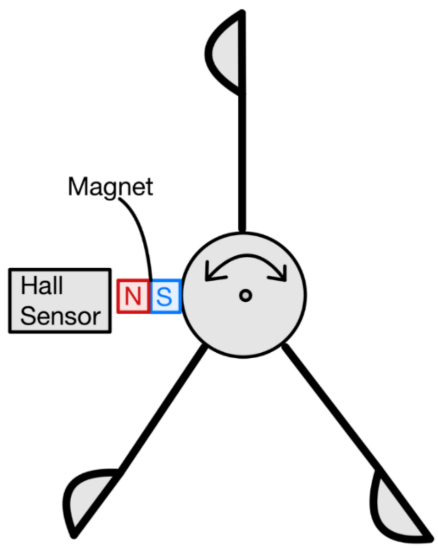
The circuitry design of the cup anemometer is much simpler than that of the ultrasonic anemometer. In this design, we are using a single sensor, the Hall effect sensor. A Hall effect sensor functions much like a switch. The Hall effect sensor resists the flow of current under nominal conditions. When a magnetic field is placed in proximity to the hall effect sensor, the switch closes and begins to allow the flow of electrons. It is important to note that the optimal positioning between the magnet and the sensor is such that the magnetic field lines pass through the Hall effect sensor at a 90 degree angle to the direction of the current flow. For a basic reference of the Hall effect sensor, see Figure 4.2.2.8.

Figure 4.2.2.8 – The Hall Effect Sensor



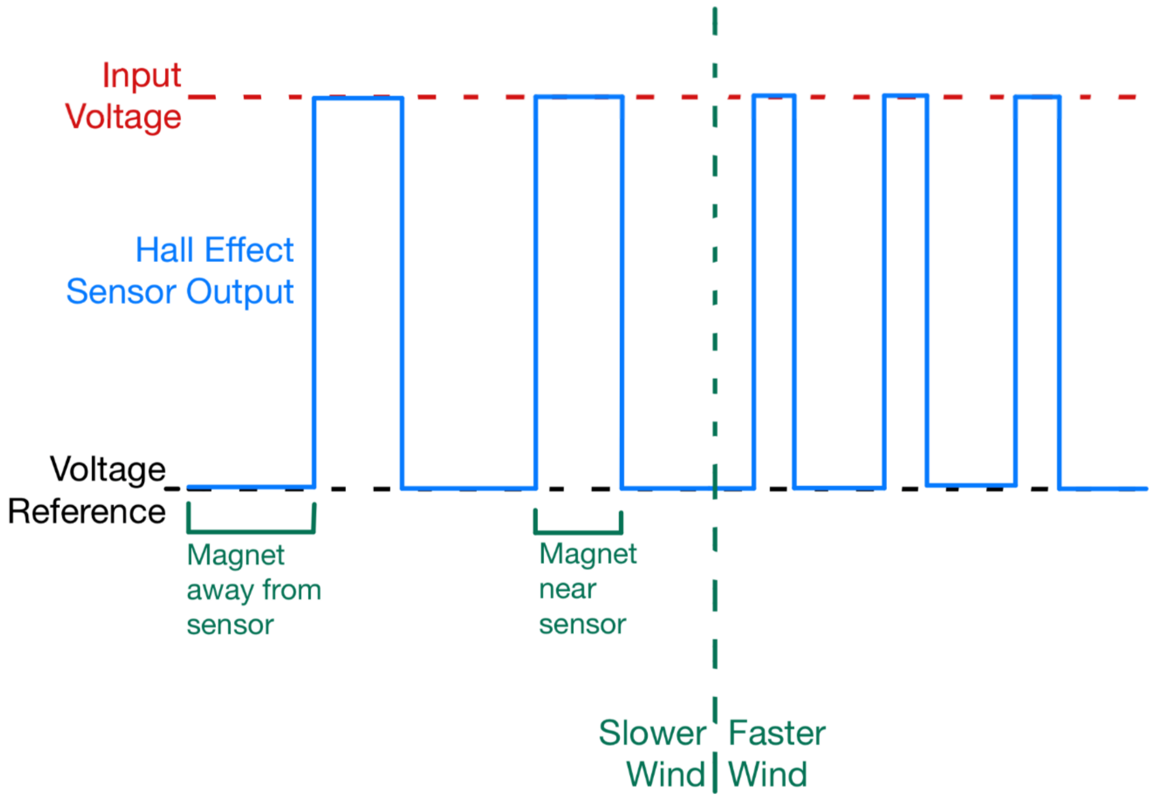
When the magnetic field activates the Hall effect sensor the output to the microcontroller becomes nearly equal to the voltage input. We can utilize this characteristic to create a signal to represent the wind speed by leveraging the mechanical design. As we discussed in the research section for anemometers, cup style anemometers rely on the ability to move freely. Figure 4.2.2.9 shows a top-down view of the basic mechanical design of the cup style anemometer. The cups are attached to a hub. The hub is then attached to a low friction bearing and allowed to spin freely. Also attached to the hub is a magnet. The Hall sensor is mounted adjacent to the hub. The Hall sensor is fixed in position. As the hub spins, the magnetic field activates the Hall sensor producing a signal output.

Figure 4.2.2.9 – Cup Anemometer (Top-Down View)



As the magnet passes the hall effect sensor, the sensor becomes active. When the magnet moves away the sensor becomes inactive. Through the use of a comparator, a filtered square waveform may be generated. The transition from active to inactive is nearly instant. The result is the spinning of the hub of the anemometer produces a square wave output from the Hall effect sensor. The pulse frequency and width may then be used to extrapolate wind speed.

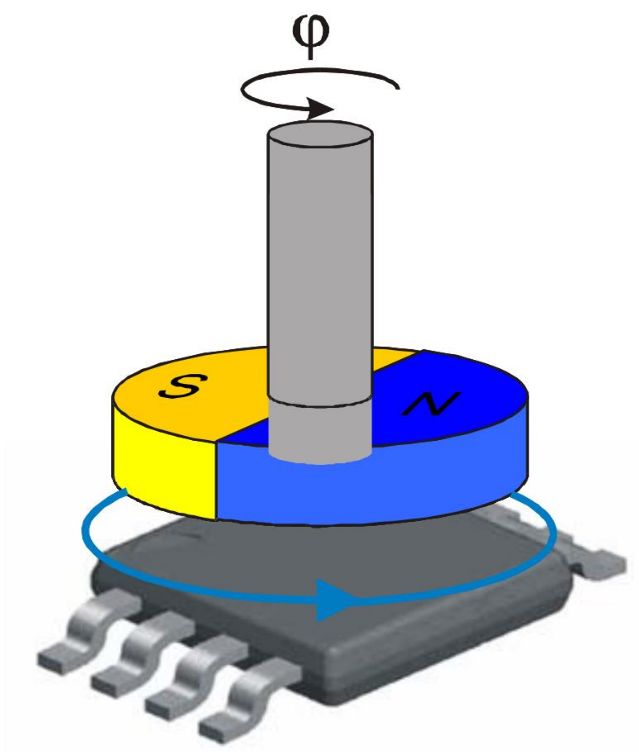
Figure 4.2.2.10 – Hall Effect Sensor Example Output



We will supply the Hall effect sensor with the high logic voltage of the microcontroller and connect both to a shared ground. The resulting signal produced by the Hall effect sensor is a square wave from logical low to logical high. This gives us the ability to interpret the signal as a digital input to the microcontroller. The microcontroller is able to determine the pulse width and frequency. This data at different known wind speeds should allow us to extrapolate the wind speed at unknown speeds. The complexity of this system is much lower than the ultrasonic anemometer. Next, we will need to conduct practical testing to ensure our theory holds true in the real world.

The other half of creating this anemometer requires a wind vane to determine direction. The wind vane will be connected to a free spinning shaft. Detecting the absolute position of a shaft proves to be challenging. The main issue is that there is no reference point to measure against after the node is power cycled. We encounter this issue if we use a Hall effect sensor similar to the cup anemometer or a traditional encoder. We are able to count the number of turns of the shaft but not able to ascertain its position in reference to the node or other objects. Our objective with the wind vane is to detect the compass azimuth direction the wind is blowing in. We considered a few methods to tackle this challenge. The first consideration was to attach a compass module to the anemometer itself. This would fix the direction of the compass to the direction of the wind vane. The issue with this is the electrical connection to the compass becomes a limiting factor. The vane needs to spin freely in any direction. This means that the connection to the compass would need to do so as well. This would require contacts and spring loaded wipers to connect from the shaft to the sensor. Which introduces two additional issues, the contacts would need to be periodically cleaned. Also, the friction force of the interface between the contacts and the wipers may reduce the accuracy of the wind vane. The next option we considered was using a continuous potentiometer. A potentiometer functions by passing a wiper over a linear resistance carbon contact. As the wiper traverses the contact, the resistance from the input to the output of the potentiometer increases or decreases. A typical potentiometer has a stop preventing the wiper from rotating 360 degrees. A continuous potentiometer removes this stop. This would allow the wind vane to spin freely. We would then pass a known voltage through the potentiometer and measure the voltage drop across it. This is done by using the analog to digital converter on the microcontroller. The functionality and implementation of this option is straightforward in terms of hardware and software. There are however two issues with this approach. The first is that there is a non-trivial amount of force needed to start and turn the potentiometer. This could reduce the accuracy of the wind vane. The second Issue is the cost. The cost of a continuous potentiometer is high enough that we begin to approach the off the shelf options for anemometers. This brings us to the final option we considered, an absolute position sensor using a magnet attached to the wind vane shaft.

Figure 4.2.2.11 – Magnetic Rotary Position Sensor [17]



We located a company named Melexis that sells a magnetic rotary position sensor. The integrated circuit chip and magnet shown in Figure 4.2.2.11 should allow us to detect the absolute position of the wind vane. According to the specification data sheet, the Melexis chip gives a voltage output to represent the position in degrees. This voltage may be read by the microcontroller.

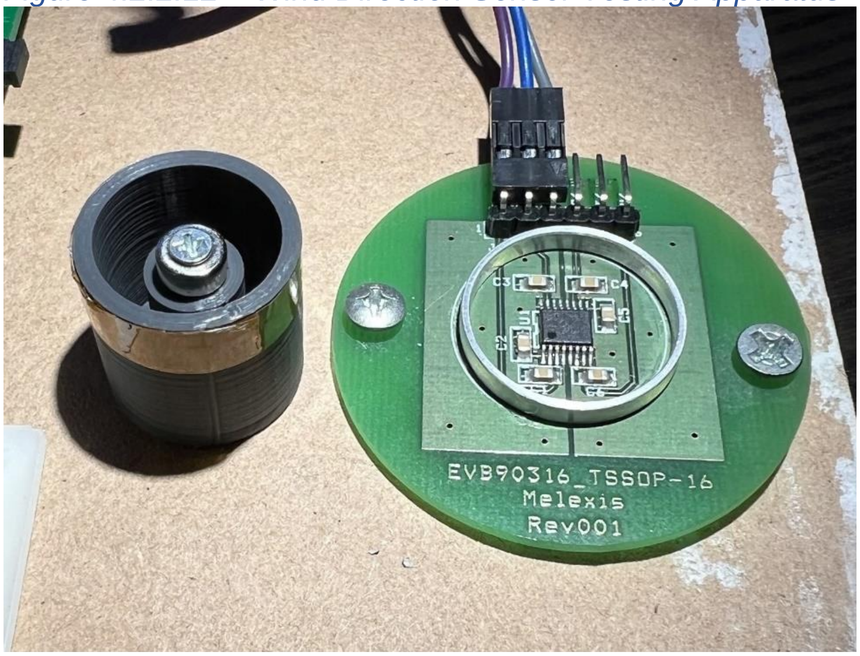
We need to develop a validation testing methodology for both the Melexis position sensor and the Hall effect speed sensor. Before we develop this methodology, it is important to consider the design requirements of the overall project. First, we are not evaluated on the mechanical design of our system or subsystems. Second, the scope of this paper covers the design concepts and does not realize the final design. With these factors in mind, we will focus on ensuring the sensors we have selected for the anemometer are capable of meeting our expectations. We will not be designing the mechanically complex subsystems to provide actual wind measurements. Alternatively, we will develop a simple, repeatable test apparatus for both wind speed and direction sensors. This sensor developed by Melexis needs to meet two main requirements to be considered functional in our system.

The first requirement is the sensor must provide the absolute shaft position of the nacelle shaft. Providing the absolute position means, the sensor does not need an external reference to give the position of the shaft. This may be tested by cycling the power of the device under two conditions. The first condition is to cycle power and leave the shaft in the same position. The passing criteria for this condition is that the sensor output is unchanged from before power is removed to after power is reapplied. The second condition is to power cycle the device and move the shaft with power removed. The passing criteria for this condition is that the sensor output will change from when the power is removed to when the power is reapplied.

The second requirement is the position is reliably and repeatably measured. The objective of this test is to ensure that the sensor output may be correlated to a human readable degree measurement. For this to be the case, the full range of the sensor output must be linear and repeatable. We will use two test conditions to satisfy this requirement. For the first condition, we will mark the shaft and the sensor body at the rollover point. The rollover point is the point where the sensor voltage output changes from the maximum value to the minimum value or vise versa. This is similar to the point on a compass where the degree heading changes from 360 degrees to zero degrees. For this condition to be satisfied, the marks must visually line up with one another after each revolution. This will be repeated and observed for three revolutions in each direction. The second condition for this requirement is for an arbitrary position selected in the sensors path of travel to be repeatably reached and measured. We will mark the arbitrary point and the shaft. Then the sensor reading at the point will be recorded. For this requirement to be satisfied, the value after the shaft has been rotated needs to be within plus or minus 40 analog to digital counts of the initially recorded reading. The number of analog to digital counts is chosen to be 1 percent of the 4096 counts representing the full range of the microcontroller.

We will conduct the tests outlined previously by creating a testing apparatus. This apparatus will consist of a knob in place of the shaft. The knob contains the diametrically magnetized magnet and is marked to indicate its position. Kapton tape is applied to the knob at the interface between the knob and the evaluation board. For our testing, we will be using an evaluation board created by Melexis. This evaluation board is assembled with a guide ring for our knob to rest in. This guide ring also acts to center the knob over the sensor itself. The evaluation board is then connected to the microcontroller for taking our test measurements. The testing apparatus may be observed in Figure 4.2.2.12. Pictured on the left is the knob, placed inverted to show the magnet housed within. Pictured on the right is the Melexis evaluation board itself.

Figure 4.2.2.12 – Wind Direction Sensor Testing Apparatus



We now have a repeatable means to test the wind direction sensor. As well as, a set of testing requirements and conditions. We may proceed with gathering the required testing data. First, we will gather all of the data needed to satisfy the first requirement in Table 4.2.2.1.

Table 4.2.2.1 – Wind Direction Sensor Requirement 1 Test Results

Condition	Position Before Power Cycle (Counts)	Position After Power Cycle (Counts)	Delta (counts)	Passing
Power Cycle – No Movement	640	640	0	PASS
Power Cycle – Arbitrary Movement	640	1298	658	PASS

Our testing shows that this sensor meets the specification of the first requirement. We maintain the positional reading even after power cycle. As well as, the position changes even in the event the shaft is moved while the power is removed.

Next, we will begin testing for the second requirement. The first condition for the second requirement states we need to arrive at the same transition point after each revolution. We will rotate the knob first in the clockwise direction three times. Each full rotation, we will line up the marks for the zero point and record the sensor reading. We will repeat this testing for the counterclockwise direction. For both direction, the test will be considered passing if the sensor reading is within 40 counts of 4096, the maximum value of the sensor. The results of this testing are in Table 4.2.2.2.

Table 4.2.2.2 – Wind Direction Sensor Requirement 2 Condition 1 Test Results

Condition	Rollover Position (Counts)	Measured Position After Full Revolution (Counts)	Delta (Counts)	Passing
CW Rotation 1	4095	4091	4	PASS
CW Rotation 2	4095	4086	9	PASS
CW Rotation 3	4095	4095	0	PASS
CCW Rotation 1	4095	4087	8	PASS
CCW Rotation 2	4095	4090	5	PASS
CCW Rotation 3	4095	4079	16	PASS

Our testing shows that the sensor meets the first condition for requirement 2. For all the gathered data, the delta between the expected and measured values was less than 1 percent of the analog to digital converter range. This held true in both the clockwise and counterclockwise directions.

For the final condition, we will begin by selecting an arbitrary point in the travel of the knob standing in for the shaft. We will record the sensor reading at this position and mark the position. This will serve as our reference starting point. From here, we will rotate the knob one full turn in the clockwise direction. We will visually line up the reference mark. We will then record the sensor output and compare the value to the initial reference reading. This will be repeated two more times in the clockwise direction. Then, we will repeat the same steps modifying the direction of rotation to be counterclockwise. Each test will be considered passing if the trial measurement is within 40 counts of the previous reading.

Table 4.2.2.3 – Wind Direction Sensor Requirement 2 Condition 1 Test Results

Condition	Reference Position (Counts)	Measured Position After Full Revolution (Counts)	Delta (Counts)	Passing
CW Rotation 1	783	781	2	PASS
CW Rotation 2	783	788	5	PASS
CW Rotation 3	783	797	14	PASS
CCW Rotation 1	783	782	1	PASS
CCW Rotation 2	783	761	22	PASS
CCW Rotation 3	783	785	2	PASS

Our test results for the final condition of the second requirement shown in Table 4.2.2.3 demonstrates that our wind direction sensor passes all requisite testing. Both for this requirement and those before it. This testing indicates that the sensor should reliably and accurately read the wind direction in an implemented design. The next steps for our design and testing will require more complex mechanical design than we have the time resources to create during our investigation stages. This testing does however validate the concept of this sensor and will allow us to proceed with the other design items to be completed in this document.

4.2.3 – Temperature, Humidity, and Barometric Sensor

Selection Methodology:

We thoroughly assessed various components and components, considering our design and cost limits, before making a final choice on what would be used in the final design. We used the research from the preceding chapters to guide our decision-making and ensure that we were properly examining all our possibilities. In addition, we weighed the benefits and drawbacks of each component in relation to our goals, objectives, and criteria. The parts that follow go into further depth on the process and general logic behind our final component and part selections. Similar Technology Information and Investigating similar products and technology that are already on the market can help us design our own technology. While no product perfectly fulfills the need for monitoring land in fire-prone regions with an emphasis on prevention, elements that have been incorporated into other items and initiatives have been discussed in length in earlier chapters. (See also Chapter 3) When choosing a temperature sensor, it is helpful to understand the different types and how they operate so that the best choice can be made when it comes time to choose a component. Thermistors, Resistance Temperature Detectors (RTD), thermocouples, and semiconductor-based integrated circuits are examples of common temperature sensors (ICs). While all these sensors are used to monitor temperature, they do so in various ways and with different materials. As a result, it is advantageous to separate these gadgets into smaller classes.

Figure 4.2.3.1 – BME280 Sensor Used for Testing

After a Lengthy consideration we finalized our decision with the BME280. The reason of the selection is because BME280 is a humidity sensor designed specifically for mobile applications and wearables where small size and low battery consumption are critical design characteristics. The unit combines high linearity and high precision sensors, making it ideal for low current consumption, long-term stability, and strong EMC resilience. The humidity sensor has a very rapid reaction time and hence meets the performance criteria for developing applications such as context awareness and high accuracy across a wide temperature range. The high accuracy capacity of the sensor was the main selling point for our team of engineers, the device integrates individual pressure, humidity, and temperature sensors with excellent linearity and precision in an 8-pin metal-lid 2.5 x 2.5 x 0.93 mm3 LGA box. The BME280 was developed with low current consumption (3.6 pA @1Hz), long term stability, and good EMC robustness in mind. The humidity sensor has a very rapid reaction time, which meets the performance criteria for new applications such as context awareness and high accuracy across a wide temperature range. The pressure sensor is an absolute barometric pressure sensor with extremely high precision and resolution while producing very little noise. The inbuilt temperature sensor has been designed with very low noise and good resolution in mind.

Parameter	Technical data
Operation range	Pressure: 300.. 1100 hPa Temperature: -40...85°C
Supply voltage VDDIO Supply voltage VDD	1.2...3.6V 1.71...3.6V
Interface	I²C and SPI
Average current consumption (typ.) (1Hz data refresh rate)	1.8 A @ 1 Hz (H, T) 2.8 A @ 1 Hz (P. T) 3.6 A @ 1 Hz (H.P.T) T . temperature
Average current consumption in sleep mode	0.1
Humidity sensor Response time (T63%) Accuracy tolerance Hysteresis	1 S +3% relative humidity <2% relative humidity
Pressure sensor RMS Noise Sensitivity Error	0.2Pa (equiv. to 1.7cm) +0 25% (equiv. to 1m at 400m height change)
Temperature coefficient offset	+1 5Pa/K (equiv. to +12.6cm at 1°C temperature change)
RoHS compliant, halogen-free, MSL1	
Package dimensions	8-Pin LGA with metal

and high precision sensors, making it ideal for low current consumption, long-term stability, and strong EMC resilience. The humidity sensor has a very rapid reaction time and hence meets the performance criteria for developing applications such as context awareness and high accuracy across a wide temperature range. The high accuracy capacity of the sensor was the main selling point for our team of engineers, the device integrates individual pressure, humidity, and temperature sensors with excellent linearity and precision in an 8-pin metal-lid 2.5 x 2.5 x 0.93 mm3 LGA box. The BME280 was developed with low current consumption (3.6 pA @1Hz), long term stability, and good EMC robustness in mind. The humidity sensor has a very rapid reaction time, which meets the performance criteria for new applications such as context awareness and high accuracy across a wide temperature range. The pressure sensor is an absolute barometric pressure sensor with extremely high precision and resolution while producing very little noise. The inbuilt temperature sensor has been designed with very low noise and good resolution in mind.

BME280 Sensor Operation

The I2C and SPI (3-wire/4-wire) digital serial interfaces are supported by the BME280. The sensor has three power modes: sleep mode, normal mode, and forced mode. In normal mode, the sensor alternates between measurements and standby periods. This mode is recommended when employing the BME280's built-in IIR filter to filter short-term disturbances (e.g., blowing into the sensor). In forced mode, the sensor provides a single measurement on demand and then returns to sleep state. This mode is appropriate for applications that require a low sample rate or host-based synchronization. A number of oversampling modes, filter modes, and data rates may be set to customize data rate, noise, reaction time, and current consumption to the demands of the user. The sensor, when combined with multiple short-term disturbance filter settings, may be tuned in a very flexible manner to respond to application and power management needs. Default settings optimized for numerous sample use-cases, such as weather monitoring, elevator/staircase identification, drop detection, or interior navigation, are supplied to facilitate the design-in phase.

4.2.4 – Air Quality

Air quality is an important factor in the health of an area and those residing within that area. For our application, we are taking some inspiration from the air quality index or AQI. The air quality index is a complex measure of the gasses and particles in the air over time. This index is typically used to indicate the pollution level of an urban area. Our application is focusing on natural areas that may be prone to forest fires. For this, we will be focusing on the air quality in the event there is an active forest fire in or near the area. Our research shows us that there are a number of gasses from carbon dioxide to methane. The largest contributor to the emissions is carbon dioxide. The carbon dioxide produced by forest fires does generally dissipate relatively quickly though does cause measurable increases. Another factor in the air quality changes during a forest fire is the presence of volatile organic compounds. These compounds are chemical compounds such as, aldehydes, alkyl benzenes and other hydrocarbons. Volatile organic compounds make up part of the smell of smoke. Volatile organic compounds also contribute part of the smell of smoke. The typical concentration of these compounds in the atmosphere is neat zero. For reference, the measure for volatile organic compounds is parts per billion. Our research also revealed there are many types of air quality sensor. There are gas sensors each of which measures a different gas. There are particulate sensors that measure the microscopic particulate matter that may be harmful to humans. There are also sensors that measure the volatile organic compounds. We have elected to measure a subset of the changes to the air. We will be measuring carbon dioxide and total volatile organic compounds. This gives our system a good balance of measurements considering the exact combination of elements in the air during a fire. We are also not attempting to detect fire using this sensor. This reduces the need for a wide spectrum of accurate air metrics. The CCS811 sensor module is expected to fit our requirements.

We are using the measurement of carbon dioxide and total volatile organic compounds to give a general overview of the air quality of an area when there are fires nearby. With this in mind, we will develop our testing methodology for the subsystem to focus on stability and the ability to measure deltas. We may start by taking a measurement of the known atmospheric baselines for both measurements. The average concentration of carbon dioxide in the atmosphere is 400 parts per million. The concentration of total volatile organic compounds is near zero parts per billion. We may expect our sensor to read zero parts per billion total volatile organic compounds when placed in a well-ventilated space. The first requirement for our testing is that when placed outdoors the sensor reads no more than 10 parts per billion total volatile organic compounds and no more than 420 parts per million carbon dioxides. With the first requirement, we establish the sensor can accurately measure our expected values. From here, we may test additional values. These additional values will be less a test for accuracy and more a test for precision. The second requirement is that the sensor will read the value and output a stable measurement for 5 measurement cycles. Stability is defined as a change of no more than 10 parts for either measurement from cycle to cycle. One cycle is one second. The second requirement will be tested in two ranges. The first range is an occupied room of a house. The expected concentration of carbon dioxide is between 400 parts per million and 1000 parts per million. As for volatile organic compounds, there are many contributing factors to the indoor concentration. For our purposes, we will look for two conditions to represent a passing test. The first condition is an increase from outdoor to indoor concentrations of volatile organic compounds. The second is that the concentration of total volatile organic compounds is no more than 500 parts per billion [38]. The second condition is intended to test an extreme condition. For this condition, we will be placing the sensor inside a candle that has been recently extinguished. The passing criteria for this test is that both measurement values read in the multiple thousands of parts. We recognize that this condition is not well defined or accurate. In later testing, we may better characterize the subsystem. The final requirement is that the sensor recover to indoor levels once removed from the extreme environment. The testing apparatus for the extreme condition may be observed in Figure 4.2.4.1.

Figure 4.2.4.1 – Air Quality Sensor Inside Candle

Table 4.2.4.1 – Air Quality Sensor

Air Quality Sensor Test Results					
Test Condition	Expeted Max CO2 Concentration (PPM)	Actual CO2 Concentration (PPM)	Expected Max TVOC Concentration (PPB)	Actual TVOC Concentration (PPB)	Passing
Outdoors	400	400	0	0	PASS
Indoors	400 - 1000	949	500	83	PASS
Candle	Greater than 1000	8224	Greater than 500	14011	PASS

The results of our testing in Table 4.2.4.1 reflect our expectations. All testing criteria were met. During the course of our testing, we did make an additional observation. The behavior when the sensor is moved from the extreme environment back to the indoor environment was unexpected. Both measurements increased and decreased quickly and stabilized as expected. The unexpected behavior occurred when the concentration was abruptly decreased. Both measurements decreased past the indoor measurement to the baseline outdoor measurement. We would expect the measurements to return to near the indoor readings noted just prior to the extreme measurements. The sensor took approximately 15 minutes to return to the indoor measurements for both values. After referencing the datasheet for the ccs811 sensor [39] we believe we may be within the burn in period for the sensor. As a result, the measurements may not react properly when exposed to large changes in the environment. We will continue to monitor this as we begin our full system level testing.

4.2.5 – Camera

We will begin the selection process for the camera module by considering its function with our system. We are using the camera to record a history of the fuel load in the area around each node. Fuel load refers to the amount of combustible material in a given area. Images are one means forestry management services may use to monitor this factor. The image needs to effectively convey the environment. To do this, the image does not need to be high quality. This is an important benefit when considering the limitations of our design. We are using a microcontroller to manage each node. Microcontrollers are inherently low computing power devices. The ESP32 for example has a 520 kilobyte memory size. For comparison, a typical smartphone image is between 1 and 2 megabytes. Additionally, there is some memory requirement for the program and the mesh network running alongside the image processing. With these factors in mind, we are searching for a low cost and low image quality camera.

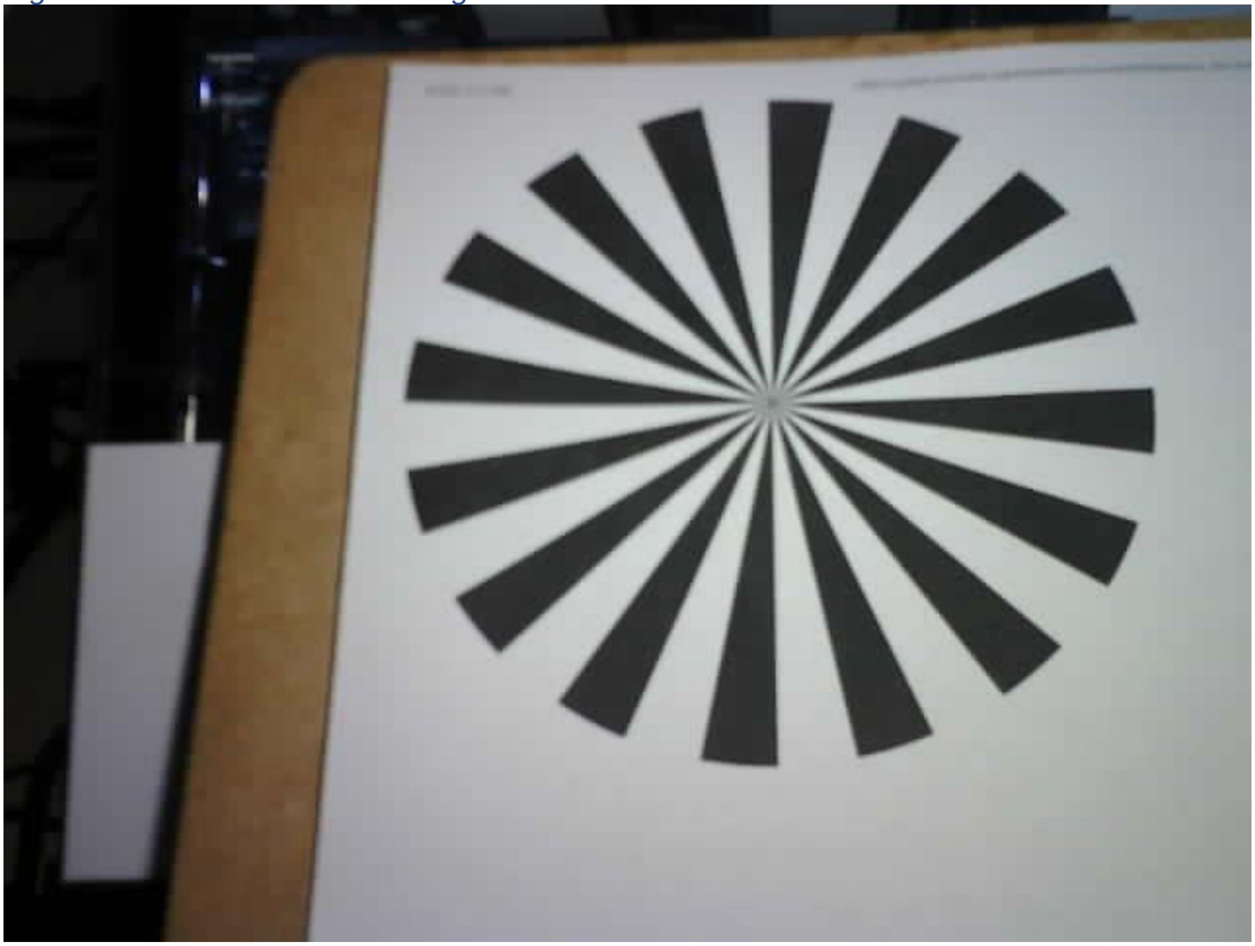
The first camera module we selected is the OV7670. This camera is capable of a resolution of 640x480 also known as VGA. We initially selected this module because the cost is low at around ten dollars each and the VGA resolution was expected to be sufficient. As we began the testing process with this module, we ran into a few issues that guided our future selections. The first issue we encountered is the lack of support documentation. There are not many existing code libraries that met our somewhat narrow field of requirements. The ESP32 is the microprocessor we have chosen. This board does run software made for the Arduino platform. The issue we encountered is that each microcontroller has a lower level architecture that is exposed to the Arduino software through a driver layer. The libraries that are available for the OV7670 are not compatible with this driver layer. The result is a compilation time error. There are a number of approaches to troubleshooting this issue. The first path we investigated was to simply find alternative libraries for the OV7670. This proved unsuccessful as we encountered the same or similar issues. The next path we considered was to modify the existing library code to run on architecture of the ESP32. This was also unsuccessful. The library files had errors in many different files. Fixing these errors would require a significant time investment into understanding both the ESP32 architecture and the library structure. The final option we explored was creating our own library for the camera module. The basic functionality of the camera is straightforward with an I2C control interface and an 8-bit digital output for pixel data. The first issue with this option is the lack of documentation for the camera module itself. The second issue is the image processing and movement of pixel data. All of the existing library functions we explored has extensive handling and processing of the pixel data. This combined together to rule this option out again for a time investment beyond the constraints of our project. We did try one additional camera module of a similar specification and interface. We were able to compile a library for the ESP32 for this new module. The issue is this library would require the ESP32 to be connected to an external non-volatile storage media. The added complexity of adding this storage would not outweigh the cost of stepping up to the next camera option we tried.

The third camera module we tested is notably different than the previous two. In contrast, this new module uses a serial peripheral interface (SPI) connection to transfer pixel data. This module also carries the burden of capturing and preprocessing the pixel data. The cost for this additional functionality is roughly double the previous two options. The new module is the ArduCam mini 2MP plus. This module uses the OV2640 camera assembly. Moving the pixel data and preprocessing to this external module affords us a few additional features beyond our initial design criteria. The first is the ability to capture higher quality photos. The pixel data is buffered in the module and may be read, sent and discarded before repeating the process. We may not implement this feature due to other limitations of the system. The next benefit is the reduction in complexity from a hardware design perspective. The number of pins is reduced from 18 on the other options to just 8 on the ArduCam module. The third benefit is the company itself supplies their own library designed to be portable across most boards running on the Arduino platform. This library has some minor issues though the ability to compile and run it allows us to begin working on solutions rather than fighting our tools.

The manufacturer of this module supplies a set of example software for testing the configuration of the hardware. This software consists of two parts. The first part is a Windows 10 application for controlling the camera and adjusting its settings. The second part is the Arduino code to be loaded onto the ESP32 that receives the controls from the computer. Thought the Arduino code is open source, the control software is closed source. Also, the documentation for the open source Arduino code does not specify how to adapt the camera for our use case. We are attempting to take a single low quality photo and send the data over serial for testing purposes. To accomplish this goal, we need to do some reverse engineering to understand the software on both sides. First, we looked into the Arduino code to find the available commands. Each command is run by sending a single byte over serial from the computer to the ESP32. The issue is the commands seemed to mix decimal and hexadecimal. Additionally, the built in serial interface for the Arduino IDE only allows sending ASCII characters. To get around this limitation, we designed our own control software in python. We may now send the exact format of bytes we and receive image data. This presented the next issue for us to overcome, the image data did not actually contain a decipherable image. After some troubleshooting, we decided to attempt to intercept the commands from the closed source drive software to understand the command structure for capturing an image. The first method we attempted is to create a man in the middle attack for the serial com port. We created a python script that would create a virtual com port for the closed source control software to connect to. The script would then print the commands to the terminal and pass the commands to the physical com port of the Arduino. In practice, this method resulted in a breakdown of the serial com port protocol and prevented any communication. In the process we concluded we only needed the commands sent by the control software. This simplifies the problem because the Arduino is already receiving these commands. To retrieve them, we added a block of code to the Arduino side to save the serial commands it receives and print them out to the serial monitor when prompted. Now that we have the byte commands, we may use our python control software to replicate them. This proves to be the key, the next block of data we receive in the python driver contains the header and footer of a jpg image file. We may then extract the bytes between these begin and end points and write the bytes to a file. Now that we have gained the ability to control the example software, we may begin the process of breaking down the command structure. There are three commands needed to capture an image. The first command sets the type of camera module and image resolution. The second command instructs the camera mode to single capture. The final command instructs the camera module to capture and send the data over serial. Using these commands as a starting point, we will be able to rewrite the example code to be purpose built for our application and increase efficiency. This basic command structure is sufficient to complete our testing for part selection.

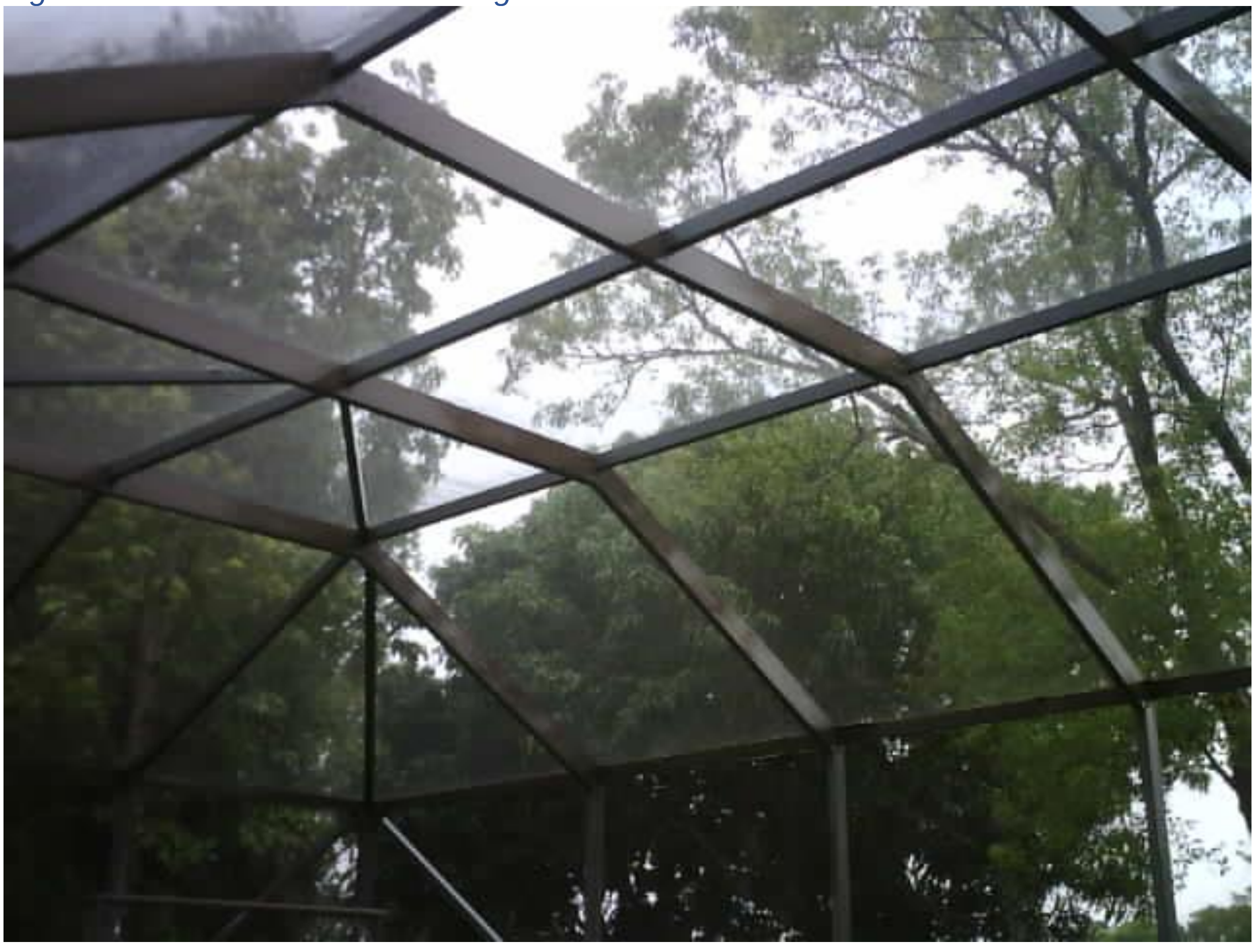
We will be conducting the majority of the testing for the camera module at the system level. The movement of pixel data through the node and over the mesh network presents challenge separate from the functionality of the camera module itself. The testing methodology for the subsystem level camera module will be to capture two images. There will be two requirements for this test to be considered passing. The first requirement is the python control software is capable of both commanding the camera to take a photo and saving the capture data to a jpg file. The second requirement is both photos be relatively focused to the eye. We will leave this requirement up to the eye of the test agent.

Figure 4.2.5.1 – Close Test Image



The image in Figure 4.2.5.1 satisfies both requirements for a successful test. This image was captured and saved using the python command script. The image subject is spoke target used for testing the optics and resolution of cameras. This gives us a clear metric for grading our image. Considering the resolution of the image, the capture may be considered passing. We may also capture an additional image to test the focus at longer ranges.

Figure 4.2.5.2 – Distance Test Image



The test at distance in Figure 4.2.5.2 shows a much clearer passing result for the focus test. We may clearly observe the definition of the edges of the trees. As well as the leaves on the branches. We may also observe some shortcomings of the camera module when it comes to dynamic range. The dynamic range is the ability to accurately represent both the highlights of the sky and shadows of the underside of the trees. This is an area we will further investigate at the system level. For now, we may conclude that this camera module is reasonably capable of filling its utilitarian purpose for our project.

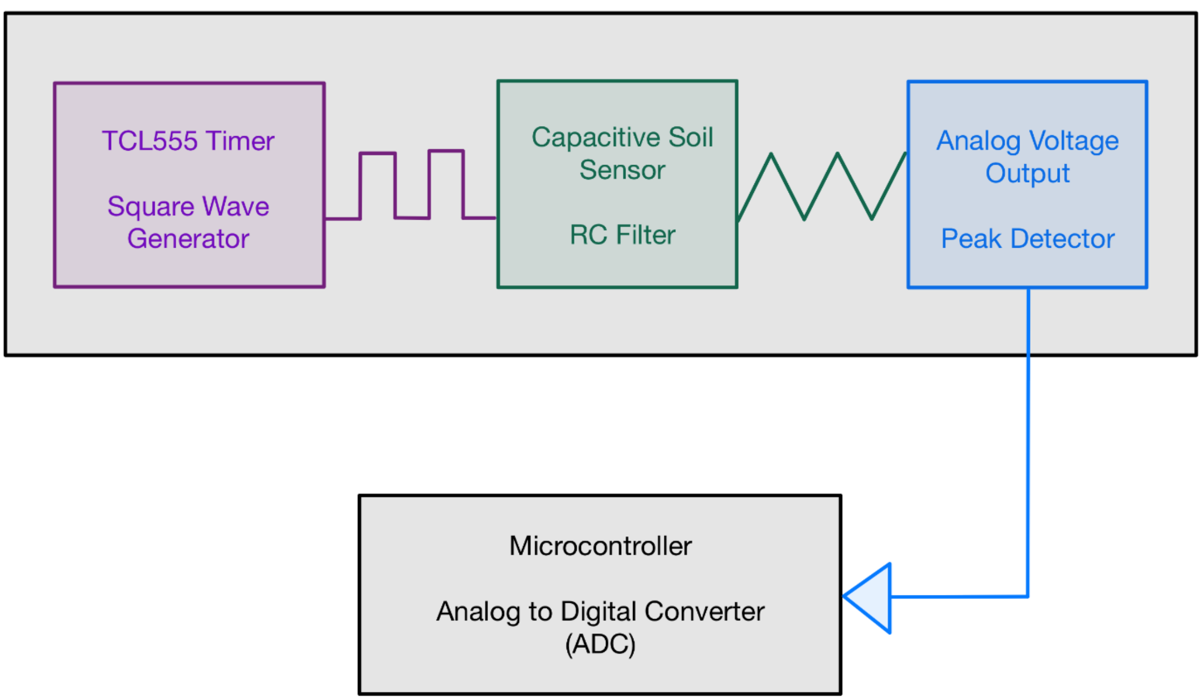
4.2.6 – Soil Moisture Sensor

We will begin our selection of the soil moisture sensor by considering the application and design requirements for this sensor. We will be using this sensor to monitor the relative water content of the topsoil. The system may be expected to measure this data point as many times as the end user specifies. This is likely to be a few times per hour. A core design consideration of our product is reducing the preventative maintenance of the system. With this, we need to consider the correlation between the number of measurements and the useful lifetime of the sensor.

We found that there are two main types of soil moisture sensor. The first type is a resistive soil moisture sensor. The basic operation of this type of sensor is relatively straightforward. The resistive soil moisture sensor has two probes separated by a fixed distance. These probes are inserted into the soil. The sensor then passes a known voltage across the probes. By measuring the voltage drop across the probes, the water content of the medium may be estimated. This mode of operation causes an issue with prolonged use, corrosion of the probes. Each time the sensor is used, the voltage passing though the soil causes electrolysis to take place. The process of electrolysis accelerates the ever continuing corrosion of the sensor. This means that the sensor must only be used when necessary. This will lead to increased preventative maintenance and repair cost even if the system design limits the number of readings of the soil moisture sensor. Fortunately, the second type of soil moisture sensor solves these issues.

The second type is the capacitive soil moisture sensor. This sensor is immediately the more interesting choice for our project. The reasoning is twofold, no exposed contacts and there is almost no cost difference between the resistive and capacitive types. Having no exposed contacts, the preventative maintenance and ongoing costs for the system may be reduced. Additionally, the cost difference is on the order of pennies. With these factors in mind, we will move forward with testing the capacitive soil sensor and validating it for use in our system.

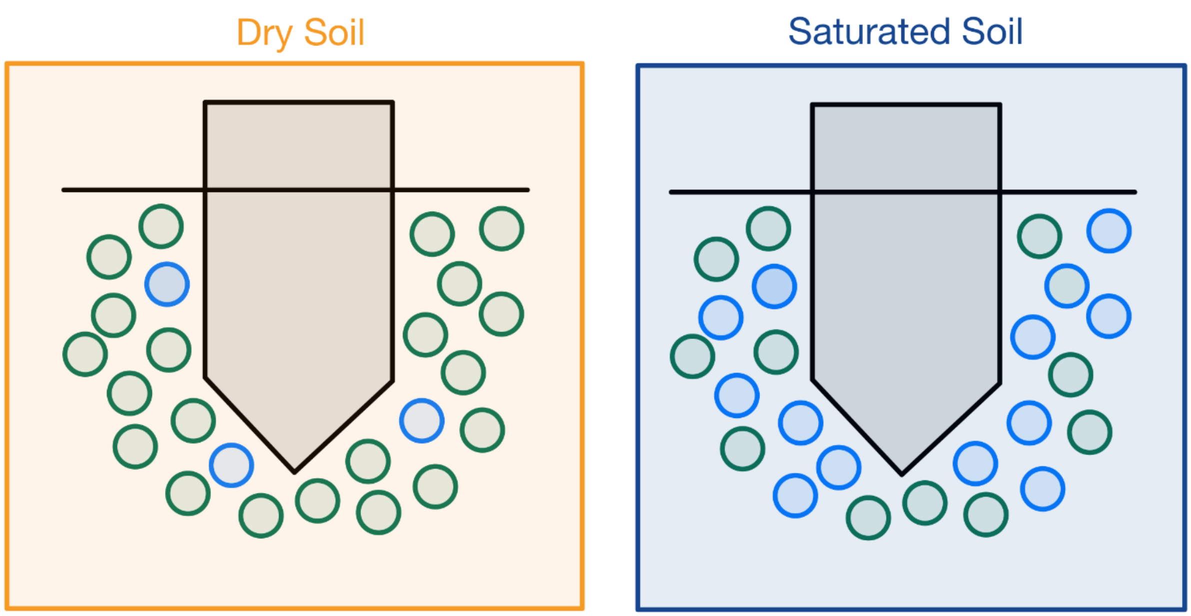
Figure 4.2.6.1 – Capacitive Soil Moisture Sensor Hardware Block Diagram



Before we develop our testing methodology, we may first gain a deeper understanding of the inner workings of the capacitive soil sensor. In Figure 4.2.6.1, we illustrate the basic hardware responsible for creating and reading the sensor value. The first thing to understand is the method to which the microcontroller communicates with the soil sensor.

The communication is one way and in the form of an analog voltage signal. This signal is produced by the soil sensor and read by the analog to digital converter on the microcontroller. There are three subcircuits in the capacitive soil sensor that produce this analog voltage signal. The first subcircuit generates a square wave signal. This is done using a ubiquitous timer integrated circuit the TCL555. The frequency and other characteristics of the square wave are set by a set of external resistors and capacitors. The values of which are responsible for determining the actual value of these characteristics. This square wave is then passed through the next component of the soil moisture sensor, the soil probe. The soil probe is the actual sensing surface of this subsystem. The probe itself is two traces within the printed circuit board that are not directly connected. These traces are placed adjacent to one another to create a capacitive effect. The electrolytic medium in this case is the soil or any other material the sensor is placed into. The capacitive probe acts as the capacitor in an RC filter. The output of this filter is a triangular saw tooth waveform that is then passed into the final subcircuit of the soil moisture sensor, the analog voltage output. The analog voltage output is generated by a peak detector circuit. A peak detector uses a capacitor, diode and a sufficiently large resistor. The diode prevents current from flowing in the reverse direction back through the capacitive probe. The resistor and capacitor are placed in parallel. The capacitor is charged and discharged according to the frequency of the triangular wave input. The voltage of the capacitor becomes the output of the sensor. As the dielectric medium encompassing the capacitive probe increases in conductivity, the output of the sensor will reduce in voltage. This reduction in output voltage is then measured by our microcontroller.

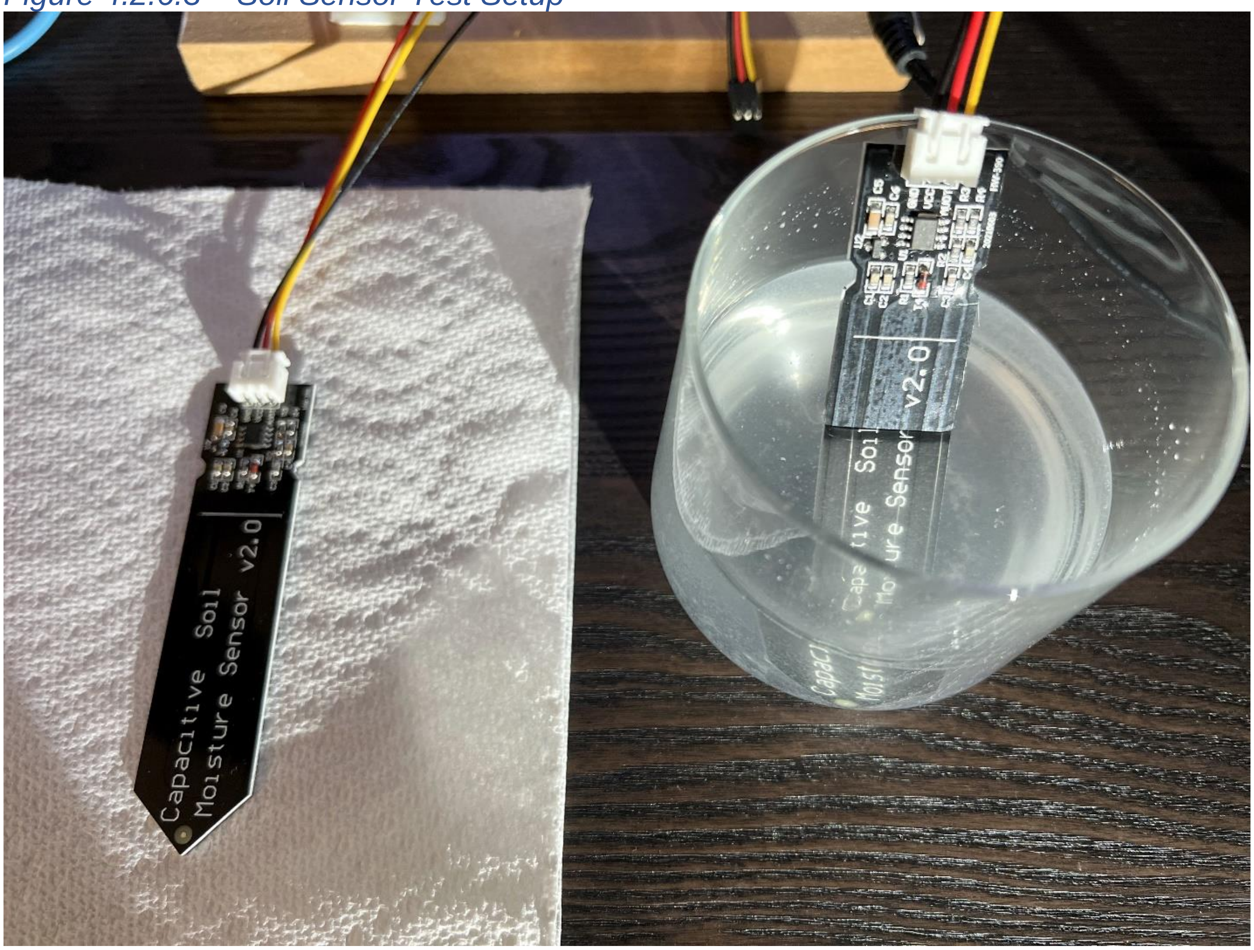
Figure 4.2.6.2 – Soil Sensor in Dry and Saturated Soils



Now we have an understanding of how the soil moisture sensor functions, we may consider the environment we are subjecting the sensor to. We will be measuring he concentration of water in the soil. It is important to note that, water on its own is not conductive. In nature, water moves through the environment in the water cycle. Along the way, particles dissolve in the water. These particles produce the ions that are the medium of conductivity within water. As a result, when the soil is saturated with ion-rich water, the conductivity of the soil increases. An illustration of the physical changes in the saturated soil may be observed in Figure 4.2.6.2.

With an understanding of the physical changes in our environment and how they correlate to the electrical properties of the medium, we may develop a testing methodology. Our methodology will focus on the extremes of possible environmental conditions. We will focus on extremes because this will demonstrate that the sensor has the necessary range. As well as, the ability to quickly react to changing conditions. The second point becomes less important in the real world as changes in soil conditions happen over long periods of time. We are however interested in the ability to adapt and the rapidness to which that adaptation happens is helpful in the testing environment. Additionally, we are building an off the grid network of sensing nodes with limited power constraints. This means, we will also be measuring the continuous current draw of the sensor.

Figure 4.2.6.3 – Soil Sensor Test Setup



Our testing methodology will consist of three cycles from one extreme to another. The first extreme is placing the dry sensor on a paper towel in open air. This represents extremely dry soil. The second extreme is to place the sensor in saltwater. This saltwater solution will be 3/4 cup of water to 1 teaspoon of table salt. The saltwater will represent fully saturated soil. This condition may not occur naturally but does demonstrate the sensors functional range. The sensor will be measured dry then submerged in the saltwater solution. The sensor will be dried thoroughly when removed from the solution. The submersion – drying cycle will be repeated three times for each sensor. We will repeat this testing on two sensors to verify repeatability from one sensor to another. The basic testing setup is shown in Figure 4.2.6.3.

Table 4.2.6.1 – Soil Sensor 1 Test Results

Soil Sensor 1 Test Results			
Continuous Current Draw (mA)		5.64	
Cycle Number	Dry Output (Counts)	Submerged Output (Counts)	Delta (Counts)
1	2870	953	1917
2	2909	961	1948
3	2903	946	1957

Table 4.2.6.2 – Soil Sensor 2 Test Results

Soil Sensor 2 Test Results			
Continuous Current Draw (mA)		5.66	
Cycle Number	Dry Output (Counts)	Submerged Output (Counts)	Delta (Counts)
1	2863	942	1921
2	2858	954	1904
3	2857	945	1912

The results of our testing are displayed in Table 4.2.6.1 and Table 4.2.6.2. We may draw three main conclusions from this result data. First, the sensors have a wide range of counts. Across all 6 trials and 2 sensors, the delta from the low to high measurement is greater than 1900 counts. This is roughly half of the full 4096 counts the microcontroller is capable of measuring. This is a high enough delta to measure the change in soil moisture. The second observation we may make is the measurements are precise. For all trials, the sensors recovered to their dry measurement after being submerged. This is true of the submerged measurements as well. This gives us confidence in the measurements to be stable when the environment is stable. The third observations is, the current draw is consistent between the two sensors tested. The sample size is small though the measurement was within 2 tenths of a milliamp indicating this is likely accurate.

Considering we are relying on solar power and batteries to power each node, we may consider power waste mitigations in the future.

4.2.7 – Power System

Several factors must be considered when determining which photovoltaic module or modules will be utilized for fire protection subsystem project. The panels used should be able to provide a considerable amount of the electrical needs. However, the project budget is critical, and committing too much of it to solar panels for energy generation may jeopardize functioning in other aspects of the project.

4.2.7.1 – Solar Panel Testing Setup

The engineering team anticipates using an 5x5 polysilicon solar panel. They provide a panel with a relatively small size of around 5 square feet and a maximum power production of 3W and a Peak output spec (500mA) at 6 volts is enough to power the ~200mA system and charge during peak daylight hours. Our engineers expected this to be sufficient, and it was validated through testing, which will be discussed further in the next sections.

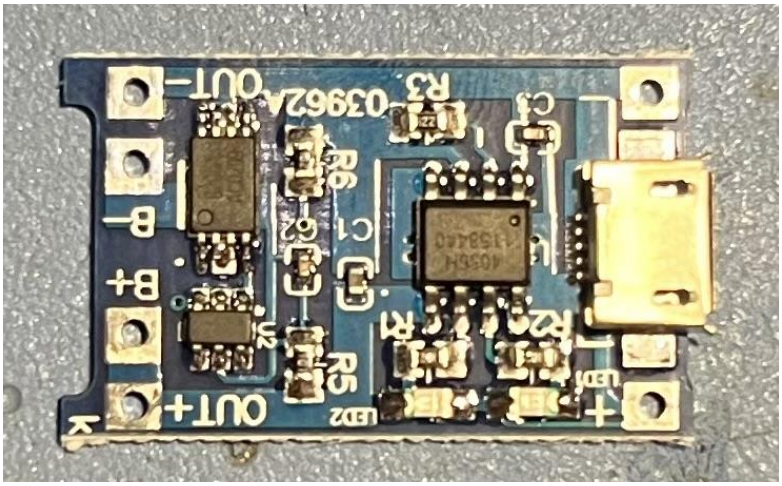
Key Reasons Selection:

- -Size fits design requirements ~ 5x5in
- -Peak output spec (500mA) at 6 volts is enough to power the ~200mA system and charge during peak daylight hours
- -6-volt panel selected for a 5v input device because the voltage of the panel drops under load – even at 6v the input of the TP4056 will tolerate
- The engineer team could consider a potential upgrade up to a larger size at the same 6v

Solar Charge Controller

The TP4056 chip is a single-cell lithium-Ion battery charger that protects the cell from over and under charging. It features two status outputs, one for charging in process and one for charging completed. It also has a charge current of up to 1A that may be programmed.

4.2.7.2 – TP4056 Charge Controller



Key Reason of Selection

- The TP4056 offers variable current control, which allows us to compensate for the solar panel's actual current capabilities as needed.
- All charging logic is housed on a single integrated circuit (IC) in the TP4056.
- The input voltage is 5-8 volts, which gives us the range we need for solar panel fluctuation.
- The TP4056 can supply and receive 1A of power, which is more than enough for our planned use case.

4.2.7.3 lithium-ion foil Battery

A lithium-ion battery pack, often known as a Li-ion battery, is a type of rechargeable battery made up of cells in which lithium ions travel from the negative electrode to the positive electrode via an electrolyte during discharge and back again during charging.

Key Reason of Selection:

- These are high-energy batteries.
- They enable the enginers to change the capacity and form factor without affecting the voltage or charging characteristics
- Once later stages of testing begin this type of battery makes modularity accessibly for the engineering team.

Testing Methodology:

Battery Regulator, battery pack and solar panel was evaluated all together during 3.5-day period. We developed a multi-axis graph consisting of Minutes for the horizontal Axis and a double vertical axis feature with Current (mA) in the left Vertical axis and Voltage in the right horizontal axis. During the day, the battery voltage occasionally rises but remains constant, and the current swings to the negative, indicating that the battery is being charged.

Figure 4.2.7.1 – Power System Current and Voltage Overview

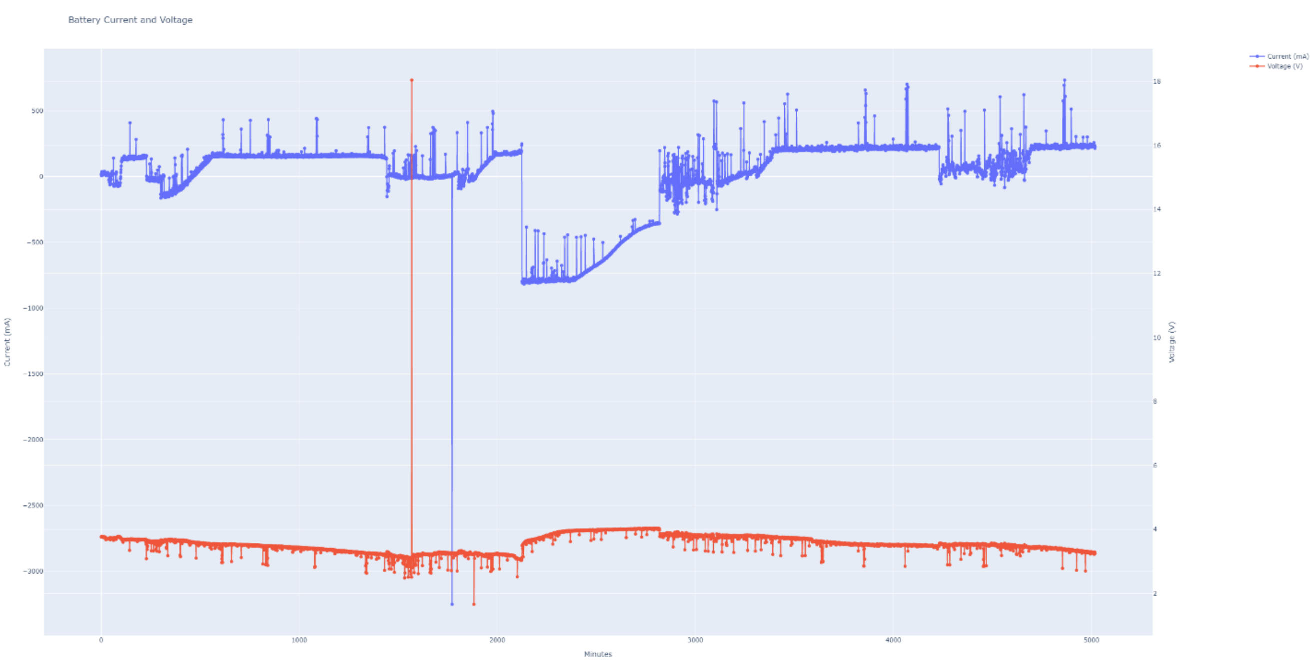
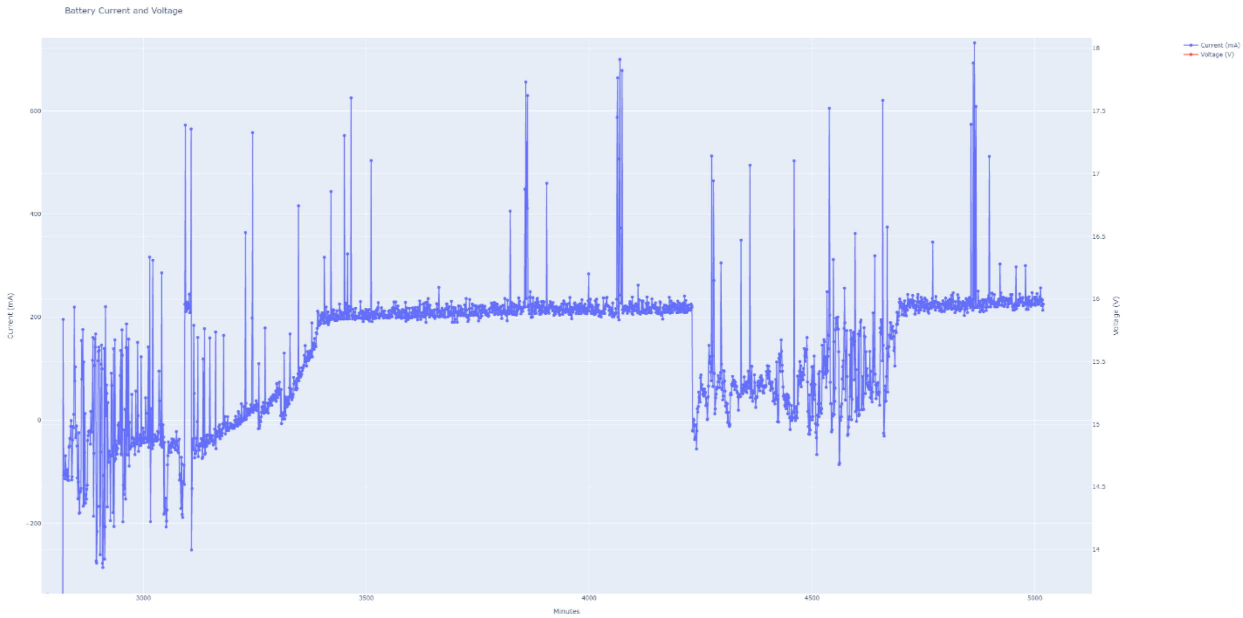


Figure 4.2.7.2 – Battery Current Draw for Day and Night



Power Systems Conclusion

We would like to conclude this chapter with some of the tasks that the engineering team is developing to further improve this subsystem. We currently facing the task that we need to implement 2 voltage regulators: 3.3 V and 5 V regulators, the reason for this is because we have different sensors with different power needs. An example of this would be our wind direction sensor (MLX90316LDC-BCS-000-SP) with an operating supply voltage of 5 V in contrast to the BME 280 with an operating supply voltage of 3.3 V, in fact, all our sensors runs 3.3 V except for our wind direction sensor, however the engineering team has decided that it wouldn't be aligned with the culture of this group to simple give up and disregard the wind direction sensor, for that reason currently this group is trying to implement a boost-buck converter which

is a type of DC-to-DC converter in which the output voltage magnitude is more or less than the input voltage magnitude It is similar to a flyback converter that use a single inductor rather than a transformer.

One of the boost Regulators being considered currently is the MCP1642 A synchronous step-up DC-DC converter that is small, high efficiency, and has a set frequency. It offers a simple power supply solution for applications that require one-cell, two-cell, or three-cell alkaline batteries.

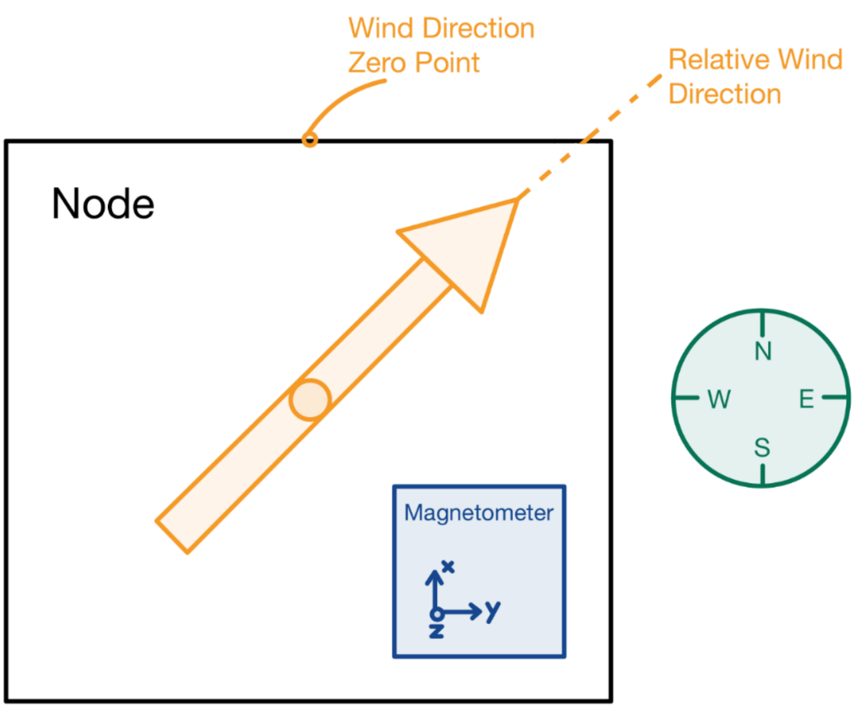
4.2.8 – Compass

We will begin our selection of the compass sensor by considering the purpose of a compass in our design. When designing the anemometer, we realized that we needed a reference point to base our measurements on. Specifically, we need a reference for the wind direction measurement. A reference point allows us to produce a measurement that is human friendly and easily usable. The measurement for wind direction will be a compass heading from 0 to 360 degrees. If the node lacked a compass, we could determine only the heading relative to the node itself. This would not provide a useful measurement. The compass allows us to determine the node's position relative to the earth. We may use this reference to determine the offset needed to extrapolate the wind direction according to the earth.

During our research for the compass, we concluded there are two main options for our application. The first option is, using a handheld compass to set a reference at setup. In this option, the user would mount the node in its operating location and note down the compass heading in relation to one face of the node. This reference could then be added to the software configuration for the node. The argument for this option is that the node should not move once it has been placed. Though this is true, we are also aiming to reduce the complexity of the system from a user perspective. As a result, we are choosing to proceed with the second option. The second option is to use a magnetometer to detect the earths magnetic field. This option adds minimal cost and complexity to the system. While also reducing human error and required input when setting up the system.

As we begin developing our testing methodology for the compass, it is important to gain an understanding of how the compass will be implemented in our design. Figure 4.2.8.1 shows the compass module mounted within a node. Also visible is the wind direction sensor. From this figure we may draw a few important observations. The magnetometer X-axis is aligned with the zero point of the wind direction. For the purposes of this example, the zero point of the wind direction is also aligned with the north compass heading. We purposefully aligned the wind direction zero point and the magnetometer x-axis as this is the axis the magnetic heading is measured. This example shows that we are able to take the wind direction measurement and add the degrees to the magnetometer compass heading. The result is the actual wind direction.

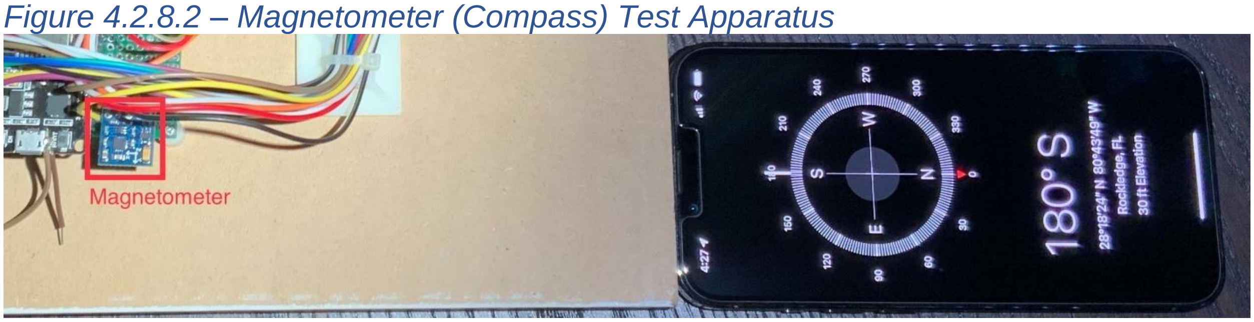
Figure 4.2.8.1 – Compass Implementation within Node



The testing methodology for the magnetometer will consist of four comparisons of the magnetometer heading against the compass app within a smartphone. We will orient the magnetometer and the phone to align their direction of measure. We will then move both devices such that the phone reads out each of the major directions, north, south, east, and west. These readings will be compared with the reading of the magnetometer.

We need to consider factors that may introduce error into our testing. The first factor is the magnets in our test smartphone. The smartphone itself contains many strong earth magnets in its construction as well as in the case for the phone. The magnetometer that is the unit under test is very sensitive to magnetic fields. We will be removing the case from the phone to reduce the number of magnets present. We will also be moving the phone sufficiently far from the magnetometer as to reduce the risk of skewing the results. A second factor to consider is the accuracy of the smartphone itself. We do not know the exact device used by the phone to read the magnetic heading. We also have no other reference to ensure the smartphone direction is reasonably well calibrated. One final factor to consider is the physical alignment between the magnetometer and the smartphone. The magnetometer is mounted in a female header on a prototype board. That board is then mounted to a wood board. The phone is placed against the edge of this wood board. All of these placements have been completed by eye. Added together, these physical attributes of our test may introduce alignment errors. With these factors considered, we will be rerunning this test in future prototypes with an analog compass mounted square in reference to the magnetometer. This rerun will avoid many of the issues noted with our current testing methodology. See Figure 4.2.8.2 for the overview of our testing apparatus.

Figure 4.2.8.2 – Magnetometer (Compass) Test Apparatus



The consideration of the potential errors in our testing leads us to widen the passing criteria for this set of testing. The test will be considered successful so long as the magnetometer reading is within plus or minus 20 degrees of the smartphone reading. The results of this test will indicate whether we may have confidence in the sensor to function at all in the final design. More testing will need to be complete when we are validating at a system level.

Table 4.2.8.1 – Magnetometer Test Results

Magnetometer (Compass) Test Results				
Continuous Current (mA)			1.05	
Major Direction	Smartphone Reading (Degrees)	Magnetometer Reading (Degrees)	Delta (Degrees)	Result
North	0	16	16	PASS
South	180	196	16	PASS
East	90	71	19	PASS
West	270	251	19	PASS

The results of our testing for the magnetometer may be observed in Table 4.2.8.1. The continuous current draw is approximately 1 milliamp. This is important to consider when we are designing our power system. Our testing does show the sensor is passing. Though, during testing it was clear the unit under test was exceptionally susceptible to magnetic interference. The magnets for the wind sensors needed to be removed from the test bench. The smartphone also needed to move farther than pictured in Figure 4.2.8.2. Without these changes, the magnetometer would fall outside the 20 degree delta. This will be an important design consideration when finalizing the physical proximity of the magnetometer to magnets within the systems.

4.2.9 – GPS

The purpose of including a Global Positioning System or GPS in our system is to allow each node to be plotted on a map. This is necessary as the location of the node is important to determine the area of physical land the node is sensing. During our research we learned there are some notable drawbacks to including a GPS system. The first is the power requirements. Our system is intended to operate off grid with minimal maintenance. This means that we are limited to the battery and solar charging capacity of the node. The GPS system draws on average 40mA of current. This may not seem high but this is more than any other single sensor in the system. The next issue which also ties into power consumption is the warmup time required. When the GPS starts up, it first needs to acquire a signal lock with multiple satellites to accurately determine its location. This may take as much as five minutes or longer depending on the location and surroundings of the device. For this period, the GPS has no useful output and is only consuming energy. The last issue we considered is the added design complexity. The unit would require additional components be added to the device. As well as an external antenna must be mounted. All of these issues combined to drive our consideration of alternative methods for determining location.

One important consideration is the real world use case of the node. The node will be deployed semi-permanently in the area it is monitoring. This means that after the initial set up, the node should not be moved. For this reason alone, the inclusion of a built in GPS unit does not have a practical design justification. The alternative we propose is the use of a handheld GPS unit. These portable units that are widely available for sale and provide reasonably accurate location data. Included in this location data is the latitude and longitude needed to determine the location of our node. At the time of setup, the personnel deploying the node are asked to use a handheld GPS unit to note the latitude and longitude. Along with the node ID, this may be saved in the configuration of the network and should not need to be changed unless the node is redeployed.

4.3 – Software Technologies Research

The list of software tools we will be using in this project consists of python which will be used on an IDE, PyCharm, which is used for server development, web interface, data parsing, and commanding mesh. So, we will use python to create a data server and a web interface for the user. The data server will be responsible for handling all the data that the nodes will contain. The plan is to indicate each node as a region or city on the map and that'll depict the area's land features. For example, Chicago will be a node which will showcase the city's wind speed, temperature, surrounding land information, etc. Then all of this information will get stored in the server as saved data for that particular date. Each passing date will parse the information obtained from the sensors and then store it into the server. The web interface will be created for the user to hover over different nodes or locations on the map in order to see if that particular area has a chance in dictating how good the area is for possible hazardous conditions. We will be using Android Arduino for making the mesh networks. We have used and seen Arduino before. They are so popular in different projects. They are used as microcontrollers which power systems. They are able to read inputs and lights on a sensor, a finger on a button operated to do many functions. Mainly, c++ is used to operate arduinos. So, we are planning to use arduinos and connect it to our mesh network. Then, that way, we can control the mesh network to display the different nodes as desired. We will use SolidWorks to build our mesh network from the beginning to the end. Initially, it is used for designing and building mechanical, electrical, and software elements. AutoCad is used for 2D related work. We will be using Eagle to build our electrical network designs and then create schematics. We can use Eagle to check for DRS errors and that will help us in identifying if our PCBs are ready to go for the next stage. We will use Cura which is used for printing 3D models. If we require any materials, then we can use it to manufacture materials in our product.

4.3.1 – Mesh Networking

Mesh. This library handles the networking with built in error handling and automatically connecting new devices. This method of mesh networking does reduce the range and capacity of the network. We have designed the software to be modular supporting future upgrades to the mesh networking if required.

4.3.2 – Dash/Plotly

Dash is a python framework made by plotly for developing interactive web applications. Dash is written through the use of Flask, Plotly.js and React.js. Through dash, HTML is not needed to be learnt. The same goes with HTML, CSS and JavaScript. In order to make interactive dashboard, only python is needed. Dash is an open source and the application is developed using the framework which could be viewed on the web browser. The building blocks of Dash consists of Layout and Callbacks. Layout describes the look and feel of the app, which defines the elements like graphs, dropdowns, etc. The placement, size, color, etc. Dash has Dash HTML components through which the style of HTML can be created like headings, paragraph, images, etc using python. Dash core components are used to create elements such as graphs, dropdowns, sliders, etc.

Callbacks are used when one needs to bring interactivity into the dash application. This function helps in defining the activity during which a user can click a button or a dropdown menu. Layouts are used to create web-based layouts using plotly dash. There are some important required packages needed to be installed. Packages like dash, dash-html-components, dash-core-components, plotly. These packages help in creating graphs, dropdown, etc and the plotly packages help in creating plots and reading various datasets. HTML is used for styling the web application. So, for our web application for the mesh networks, we will be using these tools to create a graphs or scatter plots to depict the different temperatures, wind speed, etc in different formats or colors to signify the extremes in high and low.

Callbacks in dash are used to make the web application or any application interactive. First, a callback is initialized using @app.callback(), which is then followed by a function definition. In this function, there are some arguments used to define what can change the values of the dropdown which could be interacted by the user. Some arguments include: output and input. The output function is used to define the components within the layout which will later be updated after another function is called. The output functions in our application will be developed to display the temperatures, wind speed, etc to the interactive application which the users will use. The input function is used to define the components which are used to change the values when triggering the callback. The callback needs to get triggered which is subjected on the change in the value of the dropdown.

4.4 – Stretch Goal Technologies Research

We have two main stretch goals. The first is regarding the fire danger rating system. This system helps officials to convey the risk level of a forest fire starting. Given the time and ability, we would like to explore implementing a machine learning component. This component would use the data gathered by our system to make recommendations on setting the current fire danger level. Our second stretch goal is to implement a trends page. This page would display to the user all of the trends for the measurements of the area. These trends would help to give a better picture of the health of an area over time.

5.0 – Standards, Equipment, and Safety

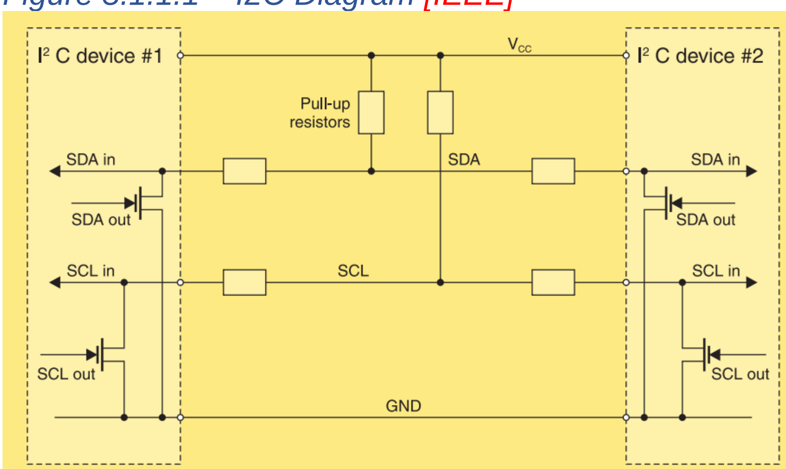
5.1 – Standards

5.1.1 – I2C

One of the communication standards that we plan to use is the Inter-Integrated Circuit, which is also known as I2C. They are used to connect integrated circuits with only two wires that work in both back and front directions called SDA and SCL into other processors and microcontrollers as a peripheral address and it helps to make PCBs easier to build. As of right now, they usually have a bus speed from a range of 100 kb/s to 3.4 Mb/s. In its protocol, it recommends that it uses 7-bit slave addresses and have its data be divided into 8-bit bytes.

The way I2C functions is that first the master sends a "Start" condition in order for the integrated circuit to listen for data being sent. Then, the master sends the address so that it can access a device and perform a read or write operation so that the circuits compare with their own address and send an "Acknowledge" signal when the address matches. When that happens, the master will be able to send or receive until it ends, in which the master will send a 'Stop" signal.

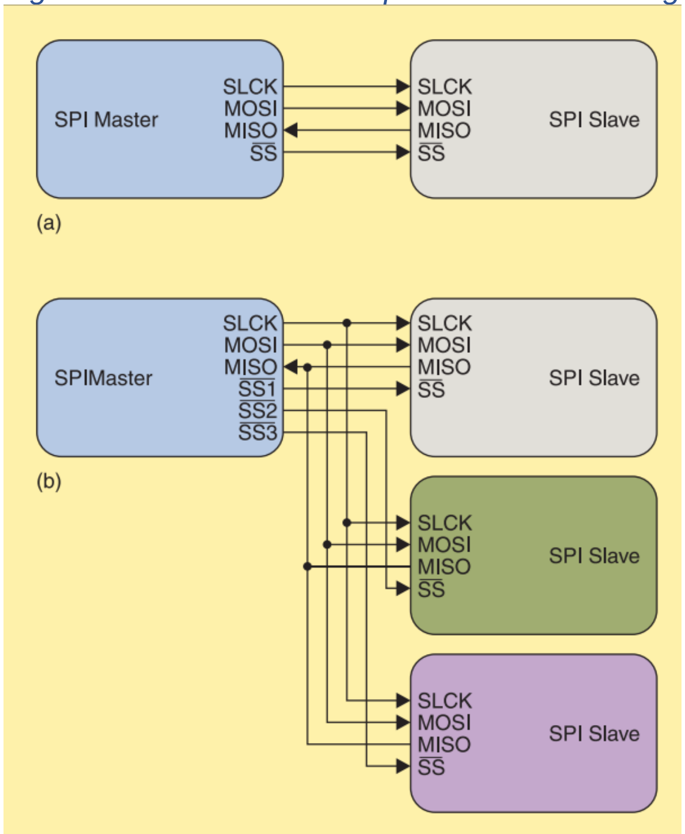
Figure 5.1.1.1 – I2C Diagram [IEEE]



5.1.2 – Serial

Another communication protocol that we plan to work with is the Serial Peripheral Interface, also known as SPI. It is mainly used to communicate to different systems in a short distance in a full duplex mode and it also consists of using Masters and Slaves like in I2C. However, unlike I2C and other communication standards, it uses more signal lines. The way how SPI works is that it has four signal lines: SCLK, SSn, MOSI, and MISO. It only contains one type of master that perform all the communication to the slaves. To send data, the master pulls the slave select "SSn" line so that it can set up the clock. By doing this, it creates data which is then sent to the MOSI line and receives data via the MISO line.

Figure 5.1.2.1 – Serial Peripheral Interface Diagram [IEEE]



5.1.3 – Wi-Fi (IEEE 802.11)

For the design we plan to use WiFi in order to transmit the data that we obtain regarding possible fire threats. The standard that we plan to abide by that pertains to WiFi is IEEE 802.11. It allows us to carry and send data to other types of equipment where it can listen to other channels. Usually, it can be divided into other protocols that contain different types of frequencies:

Table 5.1.3.1 – IEEE 802.11 Protocols

Protocol	Frequency Band	Bandwidth	Maximum Data Rate
a	5 GHz 3.7 GHz	20 MHz	54 Mb/s
n	2.4 GHz 5 GHz	20 MHz 40 MHZ	150 Mb/s
g	2.4 GHz	20 MHz	54 Mb/s
b	2.4 GHz	20 MHz	11 Mb/s

When working on the design, we should choose the most appropriate WiFi protocol so that it could be transmitted to other devices and networks in a fast and efficient manner.

5.1.4 – LoRa

LoRa, also known as “low range” is a type of networking standard created to connect battery-operated systems to internet networks in a wireless manner. It sends data using the chirp spread spectrum “CSS” technology. It can use three different bandwidths which are 125kHz, 250kHz and 500kHz and uses spreading factors from a range of SF7 to SF12 to transmit data. To get the symbol rate, we have to use this formula:

Equation 5.1.4.1 – Symbol Rate

$$Rs = BW / (2^{SF})$$

In that formula, Rs represents the symbol rate, BW represents the bandwidth, and SF represents the spreading factor.

5.1.5 – Power Standards

Certain power standards are determined to see what's the best and most efficient way for a design to function. We plan on using solar energy and reserve batteries to power our product and also making sure that they can be safe and still function during inclement conditions. On a fully charged battery, the power reserve should run for three days. By using solar energy, solar panels are going to be connected to the node on top of the product and then to the database.

5.1.6 – Printed Circuit Board Standards

A lot of the design will consist of using Printed Circuits or PCBs. The standards that pertain to printed circuits are IPC PCB and it tells how certain aspects should be put in place in those PCBs such as how to properly solder the design and how the cables and wires are assembled. When a PCB is being built, IPC divides that into three classes: general electronic products, which are products where the printed circuit is the main aspect; dedicated service electronic products, in which the PCB must always be reliable and safe from malfunctioning; and high-performance electronic products, where it performs on demand.

5.1.7 – Programming Language Standards

For this project we are most likely using python and dash to create a Web App that displays real time and historical data of an environment that we are observing. These languages have some sort of standard so that we can understand it better while programming the application

Python

An important standard to follow while using Python is PEP 8. It tells you how to properly style that code when you write it. It sometimes changes overtime because new conventions and standards are modified every year. An important aspect that this standard recommends while writing code is that it has to be consistent so that other people reading the code can understand it. It also recommends that the python code have 4 spaces in every indentation level. The lines that succeed the past lines from the code should be indented and there shouldn't be any arguments on the first line. It doesn't matter if the conditional lines on the if-statement are written similarly or differently from each other and lines should have at most 79 characters.

Another standard that is used in Python is PEP 526, which takes the syntax of variable annotations into account. It also modified how the syntax is written compared to previous standards such as PEP 484. In that case, it allowed for changes to be made regarding how the code was annotated. This was also a modification of a previous standard known as PEP 3107, which allowed arbitrary annotations to definitions of functions and promoted static analysis.

Dash

Dash is another programming language that we plan to use on the web application and it is related to C and C++ so it might share a lot of standards with that language. Therefore, it would abide to C++ standards such as C++14, C++17, and C++20. C++14 is a recent standard that was created in 2014 as a modification to other standards such as C++11 and can work with other compilers as well.

C++11 back then helped implement changes to the core language and add new features to the standard library to make it safer. Some of the modifications that C++14 implemented includes function return type deduction, alternate type deduction, variable templates, and digit separators. In 2017, C++17 modified C++14 by removing trigraphs and updated the memory allocation on the program. C++20 is another update that was done in 2020 that upgraded the programming language's syntax and library and it also improved the compiler support.

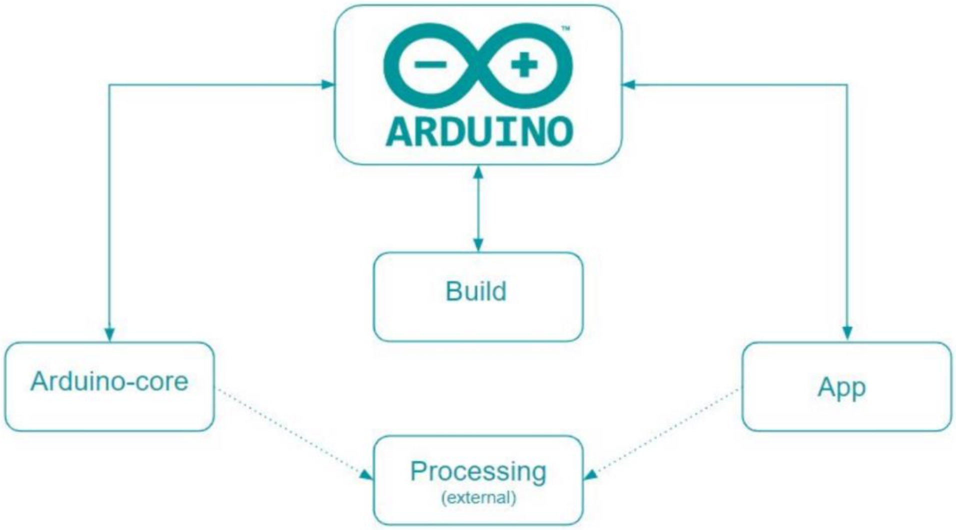
Arduino

In this project, we are also planning to use Arduino to help run the ESP32's. To make sure that we are using a proper Arduino board, we have to see that it includes a regulator, USB-to-serial interface, and an SPI Programming interface. It should also be able to work with both the hardware and software aspects of the design. To implement an Arduino board, a similar design should be followed.

While working with Arduino, other standards should be taken into account such as the ROHS 2 Directive 2011/65/EU and the Directive 2014/35/EU. These are safety standards that advise you on how to properly handle hazardous substances in electrical equipment and also to make sure that it uses an appropriate voltage amount so that it wouldn't cause any problems. When looking at the power and electrical components, we also have to make sure that they are in a proper temperature range such as being less than 85°C and greater than -40°C so that the product wouldn't overheat or freeze.

To actually program the ESP32, we will use a component called the Arduino IDE, which is an open-source software where we can write code to program and interact with the board. The IDE can be written with C, or C++ so it would follow similar standards as I mentioned before. It can also provide software applications and microprocessors as well for Windows and Linux and can implement customized libraries and command line tools as well. Arduino IDE is composed into seven parts: Developers, Build Requirements, Testing Framework, Target Platforms, Communicators, Dependencies, and Language. It also uses JUnit4 to perform unit tests. The way how Arduino is developed can be shown in this diagram below.

Figure 5.1.8.2 – Arduino Development View [The Arduino IDE]



So basically, Arduino interacts with those modules in a two-way fashion with the Arduino-core, which contains the main code for the IDE; Build, which are extra files that build the distributable zip; and the App. The Arduino-core and the App also share its dependency modules with the external processing component. To test it, we can do this by building the distribution zip by typing “ant dist” on the IDE and then to start it, type “ant run”. To compile what has been written, we type “avr-gcc” on the IDE.

It is also important that when using the Arduino IDE that proper documentation should be used. When writing and merging code, it should be consistent and follow proper code style guidelines and these standards should be added to its repository.

5.2 – Equipment

5.2.1 – Electrical Fabrication

In some parts of our design, we will be using different types of electrical circuits and microcontrollers such as the ESP32 Wi-Fi & Bluetooth MCU. They are considered the most important part of the nodes of our design since it can work with the wireless communication aspect of the microcontrollers and allows us to have access to a variety of functions provided by its manufacturer.

5.2.2 – Software

For the software component of our design, we will be building a web app that will be run using Python and Dash. We will also be using integrated development environments such as the Arduino IDE in order to run the ESP32 boards on our device and the PyCharm IDE in order to record and parse the data from the Python program that we are running. The purpose of that application is to showcase the real time and historical data of the area that we are observing. It will contain a local area network and a Linux command and control center as well. Besides the web application, the software on our design will also contain other nodes as well such as a map view and overlay, off-grid network, and a database.

5.2.3 – 3D Printer

For our design, we will be printing some of our components for our nodes by using a 3D printer. We will be using software that would allow us to build or gather information on how the 3D model will look like so that its data could be sent to the printer itself either online or as a SD file. When the data of the model is sent, it will start to print the three-dimensional object using a special type of plastic filament and that process can usually take a couple of hours. There are various different types of 3D printers and the type that we are going to use correlated on the complexity or the specific part being built for the design. The main types of printers that we are looking forward to using are the FDM or SLA printer, and these printers are known to use different types of material or approaches to print a model.

FDM

The Fused Deposition Modeling printer, also known as the FDM printer is a type of three-dimensional printer that is known for printing models using solid plastic filaments that are available as a string such as PLA and ABS. The filament gets connected and passes through a nozzle where it gets heated hot enough for it to melt. The melted filament then touches the base where it is being printed in which it then dries up and it will also print on top of the dried filament layer by layer so that it can produce a solid 3D model. Also, some commands can be written as well so that the machine knows what exact areas, corners, or coordinates it has to print on the base. It is also one of the most common 3D printers that are used due to the fact that it is economical and is simple to use. Our group currently has accessibility to a FDM printer.

There are benefits for using the FDM printer compared to other printers such as the SLA printer. It is user friendly and it is also not that expensive since it is usually available at around $100. Therefore, it can be used by people who are just starting to learn how to use 3D printers. Also, it allows us to print basic small parts that we can throw away and print anytime due to it being low-cost and simple to use. It is used for creating basic prototype models that we can test first before implementing it on the design to see if it works or not. It also doesn't have any post-processing when it prints basic designs.

However, there are some downsides to using FDM. Due to the low-cost price of that printer, it is sometimes not that reliable and efficient to use so that means that we have to make sure that we pay attention that the machine doesn't malfunction in the long run. When it prints, it prints the model layer by layer and sometimes there can be complications in the heating nozzle that can hinder the printing process. The shape of the model can sometimes appear somewhat inaccurate compared to the original design from the data because those details might be too complicated to print so that machine can avoid implementing that function, eventually leaving it as printing a simpler variation of the original model that was designed. The model might appear as of low resolution as well. If it is printing a more complex model, then a longer post-processing time is required. FDM is also not compatible when obtaining certain designs that were drawn and created due to its limitations that it has while printing the model.

SLA

The stereolithography printer, also known as the SLA printer, is another type of three-dimensional printer that unlike FDM, uses a liquid resin as its source instead of a solid plastic filament. This liquid is inserted inside a small tank of the printer. When it prints, a lifting platform touches the liquid near the bottom part of the tank so that the platform can absorb parts of it. Then, there are UV lasers connected to the printer that begin shooting beams to the liquid in specific directions so that parts of it dries up into a solid piece and begin to take the shape of the designed model. It completes this action layer by layer. When a part of the layer is printed, the solid piece is lifted to the top by the platform so that parts of the liquid resin drop and flows from the solid model. After that, the platform then lowers the 3D printed model back to the liquid resin to print the other layers. SLA can be used to build and print more complex models than can be implemented on our design so that it would be more secure and of better quality so that the design won't malfunction when it is being tested or used.

Some of the benefits of using the SLA printer is that it can produce much more accurate-looking models in respect to the original design model being drawn. It also gives the printed object a better surface finish. Due to the material that it uses and the light intensity from the laser beams that it shoots on each layer which therefore forms a chemical bond, the solid model can end up having much smoother surfaces and shapes. It can even allow the model to have specific details not available in other models such as ridges, edges, lines, and other isotropic parts so therefore it gives the printed object a better resolution in a fast-printing speed. Because of that, SLA is very compatible and allows us to print a variety of designs drawn using software such as Solidworks due to the efficiency it has while printing. Also, the printer doesn’t seem to be affected too much by outside temperature since it uses the light intensity of the laser to produce the solid model instead of relying on heat like the FDM. Therefore, the model doesn't suffer from thermal expansion which can be seen as having small threads of plastic hanging from parts of the model.

However, there are some downsides to using SLA. Unlike other printers like FDM, it can be expensive to obtain. Buying one of those machines can cost around $3,000 to $10,000. Also, sometimes when the model is finished printing, it needs to be washed and sanded in order to make it smoother. If we want to print a bigger model, we will need to buy larger parts to implement on the SLA printer in order for the model to have enough space when it prints and to keep its structure. Since SLA printers require the use of UV laser to print the object, it can expose too much ultraviolet violet in which the device can be sensitive about.

5.2.4 – 3D Printer Materials

Working with three-dimensional printers requires the use of different types of material such as filament to actually print the model. Some of the types of material that are needed to print include PLA, ABS and Resin. Since the FDM 3D printer is more accessible for use, we are most likely going to focus more on the PLA and ABS but also plan to consider other types of filaments as well.

PLA

Polylactic acid, also known as PLA, is a type of thermoplastic polyester that is normally used in FDM printers. The PLA is inserted through the nozzle of the FDM 3D where it melts from the heat that the nozzle produces so that it can print the 3D mode layer by layer in a given shape. It can melt around 190–220 °C and print at a speed of 10–100 mm/s. This type of plastic is known to be very reusable and it is also biodegradable. When a 3D model is finished printing using PLA, it has to be washed and sanded in order to make it smoother. While beginning to print the first parts of the design, it is recommended to use PLA because it can be reused and you can print many times you want.

Some of the positive impacts that PLA has is that it is cheap since it costs around $20 to $40 and easy to use. It is also simple to use in order to format it to print and it is available with different types of colors. It is also able to print at corners more accurately and faster than ABS. Compared to other filaments, it is not that heavy so that means that we can print as many objects without worrying how much the weight can affect while implementing that in our design and besides that it is also durable. The fact that PLA is environmentally friendly is important for our design since it will be used outdoors and involves collecting data about forest fire causes and prevention. Therefore, it would most likely not cause any further problems to the environment where it is being tested even if it is placed there for a long amount of time. It is able to print using a base with a cold temperature without causing further problems to the design.

Even if using PLA comes with a lot of benefits, there can be negative impacts as well. Since PLA is biodegradable, it might not be that much of a good idea to leave it outside in the middle of a forest for a long time if most of the nodes are composed of that material because it can decompose or even melt a bit, especially during chances of extreme temperature such as experiencing too much sunlight outdoors. For PLA to start to degrade or even melt, it has to be in a temperature of a range between 50°C to 60°C. So, when experimenting with something that uses this type of material, we have to avoid being close to fire, hot water, or sunlight. However, if it is placed in an area with normal room temperature, it can still manage to remain durable.

PLA, like other types of thermoplastic polyester, can bring the risks of causing environmental impacts such as pollution and landfills. A good thing about PLA is that it is somewhat biodegradable since it was not produced synthetically and contains natural chemicals that come from plants. This means that if PLA is discarded somewhere on Earth, it is able to break down without causing that much of a landfill and that can be done in a short amount of time. We are also able to recycle models made with PLA if we realize that we are not going to use it anymore but we have to take into account that it has a low melting point. This means that recycling it with other types of plastic together, we have to make sure that they are separated from each other so that they can be recycled properly based on their melting point. We should also know which recycling factories are able to recycle materials containing PLA since some factories focus just on certain types of plastic.

ABS

Acrylonitrile butadiene styrene, which is also known as ABS, is another type of strong thermoplastic polyester that is used in FDM printers. Like PLA it can come with different colors and sizes and it is usually able to melt at temperatures of a range of 230 - 250°C.

Some of the benefits of using ABS is that it is feasible and is able to work with other components such as electronic hardware and machine parts. It is also very durable and like PLA, it is cheap and reusable but however, it can withstand high temperatures better so it would be very useful when building a product that would require to stay outside in the sunlight for a long amount of time which would be in our case with the Remote Area Monitoring Device. It is also much stronger and can withstand environmental impacts better than PLA. This means that there is a chance that we can use models printed with that type of filament when we test for our final design instead of a rough draft. A model printed using ABS doesn't really need that much care when it is being sanded to make it smoother unlike PLA. ABS is also recyclable so that means that we are able to melt and reuse the parts that were left out from the original design so that we can improvise it.

Despite its benefits, it also has its downsides. ABS has a tendency to warp due to high temperatures which means that it can misprint certain parts of the model and cause it to detach it from the base where it is being printed. When printing a figure, it requires the use of a heat bed to keep the filament warm which isn't really required while using PLA. We also have to avoid cooling the 3D model being printed with ABS in a quick amount of time because it can crack easily.

Like PLA, ABS is also recyclable but it won't recycle that well because once we do that, the modified product is less durable than it was before. When they are recycled however, it is able to transform into a rubber-like state at 105°C because it is an amorphous compound. Since ABS is not considered to be a "typical" plastic, most recycling factories would not accept ABS as a type of material to be recycled, so therefore we should make sure we know the exact locations where it can be recycled. Also, since ABS is being reheated during the recycling process, it will therefore weaken in later iterations and won't be able to properly resist heat so that means that ABS don't really have a long lifespan. In order to increase its lifespan, we have to add new ABS pieces into the recycled ones.

When an ABS model is finally printed, it is not toxic anymore and that makes it safe for the environment. However, ABS can be very flammable when placed on an area with very high temperature and can end up producing carbon monoxide. Sometimes when a model is being 3D printed using ABS, it can release small particles in the air which can be harmful for the user's health.

ABS is not considered to be biodegradable and it has a higher chance of ending up in landfills compared to PLA. When it's left on the earth, it would take a very long time to decompose.

Not all recycling factories might be able to recycle products with ASA filament since they mostly focus on standard plastics, so that means that we have to find a proper factory that is able to dispose of it. Also, when the ASA filament is being recycled, we have to make sure that it hasn't been tainted or contaminated with other elements such as water.

PETG

Polyethylene terephthalate glycol-modified, also known at PETG, is another type of thermoplastic polymer filament used for printing objects using a FDM three-dimensional printer. It is basically a modified form of the PET compound that is combined with other elements such as glycol so that it can be more suitable for 3D printing. Using these elements can help the PETG filament to melt at a lower temperature based on the heat that the printer’s nozzle produces and it also makes it more bendable like a string. The temperature needed to print something with PETG is between the regular temperatures to print the PLA and ABS filaments.

The advantages of using PETG is that like PLA it produces smooth layers while printing the design. However, like ABS, the filament produces a strong and sturdy model that is safe from external damage and from breaking apart. It is also recyclable so that means when we can reuse old filament to produce new models any time we want for our design. Like ABS, it is able to withstand high temperatures and it won't melt that easily. This also means that the model is able to remain compact and sustain from damage even when it is overheated. Another important aspect from it is that it can withstand excess moisture and that is necessary since our Remote Area Monitoring Device will be placed outside in forests for the most part where rain and high levels of humidity can happen since it is one of the nodes that we are measuring. It is not that complicated to manage and to print something with that filament for beginners.

Some of the disadvantages of using PETG is that the final product being printed contains problems not seen with other filaments that we mentioned such as scratches on the surface of the model. Also, the product has to be placed away from certain elements such as ultraviolet light since it can cause damage to it. At higher temperatures, the PETG model isn't able to remain firm and compact; at above 176°F, it can end up becoming softer.

The reason why PETG is easy to recycle is because it is made from a plant-based product called glycol which is also environmentally friendly. It is also accepted by many factories as an appropriate plastic to recycle, so that means that we don't have to really be that concerned about finding a faraway place to discard material made from PETG in order to recycle it. However, it is not that biodegradable because it is mostly made from oil-based products instead of raw materials. Therefore, it is able to last a long time in a landfill and can cause environmental problems in oceans due to the elements that PETG contains.

ASA

Acrylonitrile Styrene Acrylate, also known as ASA, is another type of thermoplastic polymer filament used for FDM printers as well. It is known to be a modification of the ABS filament and its usage is recommended for building and working with outside products and for building prototypes.

Some of the positive impacts for using the ASA filament in the FDM three-dimensional printer is that it is resistant and doesn't get damaged easily when there are heavy changes in temperature or when it reheats unlike its counterpart ABS. Therefore, it can be useful when building a piece for the circuit using that material since our device will be positioned outdoors for a long amount of time with noticeable amounts of sunlight. The reason why it is so resistant is because it has high durability and it can withstand heavy amounts of ultraviolet light, which is mostly produced from the rays of the sun. It's also resistant from environmental impacts and doesn't corrode that easily. Therefore, ASA is more durable and seems to have a longer lifespan compared to other materials like ABS.

However, it can also bring some negative impacts. It is not always that safe and environmentally friendly because when printing something using that filament, it can release toxic chemicals and it is also more expensive compared to its counterpart, ABS. It can even be complicated when printing a 3D model. ASA even has a higher melting point so that means that we need to make sure that our 3D printer's nozzle is able to produce a strong amount of heat so that it is able to melt properly. It is somewhat expensive and hard to find a printer with a nozzle that is able to fill that requirement.

Not all recycling factories might be able to recycle products with ASA filament since they mostly focus on standard plastics, so that means that we have to find a proper factory that is able to dispose of it. Also, when the ASA filament is being recycled, we have to make sure that it hasn't been tainted or contaminated with other elements such as water since elements from the ASA filament can easily spread to the water and spread toxic chemicals around it.

5.3.5 – Digital Voltmeter

In this project, we will be working a lot and gathering data for our nodes such as the voltage and the current. We will need to see how the PCBs and the microcontrollers are functioning. One of the types of equipment that we will be planning to work on is the Digital Voltmeter. The voltmeter helps read the alternating or direct voltage current of a device and it also displays the value of the current as a numerical value. It also measures the input voltage and it does this by converting the analog voltage to the digital voltage of the device being measured. The voltmeter is divided into five parts which are the Pulse Generator, Voltage Control, Counting Clock Pulses, Analog to Digital Conversion, and the Latching and Display Section. For our project, we plan to wear the DC voltage of certain nodes that we are going to test.

The Pulse Generator helps create a pulse in order to generate voltage. The Voltage Control looks at the voltage from the input and also to the one that passes through the capacitor. To make sure that it gets an input current that is close to zero, it uses an Operational Amplifier chip that takes the voltage from a positive and negative value and determines whether the output voltage is high or low based if the positive input is greater than the negative input. The voltmeter also checks and counts the clock pulses between the charging signals and gets those results as a binary number value. The Analog to Digital Converter helps convert that voltage into a binary number and the Latching and Display Section displays the results of all those calculations from the capacitors as an output.

For our design, we will be using two types of digital voltmeters when designing and testing the product which are the BK Precision voltmeter and the Hyelec digital multimeter. Both of these voltmeters function similarly but the BK Precision voltmeter will be used more for our project since it gives out more accurate outputs and contains more functions. Also, we will be using a mini-3-wire standalone voltmeter to read out the solar panel voltage in the first iteration of the test circuit before obtaining the Arduino microcontroller. It is simple to use but the output results are less accurate compared to the other voltmeter. The way the small standalone voltmeter works is that it connects the red wire to a power supply and the black wire to the common ground. It also contains a microcontroller that reads the voltage value. It can be attached to almost any place on the circuit.

The way how the digital voltmeters are used for our project is that it will gather data from certain nodes on our design. We also need to make sure that the microcontroller from the circuit has a maximum input of 3.3 V before connecting it to an ultrasonic anemometer. By getting the values, we can decide whether or not we have to adjust the input voltages for the circuit in order to get an appropriate DC output voltage for the anemometer. In order to obtain these values, we have to use the minimum and maximum function on our digital volt meter. From these values, we can see whether or not we will need an analog line level translation and a 7-volt supply and also see how we can improve our design for the anemometer.

5.3.6 – Oscilloscope

The oscilloscope is an electronic device that is used for measuring and displaying electrical voltage waves as a graph. In the graph, it shows the voltage level over time from the circuit that is being measured and it also shows the frequency. We can see how much DC and AC current is flowing and see if there is too much noise in the signal. We can also tell whether or not there are irregularities in the oscillations which can mean that there are problems within the transfer of voltage in the circuit.

When the voltage is displayed on the oscilloscope as a graph, it can be displayed as different types of waves such as a sine, square, or triangle wave. We can tell that there is a change in voltage based on the height of each wave and we are also able to adjust the waveform as well. When there is no change in voltage over time, it is shown as a straight, horizontal line on the graph. We can also determine the amplitude and phase as well. In order to obtain voltage data to send it to the oscilloscope, we have to use probes that are connected to the channels of the device so that we can connect it to the circuit.

The way we will use oscilloscopes for our project is to also look at the amount of voltage that it flows for our ultrasonic anemometer. We can also see whether or not there is a change in stability based on the wind that is being blown on the circuit's sensor through a phased-locked loop. We then take the current voltage as the input and then get the output oscillation to create a feedback loop which will be shown as sine waves. Then with the exclusive or gate, the output passes through a low pass filter in which is then shown a square wave. Eventually, these measurements give us an idea of how the wind of the area that we are testing is like.

5.3.7 – Power Supply

The power supply is what it is needed to power certain aspects of our design such as the circuits. It also enhances the circuit's electrical current in order to convert it to the appropriate current, voltage, and frequency. Usually, they can either be 3v or 5V regulated power supply circuits. There are also different types of power supplies such as Switched Mode, Uninterruptible, AC, DC, and Regulated.

For our project, we will mostly focus on the DC power supplies. Some of the devices that we plan to use include the Yescom 110V AC 30V 10A DC Power Supply. This device has the ability to produce constant voltage and current and also has over voltage, open circuit, and over temperature protection and it can be used for 24 hours and it also contains a fan that prevents the power supply from overheating. The device also contains some probes that you connect from the channels of the power supply and then we can connect them to circuits so that voltage can flow through them. We are also using the Hewlett Packard DC power supply as well.

Most of the equipment that we are planning to use such as the digital volt meter, oscilloscope, and power supply is accessible for us to use because one of the members of our group owns those pieces of equipment.

5.3.8 – Soldering

We will need to work with a lot of circuits and microcontrollers, and an important aspect of working with those objects is that you have to connect a lot of pins and wires to those microcontrollers and make sure that they remain connected for a long time. So therefore, we need to melt small pieces of metal into small holes where the wire and the microcontroller are connected so that the metal dries up and becomes solid so that these two pieces remain stuck. This will create an electrical connection between these two nodes. The process of doing that is called soldering.

For this project, we will need to solder pieces of the circuits such as the camera, ultrasonic anemometer, battery, sensors, and other microcontrollers to other wires and pins so that power can be transferred from the supply to the specific part of the circuit in order for it to function.

Soldering Iron

To do this process, we would need a drive called a soldering iron. This device needs to be connected to a power supply to power it up so that the soldering pen heats up. The pen should be heated up at around 365°F so that it melts the string of metal alloy when it touches the pen but we can adjust the temperature whenever we want so that it can allow the metal alloy to melt faster or slower. Also, when we are done melting a piece of metal alloy through a part of the microcontroller, we have to clean the tip of the pen with a small sponge so that it removes all the pieces of the molten metal so that it won't interfere with having excess metal when we solder another piece of the microcontroller. If there is too much metal alloy in the microcontroller which happens to each touch with another hole that has been soldered, it can cause problems to the power connection of the circuit; sometimes, it can even prohibit the circuit design from running.

Soldering Gun

Another tool that will help out with the process of soldering parts of the circuit is a solder gun. It is similar to a soldering iron but it is a more simplified version of it. Like the soldering iron, the gun also contains tips that are heated so that it melts the metal alloy when it touches it. But unlike the soldering iron in which you have to manually control the temperature to make it hot enough to melt metal alloys, the solder gun contains a trigger that lets us control the temperature of the tip so that we can melt the metal any time we want without just touching it and waiting for it to heat up. It does this at a faster rate compared to the iron and can make it hotter. It also tends to work better on surfaces that aren't smooth such as edges and small corners and can even repair parts that have been already soldered before.

Some of the advantages of using a soldering gun is that it heats and cools quickly and that it uses an exceptional power voltage but it is not recommended when working with small pieces. The soldering iron is much simpler to use and it's good when working with less heavy equipment and the pen doesn’t produce too much excessive heat. We currently have access to both types of soldering devices since one of our group members owns them.

There are also different variations of soldering guns to use. One of them is the solder air gun. Unlike the regular soldering air guns, this version melts the metal alloy by blowing heated air to the area where it's being soldered instead of actually physically touching the metal alloy string to melt it. Then soldering gun modification can be beneficial in the fact that not only does it melt the metal alloy solder but it can also melt away the alloy in order to de-solder it by blowing it away with heat unlike using a heated soldering pen to pick it out. In the original method, it sometimes pushes the alloy further directly through the hole which will make it even harder to take it out and can even cause the PCB to malfunction. Also, they aren't that expensive to obtain compared to other soldering devices. However, they can come with their disadvantages as well. Soldering air guns aren't always that accurate; when you use it to solder something, the tube’s area from where the hot air comes from might be too big and can heat up more space than the necessary portion needed for the circuit. This can end up causing damage to the circuit’s surface.

Reflow Oven

When soldering pieces for our design, we then have to put together electrical components on top of PCB’s. In order to do this, we have to use a reflow oven. The reflow oven helps us save time compared to soldering circuits the traditional way such as using the soldering iron. It is also very efficient to use and heats up on specific areas of the circuit more accurately compared to other methods. We will plan to use other methods such as reflow ovens if the other soldering tools aren't able to adequately solder the wires to the PCB. It is especially necessary when we are soldering very small pins and if they are placed in the bottom of the circuit, since it is kind of difficult to reach it in a regular soldering tool.

The way that works is that it uses solder and flux to connect the electrical components to the circuit by first configuring a design of the holes of the PCB where it needs to be soldered and then adding the solder with a screen printer. After that, the oven places and aligns the electrical components to the soldered paste that is added on certain parts of the PCB. This is then placed into a special oven where it heats up the paste and then it dries up, leaving the two parts stuck together. When the product is being heated or cooled through the reflow oven, it preheats at a range of 4°C to 150°C and it also soaks the connected PCB in a temperature range of 150 to 170°C. When it actually reflows, it heats the product in a temperature a bit greater than the metal’s melting point in about a minute. Finally, the oven cools the soldered circuit at a temperature of about 4°C.

Reflow ovens can be beneficial in some ways because it doesn't produce too much thermal shock and it doesn't waste too much soldering metal alloy. These ovens are also recommended for low-volume production as well. Since most of the operation is inside an oven, it doesn’t really excrete that much chemicals such as flux from burning metal so it is environmentally safe. However, there can be negative consequences from the usage of reflow ovens such as that it is difficult to control when using more complicated circuit boards and that sometimes it can have temperature control problems. It can also be slow and difficult to actually obtain that device because it is expensive.

5.3.9 – Microscope

When we are soldering and connecting the wires to the PCBs and the microcontrollers, sometimes it might be complicated to see exactly where it needs to be soldered from the naked idea. That is why we need to use a microscope in order to carefully see where the piece is being soldered and connected. By doing that, it helps to prevent committing an error in the process that can end up causing the circuit to malfunction. One of these types of errors is that some of the holes of the PCB are too small to see or are placed very close to other holes. When those cases happen, you might not really see whether or not you are soldering too much or too little. If you solder too little, then the cable won't be able to remain stuck to the PCB. If you solder too much, it might not allow the power to flow efficiently. It becomes hard to carefully remove the soldered metal alloy off without damaging it and after you remove it, there's a chance that the PCB won't be able to function properly again after to re-solder it. Also, since some holes can appear to be too close to each other, we might accidentally melt the metal in a way that it touches both of the holes which will be fatal for the PCB because it won't be able to transfer any data or power. Using a microscope is also necessary when working with small pieces and nodes such as the circuit connecting to the camera, the wireless controller, the small power supply, and the magnetic wind speed detector.

5.3 – Safety

5.3.1 – RoHS

When working with the production of electronic devices, we have to make sure that anything that is hazardous is under control. Therefore, there is a standard that we plan to abide upon called the Restriction of Hazardous Substances Directive, also known as RoHS. These standards help let us know which proper electronic devices are being used because it prohibits the usage of ones that can be hazardous or dangerous such as Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls, and Polybrominated diphenyl ethers.

Abiding these standards is crucial for our project because when we are looking for elements to implement on our design, not all of them would be used and we have to throw them away and if these elements don't follow the RoHS guidelines, then it can cause dangerous environmental impacts such as pollution. The way how electronic devices are testing for RoHS compliance is by using X-ray fluorescence, which detects harmful substances

RoHS is divided into six different levels or modifications based on the elements that it restricts which is seen in this table below. The “x” value in the boxes represent which element is restricted by the respective RoHS standards.

Figure 5.3.1.1 – Element Classification per RoHS Standard

	RoHS 1	RoHS 2	RoHS 3	RoHS 5	RoHS 6
Lead (Pb)	x	x	x		x
Mercury (Hg)	x	x	x	x	x
Cadmium (Cd)	x	x	x	x	x
Hexavalent chromium (CrVI)	x	x	x	x	x
Polybrominated biphenyls (PBB)	x	x	x	x	x
Polybrominated diphenyl ethers (PBDE).	x	x	x	x	x
Bis (2-ethylhexyl) phthalate (DEHP)		x	x		
Butyl benzyl phthalate (BBP)		x	x		
Dibutyl phthalate (DBP)		x	x		
Diisobutyl phthalate (DIBP)		x	x		

5.3.2 – Solder Safety

When working with a soldering tool, certain risks can happen. It is important to learn how to avoid them. The soldering iron’s pen is able to reach very high temperatures such as 400°C so it is important for us to always take proper precaution and make sure that we are wearing protective material such as gloves to prevent ourselves from getting burned. When cleansing the soldering iron pen after using it, we have to make sure that the sponge that we use to clean it is wet because since the pen has a high temperature, it has a potential of being flammable. After that, we have to make sure that the soldering iron’s power is off and pay attention where we put the pen and not leave it unattended, due to the same reason why we need to make sure that the sponge is wet.

Not only does the soldering iron can be flammable, it can also release toxins and chemicals such as flux, lead, and rosin that without proper precaution, can be harmful for our health. That is why when we are working with it, we have to make sure that our eyes and hands are always protected and try to avoid using soldering machines that contain lead and rosin because elements like lead can pass through our skin and produce harmful fumes. When soldering a PCB, flux is produced as fumes when the metal alloy is being melted into the circuit. Flux contains an element called Rosin. Inhaling rosin, even in small quantities can be extremely hazardous and can cause lung and skin damage and headaches.

There are many other methods to control those risks. One of those methods is that we have to make sure that we are in a safe environment when we are soldering. That means that we should work on that task in an area with proper ventilation or even outdoors. Since toxic fumes can come out when soldering, we should also acquire carbon or bench top filters that extract those fumes. The filters should also require constant revisions to make sure they are working properly. Also, proper training is necessary when soldering and it is also recommended that at least two people are present when completing a task using that tool and make sure that the group members don't have any health problems beforehand. So far, there are currently no people in the group that present certain health problems so that means that we are all able to safely contribute to the soldering process.

We have to make sure that no broken cables on the soldering device can cause electrical problems. Also, while working on that, the soldering iron should be placed on a fireproof surface and away from other electrical cables since it has a high temperature, it can cause sparks while touching the cable and therefore cause flames. If the soldering iron has a short circuit, it needs to use a grounded outlet. It is also helpful that we have access to first aid close by if a medical emergency happens. When throwing away waste from working with the soldering device, we have to make sure that it is discarded in a protected box or container and know what exact type of waste is being thrown away so that we can divide the containers with the appropriate waste.

Solder Fume Fan and Filter

Since soldering can release too much fumes that can be unhealthy to the user operating the device, we should find devices that help us eliminate the excess fumes. Therefore, we plan to use solder fume extractors. There are many different types of fans and filters available but we plan to use the Solder Sentry or the Weller WSA350 120v Bench Top Smoke Absorber.

The Bench Top Smoke absorber is a device that is used to removed toxic fumes from soldering by using filters and fans. Since we are planning to solder mostly in an indoor area, using that smoke absorber would be necessary especially when a high quantity of flux is being released. The way the flux is being filtered is by absorbing them through carbon filters and we are able to replace the filter if they stop working by any chance. Compared to other types of filters, it is known to be reliable and have better performance since it is able to run for a long amount of time, which is necessary because a major component for the production of our fire prevention device includes soldering. It also has a high-rated airflow so that it would be able to filter more toxic fumes. We are also able to adjust the absorber into different positions based on where and how we want it to absorb the toxic chemicals. However, a downside of using that absorber is that it doesn't include a power rating. It also mostly seems to work with filtering flux from solder that doesn't contain lead.

The Solder Sentry is able to retract fumes from the flux being produced from soldering without relying on a carbon or charcoal filter. Instead, it uses a high efficiency particulate air filter also known as HEPA, which is more efficient it is able to filter out almost all air particles that can come out from the fumes while the other types of filters only take out odor. Even without odor, harmful particles might still come out from flux so that is the reason why we need to use more improved filters such as the solder sentry.

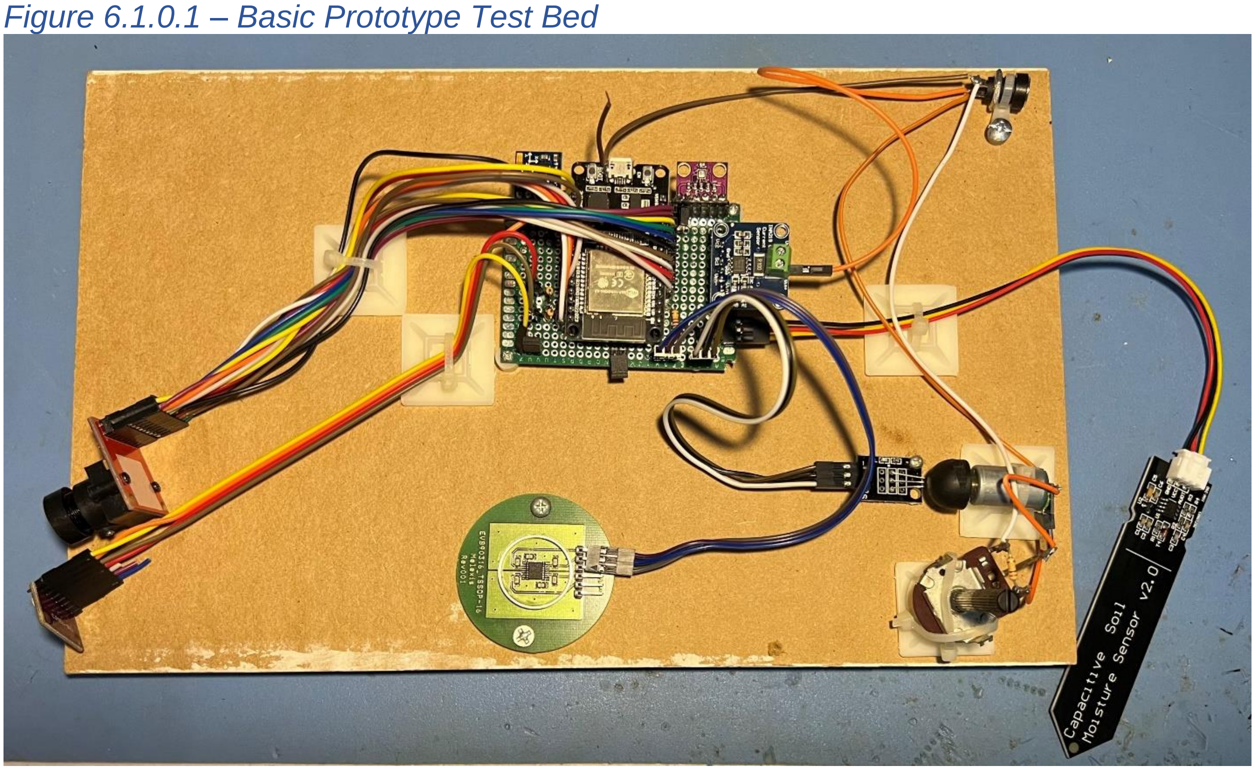
Also, the Solder Sentry places its fan in a different position compared to other filters. The Solder Sentry's fan is placed in front of the filter while other machines place it on the back of the filter. The fan positioning is important because it pulls the air toward the middle of the assembly and takes out the excess air after it. The way how the air flows determine the durability of the filter. Since the Solder Sentry places the fan in that manner, it helps to disperse air more efficiently all throughout the filter which then allows it to capture more flux particles.

6.0 – Prototyping and Testing

6.1 – Prototype Design

We developed a basic system prototype as we progressed through the testing of our individual sensors. This prototype represents a complete set of sensors and hardware. The only exclusion is the power system is replaced by a wall power supply. From a software perspective, this prototype is designed to act identically to a real node. We also included the ability to simulate wind for the wind sensors. This prototype will act as the development platform for our early software design. Here we may quickly exchange parts as required during testing. This will also allow us to have tested and functional software running before we receive all of the full prototype parts and PCB. For an overview of our development test bed, see Figure 6.1.0.1.

Figure 6.1.0.1 – Basic Prototype Test Bed



6.2 – Testing

The testing for the major hardware components of our project is captured in the part selection section 4.2. This section steps through each component and tests their functionality individually. Once we begin integrating these components into the prototype design, we will focus on validating our existing test results. This means that we will ensure the operability of each sensor and that the output is as expected based on previous testing.

The testing of our software design will evolve as we begin to create the system code. At this juncture in the project design, we may layout a broad overview of the testing we expect to complete. First, for each node, we will ensure that the sensors communicate and report their data properly at the local node level. This may be done by directly connecting to the node with a development computer. Next, we will test the basic functionality of the mesh network. This will be completed by ensuring nodes connect to the network automatically. The network needs to handle unexpected disconnection of a node. The network also needs to function as a mesh meaning that a far node can connect to the aggregator through an intermediary node. The next set of tests for the software will occur on the aggregator and web server side. We will verify that the aggregator computer can communicate through the attached aggregator node to the wider network. This is also the point we will verify the network capacity is capable of handling our data throughput for both sensor data and images. The final test for the software will be a full system test. This test will be a validation of all pieces of the system as a whole. We will start as a new system installation and progress to a fully functional network with a minimum of three nodes.

7.0 – System Architecture

7.1 – Electrical Schematics

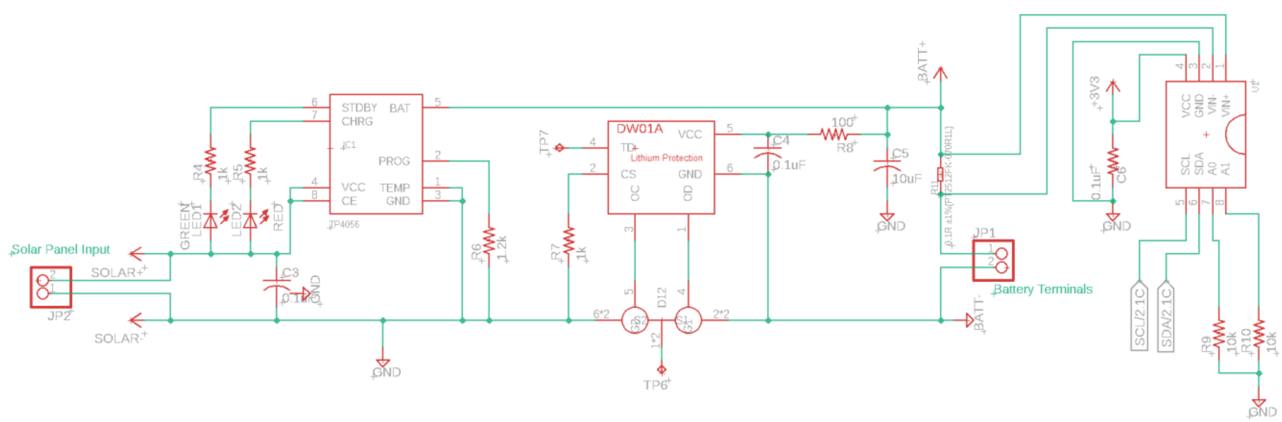
The electrical schematics depict the connections between components within our system. These connections define the functionality of our system. The components are depicted in red often with pin names and numbers. These pins are connected to nets in green. A net name is assigned to each group of interconnections. When a connection passes from one side of a component to the other, the net name changes. These net names are the map for laying out our physical circuit board in the next sections.

Throughout our design process, we maintain a prototype design methodology. We understand that this is an early stage in the product design lifecycle. With that, the design may likely need some revision as we progress through the testing process. Our design methodology incorporates a few key points of consideration. First, we connect test points anywhere that may benefit. For example, all unpopulated pins of the microcontroller and all power supply lines. These test points give us a good place to probe the prototype with test equipment like an oscilloscope. Additionally, these points give us an easy to work with point to solder to. This will greatly increase the speed and reliability of any board-level rework we may need to carry out. The second design consideration we made is to include spots for optional components even if we choose not to populate them initially. A good example of this is the pullup resistor on the address pins of some of our sensors. The address can either be grounded or pulled up to power. This change allows us to select a different address for the sensor. This may be beneficial if two devices share an address as this will cause communication issues with I2C. By adding the required components to the design, we retain the ability to use this feature should the need arise. We may also leave the physical pads empty without impacting operability or cost. The third design consideration we made was in part selection. All of the components come in different packages. The package refers to the physical characteristics of the device. One such characteristic is the size and spacing of the pins of the device. Where possible, we selected components with externally exposed pins with the largest spacing available. The reasons for this are two-fold. First, this style of component is much easier to solder by hand without the need for any specialized equipment. Second, in the event we need to troubleshoot the device, the pins are easily accessible. This helps for both visual inspection and rework. This consideration is possible because space is not at a premium in our design and the cost difference for this style of parts is minimal.

7.1.1 – Power System Schematic

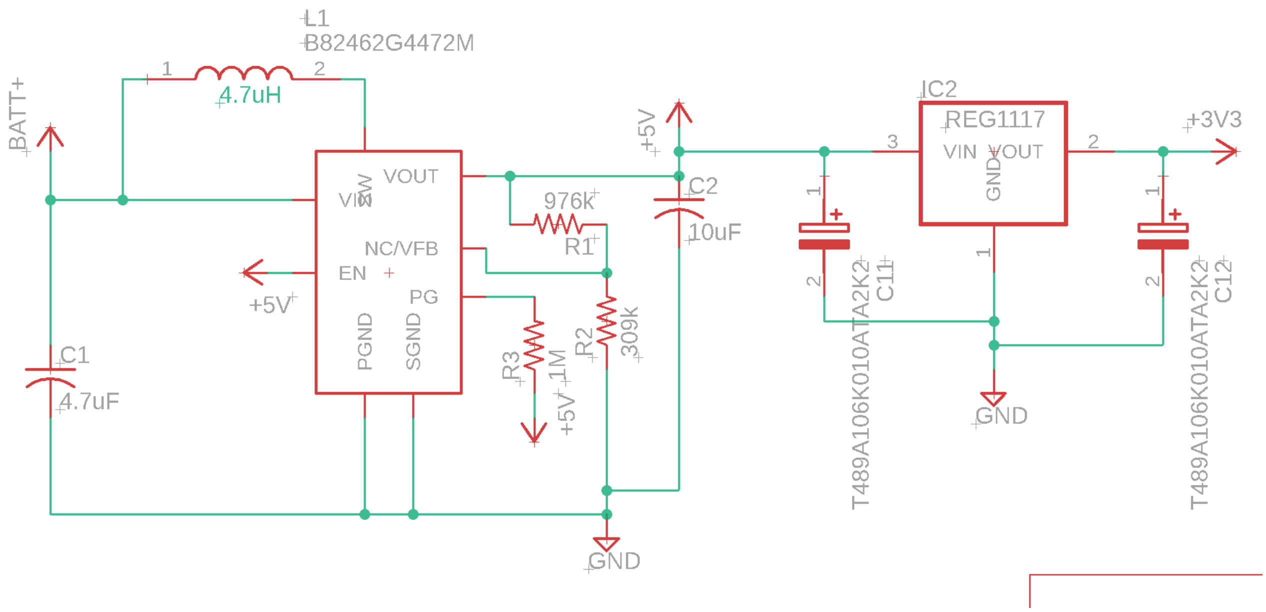
The first subsystem we will be discussing is the power storage and generation design. We are using a TP4056 charge controller to regulate the unstable input of the photovoltaic panel. See the left-most IC in Figure 7.1.1.1. Throughout the day, the power generated by the photovoltaic panel is likely to change often with the conditions of the environment. The TP4056 takes this unstable input and produces a stable output to charge the battery.

Figure 7.1.1.1 – Power Generation and Storage



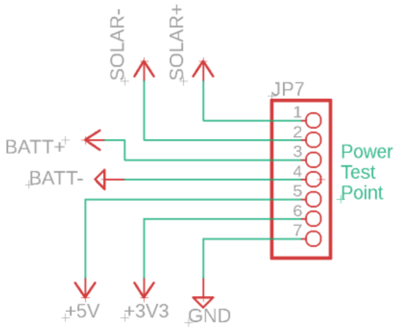
The next major component of the power system is the DW01A lithium battery protection circuit. See the center IC in Figure 7.1.1.1. This device provides protections for current and voltage passed to the lithium battery. This component is important for safety as well as prolonging the lifetime of the lithium cell. This is because lithium based batteries are sensitive to over or under discharge and over-current conditions. The DW01A mitigates these risks. The final major component in the power generation and storage subsystem is the INA219 current sensor. See the right-most IC in Figure 7.1.1.1. This sensor is used to monitor the health of the power generation and storage system. The INA219 measures the voltage drop across a 0.1 ohm resistor. With a known resistance and a measured voltage, the current may be calculated using ohms law. This sensor also provides the voltage between the reference ground and the positive terminal of the battery. This data is available to the microcontroller over I2C. The current allows us to measure the power input / output and detect any issues with the solar charging system. The battery voltage allows us to monitor the charge status. If the battery voltage falls below expected operating conditions, a system administrator may be notified.

Figure 7.1.1.2 – Voltage Regulation



The next power subsystem we will be discussing is the voltage regulation circuitry. Each node requires two voltages to properly function. The majority of the device functions on 3.3 volts. The wind speed sensor requires 5 volts. The leftmost IC in Figure 7.1.1.2 is the MCP1642B, a switching boost regulator. We selected a boost type regulator because the battery voltage will always be below 5 volts. The MCP1642B comes in adjustable and fixed voltage output packages. During part selection, we noted the adjustable package has wider availability over the fixed voltage package. We prefer the fixed voltage package to reduce the number of supporting components required. Our design allows us to use either package type by populating the resistors R1 and R2 to set the adjustable input if required. The rightmost IC is the REG1117 3.3 volt regulator. This regulator takes the output of the 5 volt regulator and reduces the voltage to 3.3 volts. We chose to use this type of regulator to reduce the design complexity. In contrast, switching regulators require a more parts and specify a layout for best performance. We expect a 10mA quiescent current draw from the REG1117. During testing of the fully integrated prototypes, we will monitor the current draw to quantify the impact of this design choice. We may consider a different regulation method for 3.3 volts in future design revisions.

Figure 7.1.1.3 – Power Test Points

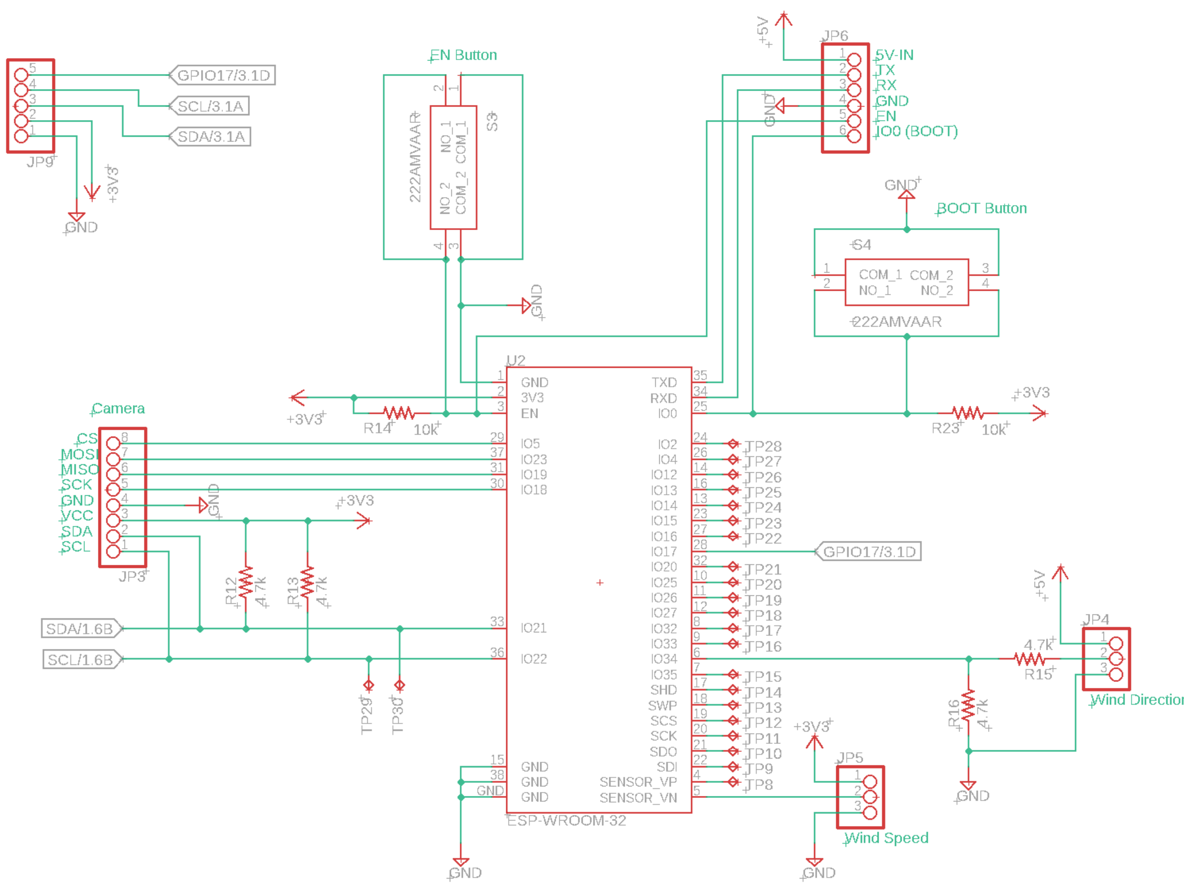


The final component of our power subsystems is a test point for each of the inputs and outputs. This test point allows for troubleshooting and rework. We may use this to monitor noise or voltage levels and supply external power or route power to somewhere it is needed.

7.1.2 – Microcontroller Schematic

The microcontroller is the center of each of our nodes. This section will discuss each of the features and connections to the microcontroller. These consist of features from on board programming to sensor communications.

Figure 7.1.2.1 – Microcontroller Schematic



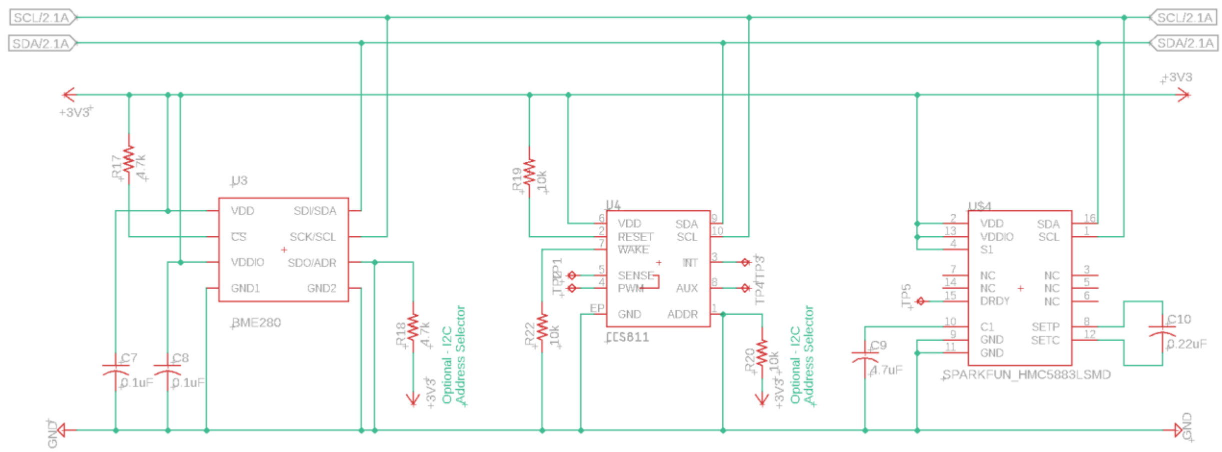
We will begin from the top left of Figure 7.1.2.1 and work our way around the microcontroller. The first component is a standard tenth inch header for connecting our microcontroller to some of the environmental sensors. The first of which is GPIO17. GPIO stands for general purpose input output. This pin is responsible for the 1-wire communication to the DS18B20 temperature sensor. The next two lines are SCL and SDA for I2C communications. These lines are often useful to monitor using an oscilloscope during development. The final two lines are power and ground. Moving clockwise around the microcontroller, the next set of components are used for programming the microcontroller. These components consist of two buttons and a programming port. The buttons are for selecting boot mode and enable. These buttons may not be required depending on the programmer we choose to use. They are included to afford us the ability to pivot to a more general programming device if the device specific to our microcontroller does not function as expected. The programming port itself exposes the transmit and receive lines of the microcontroller. Along with a 5V power input and the microcontroller specific boot select and enable lines. The next component is a labeled net for GPIO17. This net will be connected through the header to the sensor itself on the sensor portion of the physical circuit board. After this, we come to a set of two headers. Both of these headers are for connecting to the wind speed sensors. The wind direction sensor produces an analog signal with a maximum voltage above the microcontroller's analog to digital converter maximum voltage tolerance. As a result, we pass the signal through a voltage divider with the center tap connecting to the input of the microcontroller. The next set of components on the right side of the microcontroller are the communications lines SDA and SCL for I2C. These lines are pulled up to power. They are also connected to the camera connector. The camera module is controlled by I2C and sends pixel data over the serial peripheral interface (SPI). The camera connector is based on standard tenth inch center headers. This allows for wide compatibility when we select the internal connector for the camera. This connection will likely be made using a cable to reduce the mechanical design complexity.

As a final note on the microcontroller schematic, we have included test points for all unused pins. These test points would be removed for a production design. They are prototype aids. The test points give us a good place to connect test equipment or rework the board layout without the need to order a new board and accompanying parts.

7.1.3 – Sensor Schematic

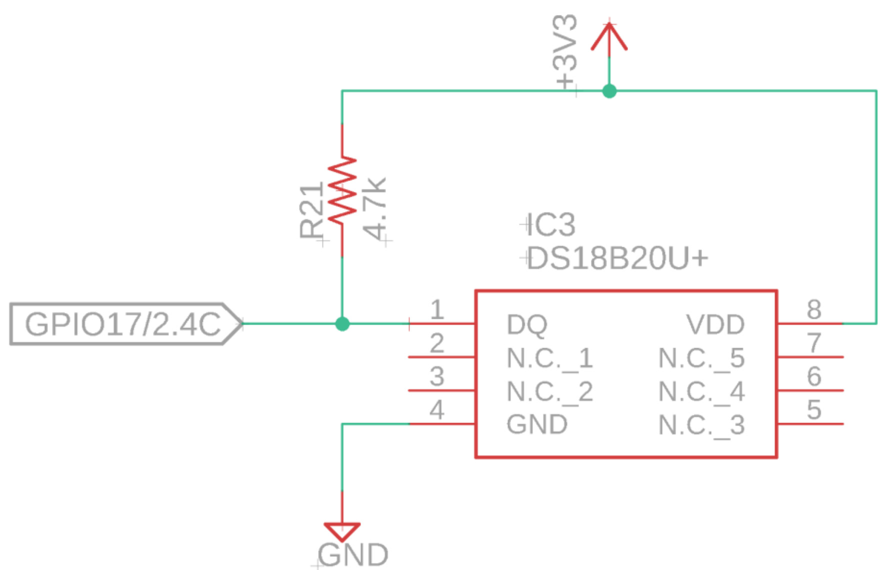
The sensor schematic consists of three I2C sensors and one 1-wire sensor. Though the sensors are populated on the same board as the microcontroller, the connections are made through the header in Figure 7.1.3.3 for prototype considerations discussed in the physical layout section 7.2.

Figure 7.1.3.1 – I2C Sensors



Three of the sensors in our design communicate using I2C. These sensors are all hooked to their respective supporting components individually while sharing the I2C lines. The first two sensors from left to right have settable addresses. These addresses may be set using a pull up resistor. We will leave this resistor unpopulated for both sensors to set the default address. The leftmost sensor is the BME280. This sensor is capable of either I2C communication or SPI communication. We pull the chip select and VDDIO pins high to enable the I2C interface of this sensor. All of the peripheral minor components for each sensor were chosen based on the respective datasheets.

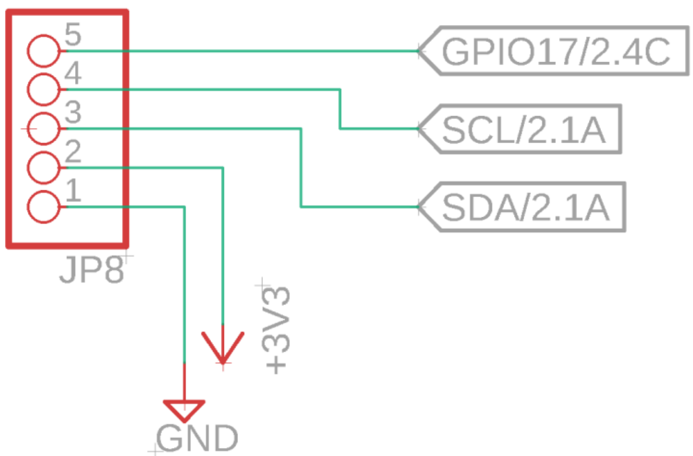
Figure 7.1.3.2 – DS18B20 Temperature Sensor



The DS18B20 sensor in Figure 7.1.3.2 is for accurately measuring temperature. The communication standard used for this sensor is 1-wire. This connection standard is developed by Dallas Semiconductor Corporation, the same company that manufactures the sensor. The 1-wire standard is tolerant to long distance for low speed communication.

The DS18B20 is available in several package types. We selected the largest surface mount part available. Size is not a restriction for this part of our design. We also gain the benefit of large pins when it comes time to build the prototypes. The package has eight pins, only three of which are connected either internally or externally. This sensor may be redundant to the BME280. However, the simplicity and low cost allows us to add the DS18B20 with minimal impact to the progress of the project.

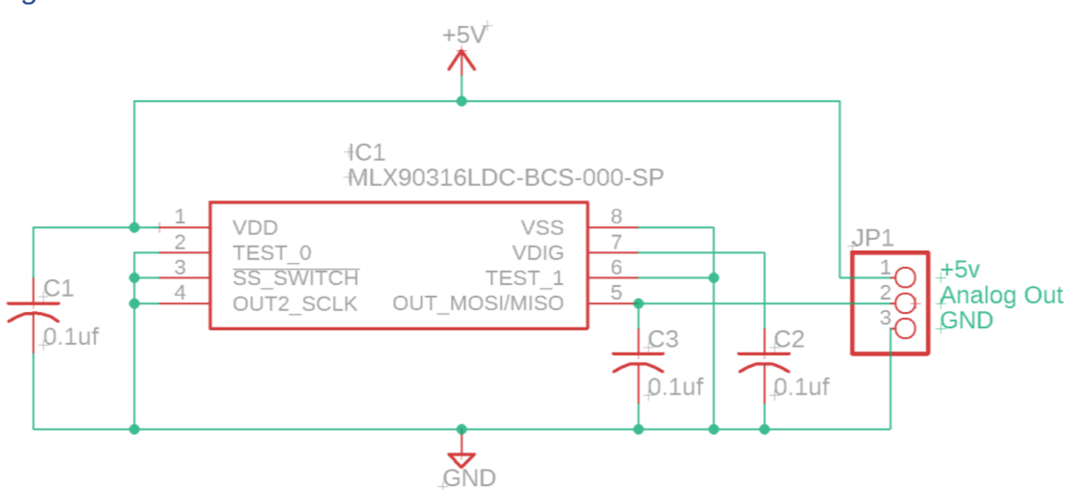
Figure 7.1.3.3 – Sensor Communications and Power Header



7.1.4 – Wind Direction Sensor Schematic

The wind speed sensor is the Melexis MLX90316 with its connections shown in Figure 7.1.4.1. This sensor is a rotary position sensor operating by measuring the magnetic flux passing through the part. During development, we used an evaluation board designed by Melexis featuring one of their 16 pin options. The 16 pin package offers two full sensors together on the same part. This additional functionality is not necessary for our purposes as we only need a single output. For this reason, we selected the 8 pin package for our prototype design. The function of the sensor we are using remains the same.

Figure 7.1.4.1 – Wind Direction Sensor Schematic



The MLX903016 is the only component in our design to require a 5 volt supply. It is important to note that this circuit is separate from the main circuit board. This explains the overlapping of component names. The header is tenth inch centers and connects to the corresponding input header on the main circuit board.

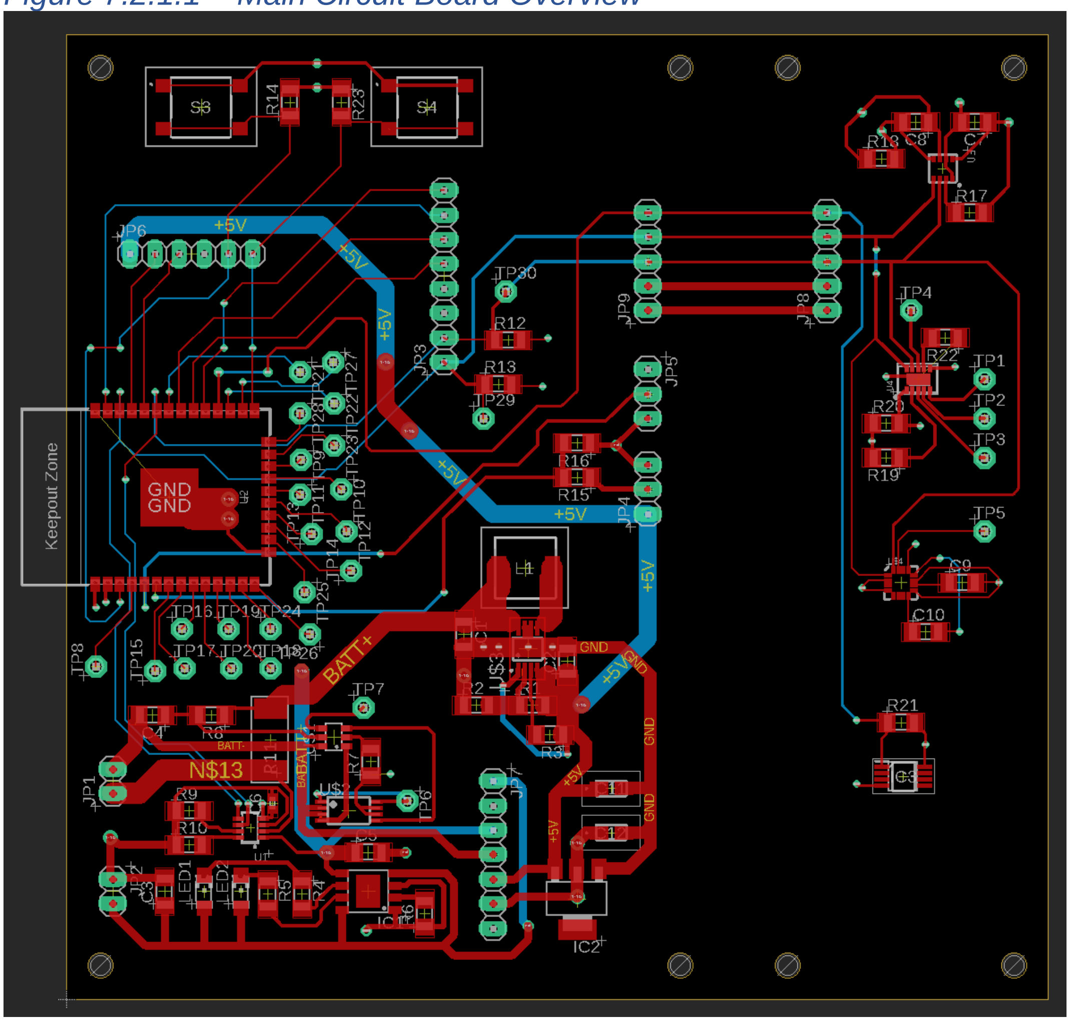
7.2 – Printed Circuit Board (PCB) Layout

The printed circuit board layout is the physical location and connection of each component in the electrical design. The layout has a direct impact on the physical mechanical design of our system. We need to consider the size of the finished circuit board and the location of the components. We will also need to consider any manufacturer recommendations for the physical layout of the parts.

7.2.1 – Main System PCB Layout

The main system PCB contains the microprocessor, power systems, and all sensors excluding wind sensors. The main PCB also houses all supporting minor components. We designed the main system PCB layout with prototyping and testing in mind. Additionally, we elected to use a 100mm square size to reduce the cost. We found that limiting the size and choosing a typical size reduces the cost of the PCB from the vendors.

Figure 7.2.1.1 – Main Circuit Board Overview



The main PCB is laid out to locate related parts near one another. We also carefully considered the physical layout of the 5 volt switching power supply. The layout is important for switching power supplies for three main reasons. First, the efficiency may be below the manufacturers rated capability. Second, the switching power supply may introduce noise into the power system. Noise on the power system may cause issues with other components that can be hard to detect. Third, the regulator may have unexpected behavior under high loads. We likely would not run into the third issue as, the supply is capable of approximately four times the expected current draw of the system. The manufacturer recommends a layout design in the datasheet for the part. We matched the electrical characteristics of the supporting components. We also matched the layout as closely as possible given the different footprints of our parts.

On the subject of power, we have chosen to create a four layer board. The top and bottom layers contain all the traces. The middle two layers are 3.3 volts and ground. We chose 3.3 volts as opposed to 5 volts for this layer because nearly all of the components run on 3.3 volts. With these power and ground planes, we may access either one from nearly anywhere on the PCB. This access is provided by small holes called vias. Eagle allows us to create a via and name it to the same net name as either power or ground. The connection to that layer is then made for us and we may connect our component to the via using a trace. We also recognize the benefits of noise reduction and shielding provided by the ground layer. A ground layer has a much lower impedance than a ground trace for each device. We also considered creating our ground pour on the bottom of the board. We ultimately decided against this as the noise reduction benefits are reduced as the traces on the bottom layer divide the ground plane. A final benefit to this design is the heat dissipation capability of these additional layers. By connecting devices to either continuous layer, the copper of the layer may spread the heat evenly across the PCB. This may be beneficial to our power circuitry as well as the microcontroller itself. An important consideration regarding the heat dissipation is the effect on the sensors. In testing, the BME280 in particular was very sensitive to waste heat from the other components.

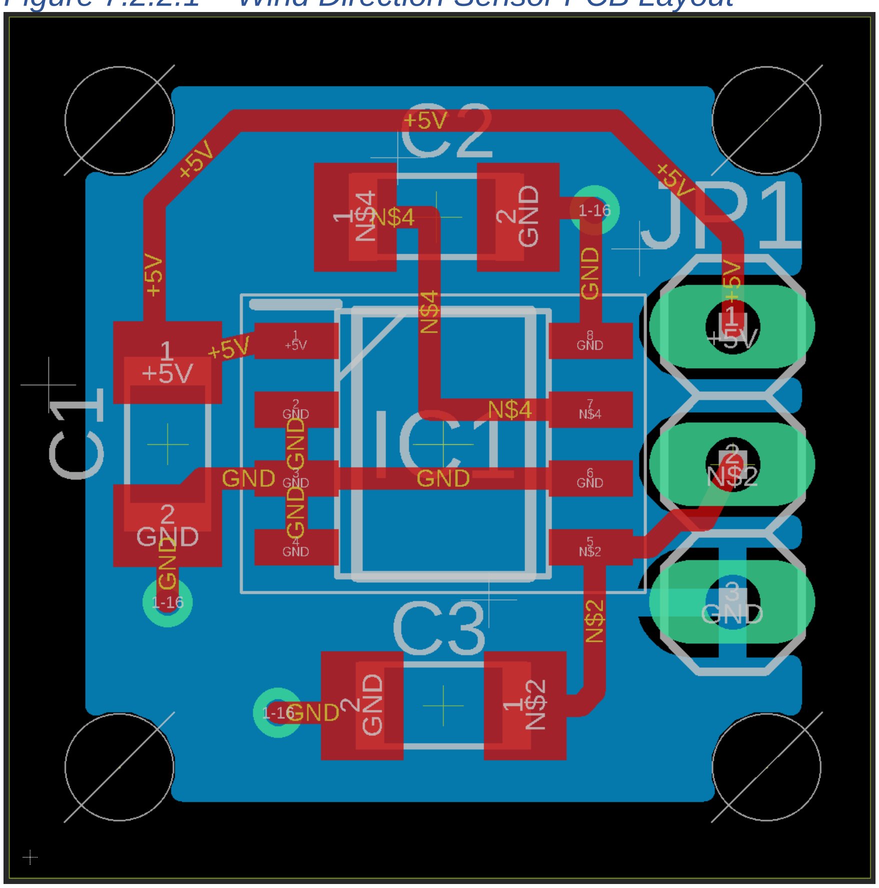
This consideration leads us to the next feature of our main PCB layout design, the division between the sensors and the rest of the circuitry. In Figure 7.2.1.1, we may observe some of the design considerations we made to support prototyping and testing. The first feature is the addition of two extra mounting holes on both the top and bottom center of the board. The second feature not pictured is the division of layers between these two sets of center mounting holes. There is no copper running through this area of the board. The only connection between halves is through the two five pin headers near the top center of the board. These design choices have two main explanations. First, the separation of ground and power layers may isolate any waste heat from interfering with the sensors. Second, should we need to move to further isolate them from the main circuitry, we may cut the circuit bord between the holes. We may need to utilize this feature either for mechanical design of the node or isolation from heat of the circuitry. We have left this as an option to allow for quick modification during our testing. Also, the cost is lower for one larger board than two smaller boards. Lastly, this form of design rework would save us time and money with minimal upfront impact. If we needed to move the placement of the sensors otherwise, we would need to reorder a new PCB and many of the components. This is a potential cost that our self-funded budget would not support.

The main PCB has all of the circuitry required for programming the microcontroller on board. A programming device is connected to the J6 header which exposes the transmit, receive, boot selection, and enable pins of the microcontroller. Additionally, the programming header allows the device to be temporarily powered from the programming device with a 5 volt input and ground lines. We also included buttons for the enable and boot selection pins. The buttons allow us to manually configure the microcontroller for accepting new programs should the need arise. The enable button may also be used as a reset button to reboot the microcontroller during troubleshooting.

7.2.2 – Wind Direction Sensor PCB Layout

The wind direction sensor is a separate PCB from the main PCB. The first reason for this is the wind direction sensors uses a strong magnet. During our testing, we found that the magnetic field from this magnet interfered with the accuracy of the compass. We were able to mitigate this interference by moving the magnet approximately one foot away from the compass. The second reason is to support a mechanical design. Both the wind speed and direction sensors require significant mechanical design. We may not reach the mechanical portion of the design within the scope of this project. In the event we are able to design a mechanical solution for these sensors, having them as satellite modules will greatly reduce the complexity of the design.

Figure 7.2.2.1 – Wind Direction Sensor PCB Layout



The physical design of the wind direction sensor PCB focused on a compact size. The compact size allows us to embed the device in a mechanical apparatus. We were able to create a board with a 0.65 inch square size. One of the methods we used to reduce the size is locating any parts possible on the main PCB. For example, the voltage divider consisting of two resistors is placed near the connector on the main PCB. The wind speed sensor is a two layer board. The bottom layer is an uninterrupted ground plane. The top layer houses all of the traces. This simple small design is low cost and fits the requirements of our system.

8.0 – Administrative

8.1 – Project Budget and Funding

The budget and the items that we plan to use for our project and the estimated price are shown here on Table 8.1.1.1 - Cost Estimate. We plan to have a budget of around $400-500. According to the table, the estimated total price would be $260.67, which satisfies the budget of $400-500. However, due to certain constraints the estimated price might change because we might plan to buy more materials and the prices might be different. We probably expect the total estimated price of all the items to be higher, most likely around $400 due to the vendors and because the shipping price of some products depending on the area might be more expensive.

The table below lists all the items that we plan to buy for our design and lists how many nodes of each item we plan to buy and the price of each node. It also lists the cost of the total amount of nodes from each item that we are going to use. As we researched further in our project and began to test some materials, we noticed that some products might be replaced or modified and that some costs might change. When we researched the product that we plan to buy, we had to search from many different types of vendors and know the exact product number. We also had to notice which products are currently in stock and the lead time. These types of information are presented in the last two table of the Bill of Materials below.

When we buy the materials for the design, we plan to buy them from online companies like Amazon due to its availability and price. Also, most of the material that we plan to use the most as the central part of our design such as the ESP32 microcontrollers are manufactured by ESP. Also, HiLetgo is another mostly used source for other nodes in our design such as other MCU’s, atmospheric pressure sensors, humidity sensors, and camera modules. Also, to test the solar charging, solar panels and batteries are being bought as well.

8.2 – Self Funding Cost Constraints

Some of the constraints that we had while buying products for our design included cost. We plan that the total price of the materials we buy doesn't exceed over $500. This can affect the types of products that we end up buying because depending how expensive they are, it can affect the quality.

8.3 – Bill of Materials

Table 8.3.1 – Bill of Materials with Manufacturer and Part Number

Part Number	Part Name	Manufacturer	Mfg. Part #	Quantity	Unit Cost
001	MCU-ESP32	Espressif Systems	ESP32-WROOM-32-N4	3	$8.00
002	BME280 - Temperature/ Humidity/ Pressure	Bosch Sensortec	BME280	3	$9.01
003	DS18B20 Digital Temperature Sensor	SUNFOUNDER	DS18B20	3	$12.99
004	CCS811 Air Quality Sensor	Digilent, Inc.	CCS811	3	$24.99
005	Current Sensor – INA219A	Texas Instruments	INA219A	3	$2.63
006	Solar Charge Controller – TP4056	JMoon Technologies	TP4056	3	$30.00
007	Battery Protection – DW01A	Unbranded	DW01A	3	$7.99
008	IC Part for Eval Board	Melexis	MLX90316KDC-BCG-300-SP	1	$6.71
009	Solar Panel	Solar Panel	6v 500mA PV	2	$15.99
010	Battery	Miisso	10000mAh	2	$16.99
011	3.3V Voltage Regulator	Texas Instruments	UA78M33CKVURG3	1	$0.92
012	5V Voltage Regulator	BINZET	B00J3MHRNO	1	$9.98
013	ArduCam Mini 2 MP	Arducam	OV2640	2	$8.99
014	Hall effect sensor	Module	OH3144	1	$1.62
Total					$156.81

Table 8.3.1 shows the bill of materials for the major components. This table gives us a good estimate of the cost of the project. For a single node, we expect a cost of approximately $150. This means to build our goal of 3 nodes, the cost will be $450 which is reasonably close to our agreed budget.

Table 8.3.2 – Component Availability

Part Number	Part Name	Vendor	Supplier Part #	Current Stock	Lead Time
001	MCU-ESP32	Espressif Systems	165-ESP32-WROOM-32-N4CT-ND	0	8 weeks
002	BME280 - Temperature/ Humidity / Pressure	DigiKey	828-1063-6-ND	220	In stock
003	DS18B20 Digital Temperature Sensor	Mechanic Surplus	DS18B20	In stock	In stock
004	CCS811 Air Quality Sensor	DigiKey	1286-1233-ND	2	9 weeks
005	Current Sensor – INA219A	Texas Instruments	296-23978-6-ND	0	35 weeks
006	Solar Charge Controller – TP4056	Roborium	JMTP40561	4	3-5 days
007	Battery Protection – DW01A	Ebay	DW01A DW01 SOT-23-6	2	Approx 5 weeks
008	IC Part for Eval Board	Mouser Electronics	482-90316KDC BCG300SP	80	7 weeks
009	Solar Panel	Ebay	CNC145x145-6	5	3 weeks
010	Battery	Amazon	B07H87HKKM	In Stock	2 days
011	3.3V Voltage Regulator	Newark	29AH8357	6,721	2-4 days
012	5V Voltage Regulator	Amazon	LTC0389-X	(In stock)	2 days
013	ArduCam Mini 2 MP	Amazon	M0023	(In stock)	Approx 3 days
014	Hall effect sensor	Module	OH3144	10	3 weeks

The electrical design was completed with component availability in mind. Table 8.3.2 shows the expected lead times of each of the major components. We also attempted to select components available from multiple vendors in the event a vendor runs out of stock of a component.

8.4 Milestones

Table 8.4.1 – Project Milestones

Senior Design Timeline	
Senior Design 1	
Date	**Details**
1/10/22	Project Brainstroming, and forming ideas with Computer Engineering group
1/11/22	Group formed
1/12/22	Decided project idea
2/3/22	Divide & conquer v1.0. Complete the D&C
2/4/22	Divide & conquer v1.0. Complete the D&C. Submit the completed D&C
2/9/22	Discuss the D&C with Dr. Richie
2/17/22	Updated Divide & Conquer Draft ready
2/18/22	Divide & Conquer v2.0 Due
2/21/22	Order parts for basic prototype
3/1/22	Assemble and test basic prototype
3/11/22	New Assignment on Standards
3/22/22	60-page draft final draft
3/25/22	**60 Page Paper due**
4/7/22	100 Page Paper final draft
4/8/22	**100 Page Report submission**
4/23/22	Final Documents draft
4/26/22	**Final Documents due**
4/29/22	Start assessing parts and order
Senior Design 2	
5/16/22	Classes begin
5/17/22	Plan May goals - Build and test components
6/20/22	June - Execute project and test software components
7/25/22	July – Finalized Prototype & Documentation
7/28/22	**Final presentations**
8/5/22	**Final day of class and submit document**

We as a group discussed the major components that were needed to be met by a particular date. Table 8.3.1 displays all the dates that showcases everything we planned from brainstorming and writing our first draft to production. The dates are divided by two semesters where the first semester contains the planning and drafting the product in documentation form from 1/10/22 to 4/26/22. The second semester begins from 5/16/22 and concludes on 8/5/22 which will comprise of development and production.

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