Wireless Mesh Network for Pesticide Spray Monitoring and Mapping

Design Document

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Executive Summary

With the global population projected to reach 9.7 billion by 2050, the demand for increased food production has never been more critical. Pesticides play a pivotal role in achieving higher crop yields, accounting for a 20–40% increase depending on the crop. However, proper pesticide application is essential to maximize efficiency while minimizing waste and environmental harm. Understanding pesticide spray distribution is vital for optimizing application techniques and ensuring coverage in target areas.

Our project focuses on developing a wireless mesh network using ESP32 microcontrollers to measure pesticide spray distribution across different levels of the crop canopy. Interdigitated electrodes (IDEs) designed by Claussen Labs will act as sensors to measure resistance, which correlates with pesticide coverage. By deploying IDEs at three canopy levels and integrating them with ESP32-based nodes, we aim to provide real-time, localized data on pesticide distribution under different application methods (e.g., drones, booms, airplanes).

Key design requirements include:

- Collecting resistance data from three IDEs at each canopy level to calculate an average.
- Ensuring each post is monitored by three ESP32 microcontrollers.
- Establishing a centralized node for data retrieval, enabling user-friendly data collection.
- Developing a robust wireless mesh network consisting of six to twelve nodes for reliable communication across the canopy.

Our design employs ESP32 microcontrollers due to their cost-effectiveness, long-range Wi-Fi capabilities, and ease of programming. The resistance measurements taken from the IDEs will be fed through a separate PCB made up of a Wheatstone bridge and a comparator. The circuit allows us to accurately convert resistance measurements to voltage. The step is imperative, as it allows the values to be input to the ESP32 analog-to-digital converter (ADC). The ESP32s will store these digitized voltage measurements on an SD card and then transmit the data through a mesh network of nodes. An additional microcontroller will serve as the centralized hub to collect and store the data in .txt files for post-analysis by our clients at Claussen Labs.

Progress so far includes finalizing our choices for our communication protocol, base station, and hardware components. We have also constructed our conversion circuit design, ran error analysis tests on the circuit, successfully established communication between microcontrollers, read and stored digitized voltage measurements via the ADC into a text file, and stored text files on an external SD card. Finally, we have begun the preliminary formatting of data for transfer and clock coordination.

The progress made this semester aligns well with our requirements. We have simulated voltage measurements from the resistance ranges of the IDEs, established communication between multiple nodes, collaborated with the client to determine what format is most user-friendly, and begun conglomerating nodes to create a mesh network. Our meeting with our client on December 4th has reinforced our confidence that we are on the right track.

We have an array of steps ahead of us as we transition into the second phase of senior design. The most imperative is finalizing the formatting of our data to efficiently transfer packages between microcontrollers. We also need to better calibrate the ADC to align with our client's needs and synchronize time across nodes. It's also important to begin testing our circuitry with actual IDEs with different saturation levels to finalize the design and order PCBs. Finally, we will need to begin scaling communication to meet the requirements for the number of nodes constructed. Overall, we feel equipped to plow ahead in our project.

Learning Summary

Development Standards & Practices Used

While pushing ahead in our project, we have and will continue to implement good practices in the hardware and software facets. Some hardware practices include the following:

- Proper grounding measures
- Implementation of safeguards such as diodes to stay within manufacturer-provided voltage inputs
- Verification of pull-up and pull-down resistors to avoid floating states and therefore unexpected digital responses.
- Conduction of hardware simulation before building physical circuits
- Selection of energy-efficient parts

Similarly, it is important to consider software practices, including:

- Adherence to C programming principles for ESP32 microcontrollers.
- Modulation of code to improve performance, flexibility, and decoding.
- Use of a Git library to collaborate among group members.
- Utilization of manufacturer-provided libraries, particularly for establishing the mesh network.
- Standardization of data text files to ensure reliability and readability.

The usage of standards is at the heart of any engineering practice related to our field. There are numerous IEEE standards applicable to our project. One is IEEE 802.11 lr, which governs Wi-Fi communication across the ESP32 mesh network. It is specific to the ESP32 microcontrollers' communication protocol. Another of relevance is IEEE 1588, which enables precise synchronization of clocks in measurement systems related to networks.

Summary of Requirements

As aforementioned, our key requirements include the following:

- Collecting resistance data from three IDEs at each canopy level to calculate an average.
- Ensuring each post is monitored by three ESP32 microcontrollers.
- Establishing a centralized node for data retrieval, enabling user-friendly data collection.
- Developing a robust wireless mesh network consisting of 6–12 nodes for reliable communication across the canopy.

Applicable Courses from Iowa State University Curriculum

Some of the most fundamental courses for our degree areas apply to our project. For instance, the core principles of circuit design covered in EE 2010 and EE 2300 have been invaluable to our hardware development. Without a firm grasp of operational amplifiers, diodes, voltage regulators, and Wheatstone bridges, our team would not have been nearly as successful this semester. The basics of troubleshooting and simulation techniques covered in these courses have also made the team far more efficient. EE 3030 has also been useful in determining power requirements and battery selection.

On the software side, one of the most influential classes has been CprE 2880. The class covered the fundamentals of embedded systems programming. It has been incredibly helpful in our development of low-level code that allows the microcontroller to read data, write it to a text file, and then transfer it. Other basic programming classes, such as ComS 2270 and EE 2850, have enforced our good practices in documenting code clearly and pulling from APIs. Finally, ComS 3090 has bolstered our understanding of software development. It has allowed us to more easily navigate the complexities of managing front-end and back-end team structure, which mirrors our software-hardware interaction and communication.

New Skills/Knowledge Acquired

Both as a team and as individuals, we have acquired an array of new skills and knowledge that were not explicitly taught in our curriculum. As a team, we have acquired plenty of knowledge specific to our microcontroller and overall project scheme. Previous to senior design, none of us had had the opportunity to work with mesh networks. It has taken plenty of time, effort, and focus just to understand the concept. In particular, it has challenged our software team to design communication schemes that can track data with time stamps and indications of which microcontroller or node data has been derived. The process requires the use of synchronous clocks, structured Wi-Fi packages, and other practices that we were either unaware of or simply not equipped for. We also have had to learn how to use the libraries manufactured for our specific microcontroller to utilize the ADC, store data locally on an SD card, and communicate between microcontrollers. It has taken patience to attain new skills and knowledge, but our software team has taken leaps and bounds to expand our understanding and begin putting ideas into action.

Our hardware team has also acquired plenty of new experience and skills in order to guide our project towards success. The members were required to learn new practices related to Wheatstone bridges, a type of circuit that measures resistance by balancing two legs of a bridge circuit. Through simulation and testing, our team has engineered a highly accurate circuit to measure the most fundamental data (i.e. the sensor saturation). The team has also learned how to do worst-case analysis sweeps. The strategy allows us to account for and calibrate out errors that we anticipate in our final design, specifically related to fluctuations in resistance measurements. The hardware team has made strides to develop the most precise circuit through patience, research, and asking for advisor feedback.

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List of Figures/Tables/Symbols/Definitions

1 Introduction

1.1 Problem Statement

With the global population projected to reach 9.7 billion by 2050, the demand for food will require a 60%-110% increase in production. Improved pesticide use will be necessary to improve crop yields and achieve this goal. However, increasing the efficiency of pesticide application requires new techniques to spread pesticides more precisely and minimize waste.

Our project focuses on the creation of a wireless mesh network using ESP32 microcontrollers to measure the pesticide spray distribution of a corn crop. Interdigitated electrodes (IDEs), developed by the Claussen Labs research group, will be positioned at three levels of the canopy to gather resistance readings. These readings will provide a numerical value for the amount of pesticide reaching these three levels. Data collected from the network will be transmitted to a central node, a microcontroller, allowing users to analyze pesticide spray efficiency and optimize future pesticide application practices.

1.2 Intended Users

Several key user groups will interact with or benefit from the product, including researchers, graduate students, and farmers. Each of these has distinct needs related to the project, and the product will provide them with valuable data to help optimize pesticide usage and improve agricultural productivity.

Nathan Jared, a researcher and PhD student at Iowa State University working with Claussen Labs, has a background in Mechanical Engineering and experience in Chemical Engineering research. His role involves developing sensors to measure pesticide distribution. Nathan needs accurate data from the IDEs (interdigitated electrodes) placed throughout the cornfield to evaluate the efficacy of his designs. By obtaining precise resistance readings from the sensors, Nathan can identify inefficiencies in the current design and adjust the sensors accordingly to enhance their performance. The wireless mesh network we are developing will allow Nathan to receive data from many nodes at once, minimizing the need for manual data collection and reducing the time needed for troubleshooting. This data will ultimately help him refine the sensor design, improving pesticide measurement accuracy, and contributing to more efficient crop management practices.

Griffin Ellis, a graduate student also working at Claussen Labs, collaborates closely with Nathan Jared and the Senior Design Project team. As a Mechanical Engineering student, Griffin focuses on the technical aspects of the project, such as system calibration and programming. His main goal is to ensure the sensors function correctly and that their data can be used to refine his calibration algorithms. Griffin needs access to data from the IDEs to fine-tune the software responsible for analyzing pesticide distribution. The wireless mesh network we are building will provide Griffin with the data necessary for calibration, making his process more efficient by providing consistent and reliable feedback from the sensors. This will help him better understand the real-world performance of his program and optimize the system for precise pesticide application.

Farmers can majorly benefit from the technology of our project. Farmers rely on efficient farming practices to maintain the health and productivity of their crops. Their primary need is to ensure that their fields are evenly coated with pesticides, preventing both under-application, which could lead to pest issues, and over-application, which would waste resources and harm the environment. The product we are developing offers a significant benefit to farmers by providing real-time data on pesticide distribution. This information will help them adjust their pesticide application methods, ensuring that their fields receive the proper coverage and reducing the risk of crop damage or pesticide runoff. Ultimately, this will lead to improved crop yields, reduced costs, and more sustainable farming practices goals that align with the overarching problem of increasing food production efficiency to meet global demand.

Appendix

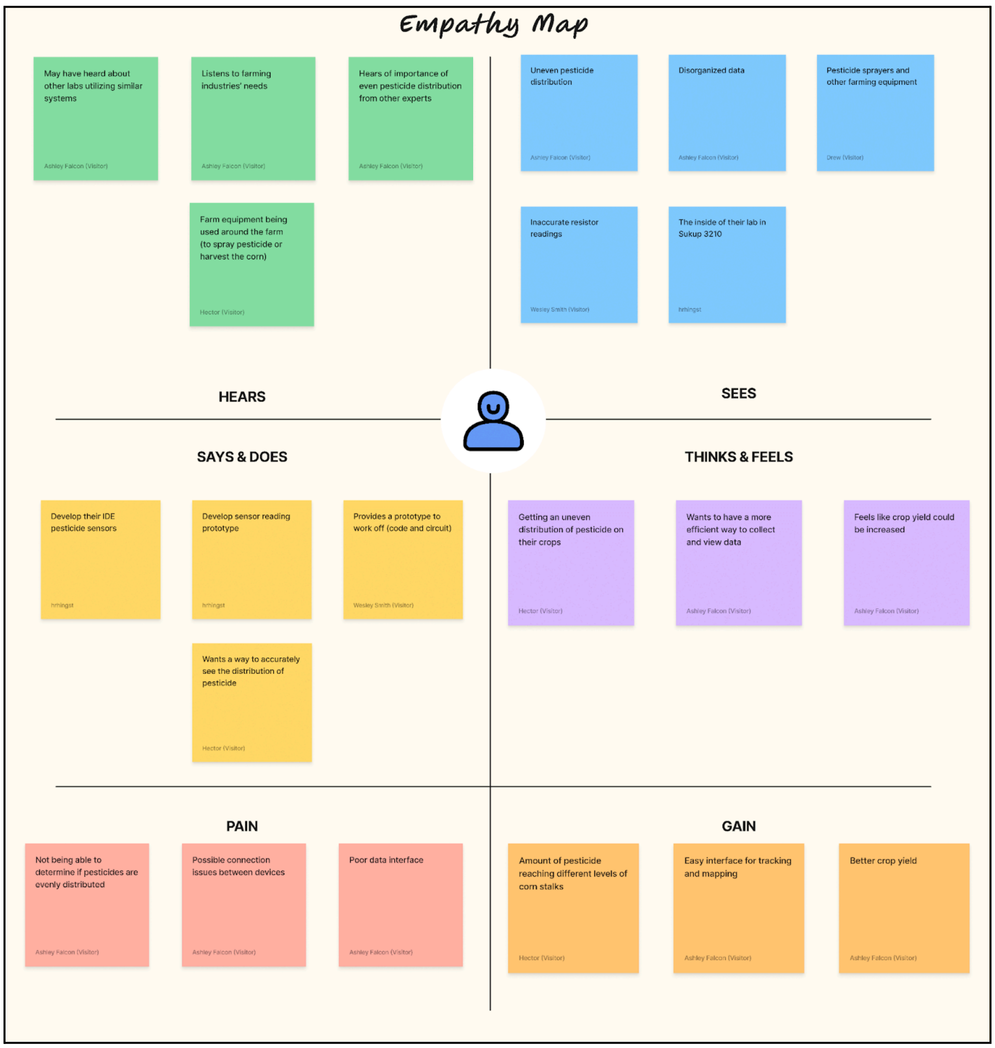

Figure 1.2.1: Empathy map of the user base for this project

2 Requirements, Constraints, and Standards

2.1 Requirements & Constraints

Functional Requirements

The wireless mesh network for pesticide spray monitoring and mapping will have to store the measurement of resistance across the interdigitated electrodes (IDEs). These IDEs will be placed at three levels of the crop canopy with ESP32 microcontrollers which will transmit the data (resistances) to the master node. The wireless mesh network will be implemented using ESP32 microcontrollers (MCU). The transmitted data will be stored in a user-friendly format, such as a .txt file, for future analysis. The network supports real-time data monitoring, allowing users to check measurement consistency. The system will have a low power consumption and long-term deployment in the field. The mesh network will have a minimum of six to twelve nodes.

Resources Requirements

Sensors

The sensors (IDEs) will be placed on three levels of a corn canopy. Each will be connected to an ESP32 microcontroller. Each level will have a minimum of three IDEs, so each pole will consist of nine IDEs and three ESP32 microcontrollers, and the sensor's accuracy will be ±1% of actual resistance with minimal noise. The sensor will be operated for three hours on battery power and will send voltages to the microcontrollers that are connected which will communicate and send information to the master node.

Master Node

We must have a master node and a centralized device to communicate to all the nodes and receive data from them, this device will be another ESP32 microcontroller. This master node will collect all the data being received and organize it in a user-friendly format that can be accessed at any time. The master node will have a sleep/wake command for the nodes to verify that the nodes are functioning.

Mesh Networking

Each ESP32 will act as a node in the mesh networking system. The ESP32 will have the capabilities of long-term and reliable communication and communicate directly to the master node. The transmitted data should not be lost and will be communicated with a minimum of nine sensor nodes. Each of the nodes will have a distance of two-hundred feet from other nodes, this way the nodes are still able to communicate with one another. The master node will periodically send commands to wake the ESP32 nodes to get the data and the operational status. This networking system will support real-time data transmission, which allows users to receive data from the master node.

2.2 Engineering Standards

IEEE 802.11s [1]

This standard defines protocols for creating a wireless mesh network using Wi-Fi and supports broadcast/multicast and unicast data delivery. This will apply to our transmission on the data line. Multiple data transmissions can occur to and from the master node.

IEEE 1588 [2]

This standard defines synchronizing time across distributed systems using precision time protocol (PTP) and ensuring high-accuracy timing. This is important to our project because we are going to be receiving multiple values from the sensors which will be transmitted to the master node. Our system requires consistent and accurate timing which will provide the user with accurate and reliable real-time data analysis.

IEEE 802.15.1 [3]

This covers Bluetooth BR/EDR (Basic Rate/ Enhanced Data Rate). This standard is designed for wireless networks and low-power wireless communication between devices. In our project, Bluetooth LE is designed and will be used for low-energy and periodic communication.

IEEE 1801 [8]

This standard is designed for power management and low power in integrated circuits (IC). Our circuit contains integrated circuits which help with the power efficiency of our circuit as a whole.

3 Project Plan

3.1 Project Management/Tracking Procedures

We've chosen the waterfall approach as our project management plan because this will allow us to achieve our goal step by step and effectively. This approach fits best in our project because it involves iterative execution and does not advance to the next phase until we finish the current phase.

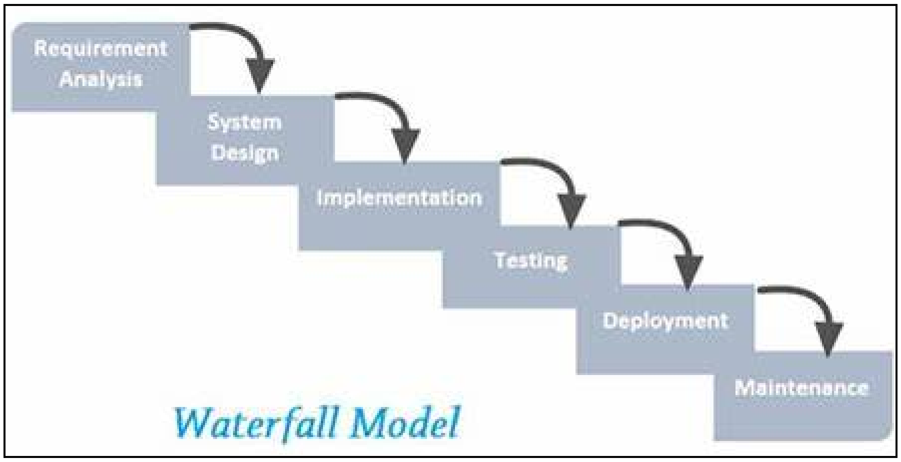

Figure 3.1.1: Project Management Style: Waterfall Model

Our team is divided into two groups: software and hardware. Software groups leveraged platforms like GitHub as the primary repository. The source code is primarily uploaded to a GitHub repository to share with all the other team members. Meanwhile, the hardware group shares the simulation files among team members. They collaborate closely on circuit testing, and ensure that hardware and software components are aligned through each project phase.

3.2 Task Decomposition

Our focus is building a prototype with a single pole with three levels of microcontrollers each with three IDEs rather than replicating the whole system setup. The final system will easily be scaled by duplicating our initial design. The diagram shows a stage approach for our project. Tasks range from designing a circuit to read the sensor data to receiving and transmitting data through the completion of the mesh network.

Following the diagram from the bottom up, the hardware group members will start by designing circuits that allow sensors to read accurate data. We designed a Wheatstone bridge circuit with our sensor, providing an output range of 0.1V - 1.1V. Software group members then write firmware to implement the Wheatstone bridge circuit that can capture the sensor reading accurately and stably. Then we will use the ADC internal to the microcontroller to do so. After that, we will start designing an SD card circuit to write and store our data in the SD card for backup. Once again, the software team will collaborate to create the firmware.

Next, we will implement the data transfer with 802.11 LR, setting up the mesh network with dummy data and testing the functionality of the mesh network. Once the mesh network is functioning properly, we will start collecting real-time data from the sensor and aggregating the data into a .txt file into the SD card and the base station.

Once we are confident that our data is transmitting correctly, we will set up a web server in which an external PC can download the text file from the base station. We will need to ensure the file is formatted in a way that's easily readable by those using the data.

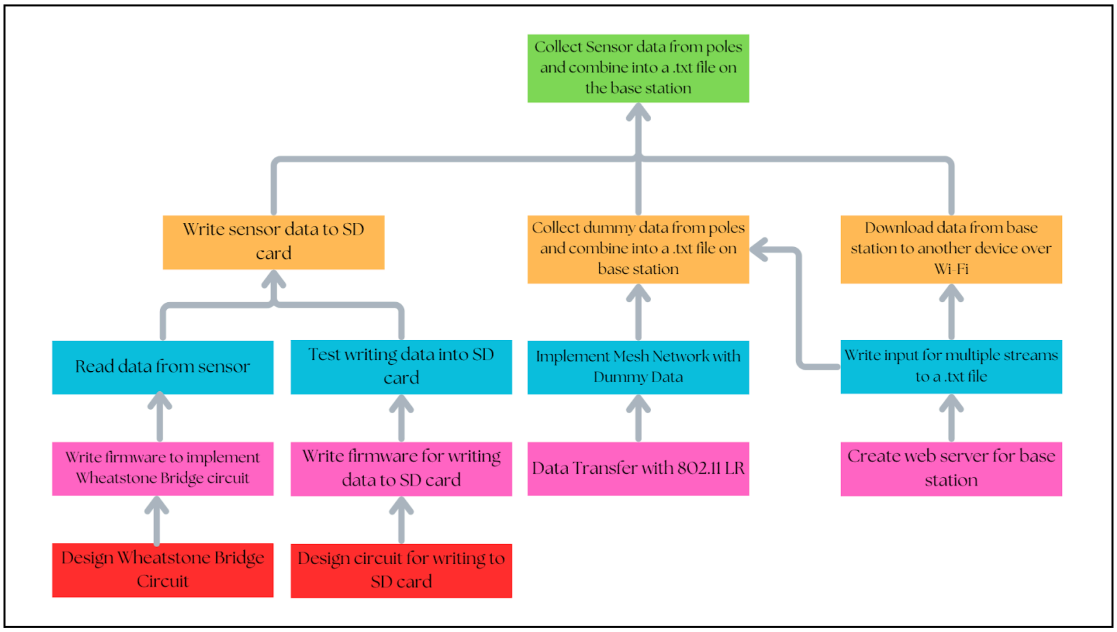

Figure 3.2.1: Flowchart of Our Project

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Goal 1: Collect dummy data from poles and combine them into one .txt file on the base station.

Task 1: Data transfer with 802.11 LR

Achieve a data transmission rate of at least 95% packet success over a distance of at least 10 meters with minimal latency. The progress will be evaluated by ensuring successful ping communication between nodes and measuring both average and maximum latency values.

Task 2: Implement Mesh Network with Dummy Data

Achieve a packet reliability of at least 90% with a redundancy built-in in the system. The progress will be measuring the reliability of the network by the ratio of the successfully routed packets and the total packets sent.

Goal 2: Download Data from Base Station to Another Device Over Wi-Fi

Task 1: Create a Web Server for the Base Station

To create a web server that can handle simultaneous connection from a device with a response time that is less than 200ms. The progress will be evaluated by latency testing, it will take the average and maximum time to load data from the server interface.

Task 2: Write input from Multiple Streams to one .txt file

The data from all nodes is consistently combined into a .txt file with less than 0.5% data loss or corruption. This task will be evaluated by comparing the transmitted and received data sets. We will measure the time that took to update the .txt file with the data from all different nodes.

Goal 3: Write Sensor Data to SD Card

Task 1: Read Data from Sensor

- Subtask 1: Design Wheatstone Bridge Circuit
  - Design a circuit that can output consistent voltage readings less than an error of 0.1%.
- Subtask 2: Write firmware to implement Wheatstone Bridge Circuit
  - Design a firmware that can read resistance values with an error of less than 0.5%. The value will be compared to the expected value to ensure the accuracy.

Task 2: Test Writing Data to an SD Card

- Subtask 1: Design a circuit for SD card
  - The circuit will be able to let the SD card write and read data with an error of 0.5%. This will be monitored by testing the error rate through the writing operation and compared to the total operations.
- Subtask 2: Write firmware for the SD card functionality
  - The firmware should be able to write data with an error rate of less than 0.5%. This will be measured by the speed of data writing for fixed size and verify the error of less than 0.5% data corruption across multiple write and read operations.

3.4 Project Timeline/Schedule

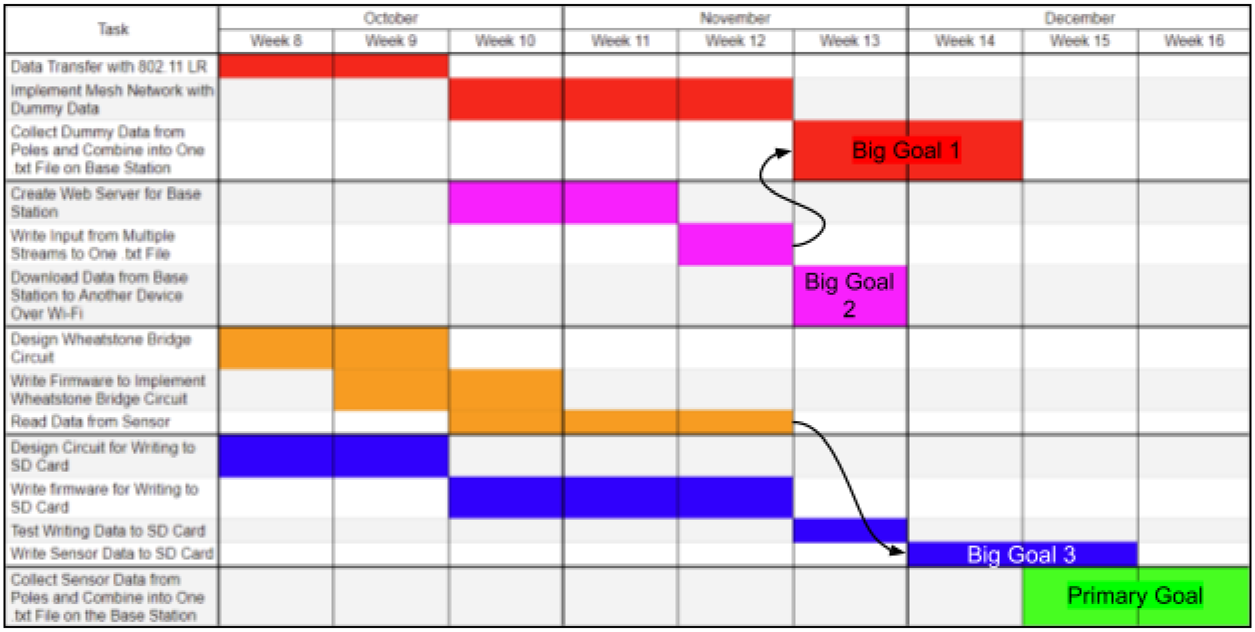

Figure 3.4.1: Timeline of Our Project

This is the rough timeline that we created for this class. We made one Primary Goal, collecting sensor data from the poles and combining it all into one text file at the base station, as the endpoint for the semester which we aim to complete by/at the end of the semester. We divided this Primary goal into 3 "Big Goals," collecting dummy data from the poles and combining it all into one text file at the base station (complete by the end of week 14), downloading data from the base station to another device over Wi-Fi (complete by end of week 13), and writing sensor data to an SD card (complete by end of week 15). Each of these 3 "Big Goals" were broken down into sub-goals, with sequential deadlines.

3.5 Risks and Risk Management/Mitigation

Risk	Probability	Mitigation Strategies
Not being able to complete the project on time	5%	• Regularly adjust the project timeline based on the progress • Break down the task into smaller, easier-to-track progress • Adjust team members or resources as needed
The connection of the mesh network is unstable	20%	• Conduct extensive testing in both lab and field • Test with alternative wireless protocol if having interference issues • Consider using a longer range of

		communication modules ● Improve the communication of the firmware and sensor
Incorrect sensor reading	10%	● Implement signal filter circuit/ averager & summer circuits ● Replace sensors if needed ● Revise the designed circuit that captures sensor outputs
Power Management	10%	● Select batteries designated for the circuit ● Design the circuit with a battery holder for easier replacement
Inability to make process or text files user-friendly	5%	Collaborate with client to see how straightforward it is Make clear instructions for retrieving text files

Table 3.5.1: Risk Management and Mitigation

3.6 Personnel Effort Requirements

Task	**Done?**	**Total Hours**
Design Wheatstone bridge circuit	Y	35
Finalize circuit PCB	N	10
Download ESP32 repositories and Linux	Y	5
Initialize and calibrate ADC to take voltage values	Y	10
Implement IDE into the Wheatstone circuit	N	15
Design circuit for SD card writing	N	30
Write firmware store data on SD card	N	20
Test and troubleshoot SD card data	N	15
Establish protocol framework for data transfer	N	15
Troubleshoot data transfer errors	N	25
Implement and test mesh network with known values	N	15
Combine known values into text file	N	8

Create a web server for base station	N	5
Write input from multiple streams to text files	N	15
Determine how to download data from base station	N	5
Format and simplify text values	N	5

Table 3.6.1: Task Decomposition List

Via our task decomposition list, we have established individual tasks seen on the left side of the table. We keep a running document each week of how we are splitting project-related tasks and constantly communicate with our advisor for advice on short-term goals.

The hours may seem like a lot, but we think it is reasonable and accomplishable with a project of this scale and with 6 people splitting man hours. For instance, while something may take 2 people only 5 hours to do, that means it's 10 man hours. Hence, we think we have a reasonable sum of hours.

Finally, it is important to note that these are purely estimates. Certain tasks may be accurately measured, while others may take far more time. That is why it's important to over rather than underestimate. We've done this to some extent by separating implementation from testing for multiple tasks. We expect to run into issues and are prepared to address them. We also understand that more tasks may be added.

3.7 Other Resource Requirements

There are several tangible and intangible resources we will require. Some include software, Wi-Fi, IEEE codes, online databases, and people.

As mentioned, our project requires various forms of software. The Software team relies on coding environments and Linux terminals to initialize and flash to the microcontroller. It will also apply to the base station and the ability to properly output a text file. The Hardware team also relies on various simulators and CAD software. They have used LTspice to mock and test their Wheatstone bridge. They will eventually need to replicate it in ECAD so that a final version of the PCB can be ordered.

This network also relies on Wi-Fi and wireless communication. It is important that we understand the limitations of wireless "reach." For instance, the corn stalks will limit our communication ranges.

IEEE resources and codes are imperative for our project. Specifically, Wi-Fi has stringent rules we must abide by to maintain best practices. We are currently using the 802.11 IEEE standard to ensure our use of a wireless network is properly and ethically implemented. We will rely on future standards for using physical hardware and servers.

Next, it is important to take advantage of existing resources. For instance, Espressif (the manufacturer of the ESP-32 microcontroller) has endless repositories and code outlines that can reduce man hours. For instance, much of the existing ADC initialization and implementation code could be easily drawn from their GitHub repository. Since we are pulling from the same databases, our code is more uniform, increasing readability and compatibility.

Finally, and maybe most importantly, we must lean on our clients and advisors for information. There is only so much that we can research and troubleshoot, and at a certain point, it is critical to approach the people guiding our project. They have far more knowledge and experience that has proven to be invaluable. Roadblocks will be far easier to overcome by relying on our mentors.

4 Design

4.1 Design Context

4.1.1 Broader Context

List of relevant considerations related to our project in each of the following areas:

Area	Description	Examples
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., the solution is implemented in their communities)	Increasing/reducing exposure to pollutants and other harmful substances, increasing/ reducing safety risks, increasing/ reducing job opportunities
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	Development or operation of the solution would violate a profession's code of ethics, implementation of the solution would require an undesired change in community practices
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	Increasing/decreasing energy usage from nonrenewable sources, increasing/decreasing usage/production of non-recyclable materials
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	Product needs to remain affordable for target users, creates or diminishes opportunities for economic advancement, high development cost creates risk for organizations

Figure 4.1.1: Broader Context

4.1.2 Prior Work/Solutions

John Deere Operations Center

This system integrates precision agriculture tools with IoT and provides comprehensive field monitoring. However, it relies on centralized cloud-based data processing, which may introduce latency issues and limit scalability for remote fields without robust internet access. [10]

CropX Soil Monitoring System

This solution uses wireless sensors for real-time soil moisture and temperature monitoring. While effective for soil conditions, it lacks capabilities for monitoring pesticide application metrics. [11]

SmartSpray Technology

Recent advancements in smart spraying technologies include systems that use camera-based sensors and AI to optimize pesticide application. These systems, while innovative, are often expensive and limited to proprietary platforms. [12]

4.1.3 Technical Complexity

Microcontroller Network (ESP32-C6 Nodes)

Engineering Principles

- Implementation of IEEE 802.11s for wireless mesh communication
- Configuring the ESP32-C6 microcontrollers to handle real-time data acquisition and transmission
- Synchronization of multiple nodes within a mesh network to ensure reliability and scalability

Mathematical Principles

- Signal processing techniques to filter and normalize data from sensors before transmission
- Optimization algorithms for dynamic routing and load balancing in the mesh network

Scientific Principles

- Electromagnetic theory for efficient base station placement and Wi-Fi signal propagation

IDE Sensors and Wheatstone Bridge Subsystem

Engineering Principles

- Designing a Wheatstone bridge to measure changes in resistance due to pesticide spray deposition
- Integrating sensors with microcontrollers via analog-to-digital converters (ADC)

Mathematical Principles

- Ohm's Law and voltage divider equations to calculate resistance changes accurately
- Calibration curves to correlate sensor resistance with pesticide spray concentration

Scientific Principles

- Principles of material science to understand the IDE sensor’s sensitivity and response to the sprayed chemicals

Power Management System

Engineering Principles

- Utilizing batteries with voltage regulators and inverters to maintain stable power for sensors and microcontrollers
- Implementing energy-efficient designs to prolong system operation in remote agricultural fields

Mathematical Principles

- Power budgeting to ensure all components operate within their specified voltage and current limits
- Efficiency calculations for voltage conversion and energy storage

Scientific Principles

- Electrochemistry for battery performance and longevity under variable environmental conditions

Base Station Subsystem

Engineering Principles

- Configuring an ESP32-C6 as a base station to collect, aggregate, and transmit data to a remote server
- Implementing error correction and secure data protocols to ensure data integrity and privacy

Mathematical Principles

- Compression algorithms to minimize data size during transmission
- Statistical analysis for preliminary data insights at the base station

Scientific Principles

- Principles of wireless communication for seamless connectivity between nodes and the base station

Conclusion

The integration of multiple subsystems, each relying on distinct scientific, mathematical, and engineering principles, demonstrates the technical complexity of our project. By addressing a range of challenging requirements from real-time data processing to energy efficiency our system aims to provide a robust, scalable, and precise solution that aligns with and surpasses existing industry benchmarks.

4.2 Design Exploration

4.2.1 Design Decisions

ESP32-C6

The ESP32-C6 has built-in Wi-Fi capabilities, low power consumption, and energy efficiency. All these functions are critical for our project since we will deploy the poles in a cornfield, and batteries will supply it. The connection between the nodes will be relatively stable, allowing us to transmit and receive the resistance data. ESP32-C6 supports a higher standard Wi-Fi with a stable connection and faster speed. This will be suitable to our case due to the high counts of microcontrollers placed in the field, this will not interfere with other nodes. The ESP32-C6 has a built-in security feature which is WPA3, enhancing the network's data protection. Using this microcontroller to build out wireless mesh networks can be easily scaled to different ranges, and it can cover more area by adding the pole in the field.

Placement of Interdigitated Electrode (IDE)

We will place the sensors on three different levels, each of which has three sensors. This allows us to get a more comprehensive analysis of the pesticide spray distribution. The sensor at different heights will capture different data during the spray. The sensor's placement is critical because the data we get will affect the spray techniques.

Base Station

We will use an additional ESP32-C6 as our base station to store the data from multiple sensor nodes. A central node will allow us to manage and analyze data from the whole mesh network. The microcontroller has the capability to store the data from six to twelve nodes from the mesh network in a .txt file. The ESP32-C6 has a built-in long-range Wi-Fi protocol which will make it far easier to transmit data between nodes and the base station.

Wheatstone Bridge

The Wheatstone bridge design in our circuit aims to get a precise resistance voltage from the IDEs. Due to our needed accuracy resistance measurement, a Wheatstone bridge will be better than a normal voltage divider. Wheatstone bridge circuit is more sensitive to small value changes; in our case, the sensor will measure different resistances ranging between 100k to 200k ohms. The ratio-based circuit will reduce the error created by the supply voltage fluctuations. We selected an op-amp with low noise and high input impedance, LMC660, which allowed us to output the range between 0.1V to 1.0V.

4.2.2 Ideation

Raspberry Pi Built-in Wi-Fi Locally stored/ external storage Access remotely Low power consumption	**Arduino** Low power consumption Support basic data storage Lack of real-time processing	**Industrial Standard** Might require specific soft for data access High cost High reliability Weather proves
ESP32-C6 Limited data storage Low cost Low power consumption	**Data Collection For Wireless Mesh Network**	**Cloud-Based** Real-time data collection High cost Depends on cellular coverage
Laptop with Data Software Large data storage High power consumption Less durable Complex data analysis	**Custom Build(SD Card)** Low power consumption Customizability Limited Capability Data management challenge	**Lo-Ra** Long-range data collection Low power consumption Depends on the range

Table 4.2.2: Comparison of Data Collection Solutions

4.2.3 Decision-Making and Trade-Off

During our decision-making, we focus on five aspects based on the project requirements:

Criteria	Weightage
Data Storage Capacity	20%
Power Efficiency	15%
Real-time Data Processing	25%
Measurement Accuracy	20%
Cost	20%

Table 4.2.3: Criteria and Weightage of Data Collection

Data Storage Capacity

Based on these criteria, we have chosen the ESP32-C6 as our central device for the data collection in our mesh network system. The ESP32-C6 has built-in flash memory, which is enough for moderate data logging. Pairing this with external storage such as an SD card enhances its capacity for larger data sets, especially for long-term data collection. In our case, we need our system to collect data for 3 hours. This decision allows us to ensure this happens.

Power Efficiency

The ESP32-C6 is designed for low-power applications. It supports various power-saving modes, making it an energy-efficient choice. This microcontroller is especially useful in remote installations, where battery life is crucial. This also reinforced our decision.

Real-time Data Processing

With a relatively high processing power and Wi-Fi 6 capability, this microcontroller is suited for low-latency data processing applications. The Wi-Fi feature allows faster data rates and reduced latency, which is essential for real-time processing in a distributed network.

Measurement Accuracy

Accuracy largely depends on our sensors provided by Claussen Labs. However, the ESP32-C6's reliable 12-bit ADC (analog-to-digital converter) and other input interfaces support accurate sensor data capture, making it a solid choice for environmental sensing applications such as pesticide spray monitoring.

Cost

The ESP32-C6 is known for its affordability compared to other microcontrollers with similar capabilities. Priced at nine dollars, it allows for the scaling of our project to cover multiple nodes without exceeding budget constraints.

4.3 Proposed Design

4.3.1 Overview

Our design will collect and conglomerate pesticide data. Essentially, we will scatter sensors throughout a corn field at different crop canopy levels that record pesticide saturation at that point. Each sensor will have a microcontroller to which it will feed data. In basic terms, the microcontroller acts as a digital log to collect the sensor measurements. Data can then be sent between these microcontrollers and eventually to a central node (see Figure 4.3.1). The central node acts as a base station where all sensor data ends up. It allows researchers to remotely pull all pesticide saturation data from one station. The measurements will be organized into a user-friendly text file.

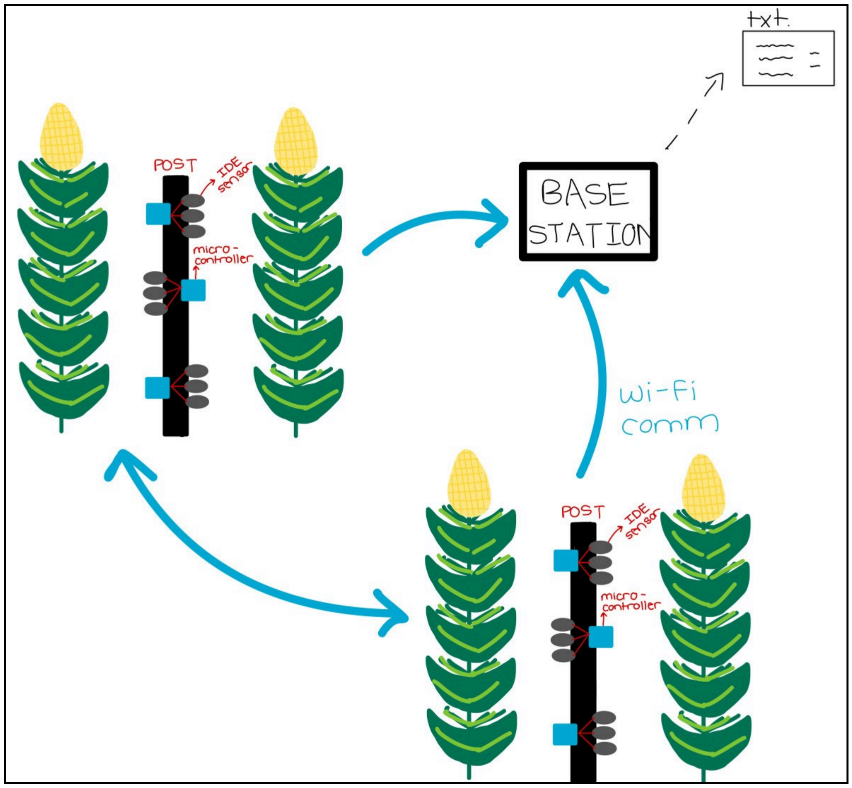

Figure 4.3.1: Simplified overview of the communication system

4.3.2 Detailed Design and Visuals

The goal of our project is to develop a wireless mesh network that assists in the monitoring and mapping of pesticide spray. Using interdigitated electrodes (or IDEs) developed by Claussens Labs, we can collect resistance values at different levels of the crop canopy. These values will correlate to the pesticide saturation at that level of the post.

Each post will have nine different sensors (IDEs) connected to three different microcontrollers or nodes. Acting as a gate between the sensors and microcontrollers will be a PCB. The PCB is known as a Wheatstone bridge circuit. We have designed it to take in a resistance value and convert it to a corresponding voltage. It is an imperative step since the microcontroller takes in data via voltages rather than resistance values. It does this via its built-in ADC (analog-to-digital converter). The digital voltage values will be converted back into resistance measurements through programming. Next, the output will be written to a physical SD card in addition to being transmitted (see Figure 4.3.2).

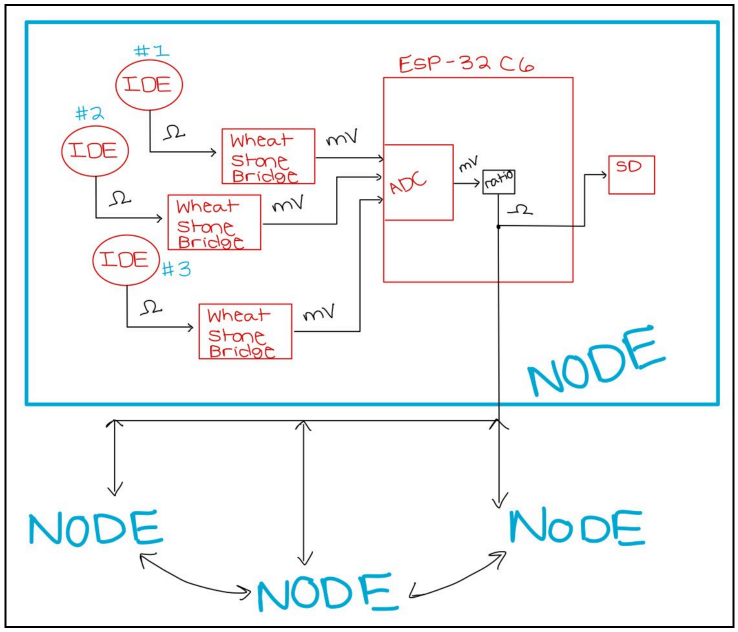

Figure 4.3.2: Block diagram of the sensor data path

The microcontrollers will transmit the data between nodes (i.e. other microcontrollers scattered throughout the field) and to the base station by a mesh network. A mesh network is useful as it allows data to be transmitted between poles, reducing the need for all microcontrollers to be within the base station's connectivity range. We will utilize the built-in long-range Wi-Fi on the ESP32-C6 microcontroller to consolidate the data at the central node into a user-friendly text document that researchers can pull and analyze. Researchers will thus be able to gather data remotely and automatically, reducing time in the field and increasing productivity.

Our project will propel Claussen Labs forward in their expedition to determine which pesticide distribution methods are most efficient. With an ever-growing world population, determining the best means of pesticide application is necessary for creating dependable and high-yield food sources.

4.3.3 Functionality

In this design, researchers or farmers can efficiently monitor pesticide distribution across a crop field. To begin, the user places sensor-equipped poles in different field areas, each with ESP32 microcontrollers that form part of a mesh network. After powering on the devices, the user goes to a central node accessible via a laptop with an SSH connection over Wi-Fi and sends a wake signal that activates all sensor nodes. The central node displays the status of each node, ensuring they are ready for data collection.

As the user applies pesticides, each sensor node records data on pesticide levels at various canopy heights. The user can monitor network health and confirm that all sensors are operational via terminal commands on their laptop. When the application is complete, the user returns to the central node, issues a command to stop data recording, consolidates data at the central node, and puts all the nodes into sleep mode to conserve power.

Next, the user retrieves the data by downloading a .txt file from the central node, which contains all recorded readings for analysis. Additional terminal commands allow the user to monitor network status and troubleshoot as needed, providing feedback on each node's connectivity. Overall, this design streamlines field monitoring, allowing the user to control the mesh network and data collection from a single interface, reducing manual handling of each sensor and making the system easy and efficient for field operations.

Timeline			
Step	Action	System Response	User Benefit
1	Pole Setup	Nodes initialized in sleep mode	System conserves energy until needed
2	Wake-Up Signal	Nodes activated and confirm presence	User confirms all nodes are active
3	Pesticide Application	Nodes continuously collect data	Insights into pesticide application over time
4	Application Completion	Nodes sleep; data compiled to .txt file	Full record of pesticide distribution
5	Data Retrieval	User obtains .txt file for analysis	Enables post-analysis and optimization

Table 4.3.3: Timeline of system use/functionality

4.3.4 Areas of Concern and Development

In this design, several key concerns need to be addressed to ensure it meets user requirements effectively in a real-world agricultural setting. One primary challenge is crop height interfering with network connectivity. Dense or tall crops may block signals between sensor nodes, potentially leading to data gaps in the mesh network. To counter this, we’ll experiment with network topologies and node placements, and possibly strengthen signals with additional hardware. Another concern is data accuracy, as environmental conditions like humidity or interference from other devices can distort sensor readings. Developing calibration protocols that account for these factors will be essential, and cross-verifying data with multiple sensors may help filter out inaccuracies.

Sensor calibration itself is a crucial factor, as inconsistencies among nodes could lead to unreliable measurements. Regular calibration, potentially with an automated feature at startup, will help maintain uniformity in data collection across the field. Additionally, power management is a challenge due to the energy needs of the distributed sensor nodes. By implementing low-power sleep modes, optimizing data collection intervals, and facilitating rechargeability, we aim to ensure battery life without compromising data coverage. Scalability also presents a challenge as field sizes and monitoring needs increase. Larger networks might require more sophisticated data routing and adaptive node configurations to handle increased loads without compromising performance.

Overall, the current design largely meets user needs by providing a flexible, SSH-based interface that allows users to control data collection and monitor network status centrally. However, ensuring consistent performance across various field conditions and scaling the system for larger fields remain concerns. To address these, we plan to conduct testing to evaluate connectivity, implement sensor calibration protocols, test energy efficiency features, and simulate larger network topologies.

For further development, we'll seek client and advisor feedback on acceptable data accuracy and frequency requirements to help us fine-tune data collection protocols. Additionally, they can provide insights on power management with ESP32-C6 microcontrollers in remote setups, and guidance on calibration techniques for environmental variability, which will be invaluable in refining our approach to better meet user expectations and real-world conditions.

4.4 Technology Considerations

For our project, we are using both internal and external technologies. Both forms of technology will still be used together and are ultimately going to be connected. First, the ESP32-C6 microcontroller, as explained before in our design decisions, the ESP32-C6 has various strengths such as built-in Wi-Fi capabilities, low power consumption, and energy efficiency. Next, our circuit design includes a Wheatstone bridge which allows us to precisely measure the resistance of an unknown resistance, which will be coming from our pesticide sensor. Although the Wheatstone bridge is more sensitive to voltages compared to a simple voltage divider it also allows for more accurate resistance measurements, which is exactly what we need for our project. Finally, the pesticide sensors provided to us by Claussen Labs are a part of our Wheatstone bridge. When the time comes to spray pesticide on the crops, this sensor will be doused with a certain amount of pesticide depending on the location of the sensor. The amount of pesticide on our sensor will give us a certain resistance measurement which will be stored in an ESP32-C6.

When it comes to the technology available that has similar functions to our project, there is a good amount of products to look into. First, the Libelium [6], allows the monitoring of multiple environmental parameters involving a wide range of applications, from plant growing analysis to weather observation. The strengths of this technology are; that it supports 30 different sensors covering critical environmental parameters such as soil moisture (can also do temperature, humidity, solar radiation, wind speed, and rainfall), easy to deploy, functional wireless mesh network, and energy efficient. The weaknesses of the Libelium are; high cost ($5,000 - $20,000) for the whole system, complex maintenance, connectivity issues in remote areas, and low data security. Another available technology is the iMETOS [7], which has the strengths of real-time data access from the platform, alerts for critical weather events, durability to harsh weather, and integration with other sensors. The weaknesses of this technology are Doesn't directly monitor pesticide spray, poor connection in some areas, high initial cost ($1,500 - $3,000), and a complex setup.

For our project, we looked at these available technologies and found possible solutions and designs that could be implemented into our project. Including the solutions and resources provided to us by our client, we were able to narrow down and start designing our own circuits and mesh networks. For our circuit, which will be connected to the sensors and microcontroller, we initially started with a simple voltage divider. This worked but had to have such a high resistance that ultimately caused a lot of room for unexpected error. We then found the solution of the Wheatstone bridge, which can be seen in Figure 4.5.1. This new circuit allowed us to lower the resistances and lower the room for error, it did not erase it but it allowed us to be able to control it easier. Additionally, the new feature of the Wheatstone bridge resulted in more accurate voltages and it also made it easier to find certain voltages due to being able to easily change resistance values on either side of the bridge.

4.5 Design Analysis

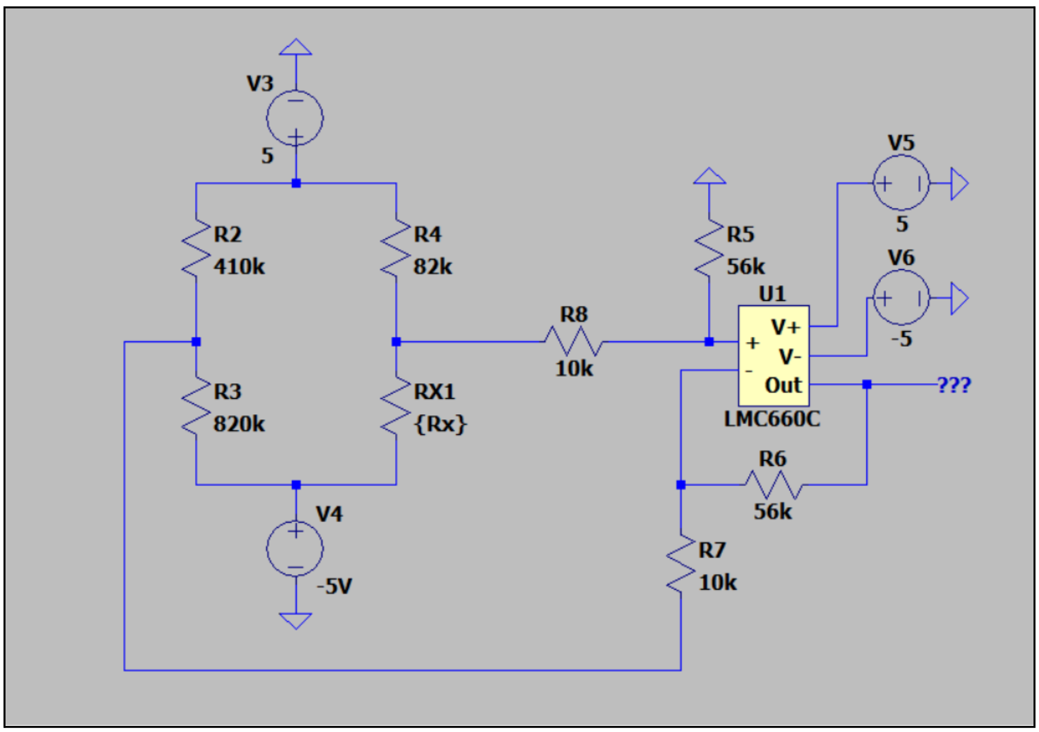

Figure 4.5.1: Circuit Design

On the hardware side of our project, we have built a circuit shown in Figure 4.5.1. The circuit will be implemented with the pesticide sensors provided to us by Claussen Lab. The circuit consists of two big parts, the Wheatstone bridge and a Differential Amplifier. The Wheatstone bridge is the left side of the circuit diagram and its function is to measure an unknown resistance, in our case, it would be our sensor, by balancing two branches of a bridge circuit. This bridge allows us to get accurate voltage readings to then send through the differential amplifier. The differential amplifier, which is the right side of our circuit diagram, takes two input voltages and outputs the difference between the two. After the differential amplifier, its output will be sent to the ESP32 microcontroller, specifically the ADC of the microcontroller, where the voltage will be converted to the resistance value of our sensor.

When we are not able to get on campus to use the voltage sources and other instruments to test our circuits, we simulate them on LTSpice. From our experience, both forms of testing work well and even give us very similar results. Currently, we are working on redesigning the circuit due to some unexpected errors occurring. Through LTSpice, we ran a worst-case scenario on the resistor components which led to an output voltage that was out of our range, to fix this we are currently working on reducing resistor values as well as changing our reference voltage to give us a bit of room for slight error that is out of our control. This worst-case scenario is Figures 8.3.1-8.3.3 attached in the appendix portion.

For the future, we are planning on adding a power source and voltage regulators. This will allow us to power our circuit with batteries and regulate the voltage that is coming from the batteries and entering our circuit to consistently have an input of 5 volts. Additionally, we plan on adding diodes after our differential amplifier to prevent too much voltage or too little voltage from entering the ADC of the microcontroller.

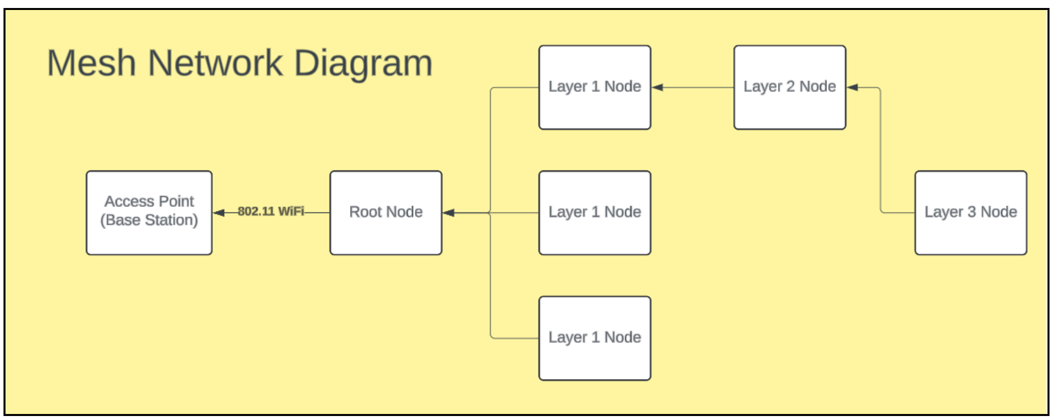

Figure 4.5.2: Mesh Network Design

For the networking side of our project, which will be used to transfer sensor data to a central node, we have successfully set up a mesh network framework created by Espressif. It works by programming a single ESP32 (the base station) as an access point. It is to this ESP32 that all the rest will form a network to connect to. The rest are flashed as mesh nodes. They are given the SSID and password for the access point. Upon being turned on they search for both the access point and other mesh nodes. The nodes automatically organize themselves into a network where any ESP32 can send a Wi-Fi packet to any other ESP32 in the network. Theoretically, the network is self-healing meaning that if a node were to be disconnected, the remaining nodes would reorganize to reconnect any other nodes that were connected to the disconnected node.

This current implementation is functional, however there are several areas to be improved. Firstly, the whole network uses conventional 802.11 Wi-Fi. To meet the requirements of our project we will likely need to use 802.15.4, a special long-range Wi-Fi protocol developed by Espressif. Another area that could be improved is that by default only one node connects to the access point (base station). This means that all traffic will need to be routed through one board which could prove to be an issue with the 802.15.4 protocol's low bandwidth of ~250kbps. It would be beneficial if multiple nodes could be connected to the access point to avoid bottlenecks in the network.

5 Testing

5.1 Unit Testing

For the circuit we created, the unit that is being measured is voltage. With the design that we have created, the amount of pesticide that covers our sensor will create a resistance value and when this resistance value is introduced to our Wheatstone bridge, the two sides of the bridge will be put into a differential amplifier which will take the difference of the two voltages and will multiply it by a gain that we set. The output will be a voltage in the range of 0.1-1.1 volts, to ensure the ADC component of our microcontroller is not damaged. The tools we used to get the voltage values are LTSpice and the multimeters in the labs in Coover Hall.

5.2 Interface Testing

One interface being used by our project is the mesh event handler provided by Espressif. It is a piece of software that handles many of the core functions of creating, maintaining, and using a mesh network of ESP32-C6 microcontrollers. It allows us to schedule tasks such as sending or receiving packets over the network. Because of how integral the mesh network is to our project this interface will need to be tested thoroughly. What the interface does when packets aren't received by their recipient, what happens when the network gets too congested, and what happens to the packets addressed to a node that disconnects unexpectedly are all things that will need rigorous testing. To test these, we will likely only need the ESP32-C6 boards.

Another interface that will need to be tested is the analog-to-digital converter on the ESP32-C6 chip that we are using to collect sensor data. We will need to test how accurate the measurements of the ADC are, how it handles any mistakes in connecting the sensor and Wheatstone bridge, and how repeatable its measurements are. To do this testing we will likely need an ESP32-C6 board, pesticide sensor, Wheatstone bridge circuit, multimeter, and possibly an oscilloscope.

5.3 Integration Testing

Our project has three major integration parts. These include the circuit that consists of our sensor which is connected to the analog-to-digital converter (ADC) of the microcontroller. Following this connection is the connection to the master node, which is another microcontroller that collects and stores the information being received from other microcontrollers. These integration parts will be tested by looking at the data being collected by the microcontrollers and verifying that the voltage values the ADC is converting to resistance values are within our 1% acceptance range. Following this test, we will test how the microcontrollers communicate with one another.

5.4 System Testing

For the hardware side of our project, we tested many different circuits in two ways, in the lab and through LTSpice. We conducted tests on this circuit using the voltage sources and multimeter provided to students in the Coover Hall labs. LTSpice was used to test the margin of error that our circuit could potentially have, which helped with tuning the components of our circuit to give us the desired voltage results.

5.5 Regression Testing

As we planned our hardware implementation, we looked into ways to prevent hardware malfunctions. These malfunctions could occur when too much voltage is introduced to the ADC component of our microcontroller. After the hardware implementation and verifying that the circuit is reliable and accurate, it is also important to ensure the code for our microcontrollers, both the microcontrollers that will be collecting data and the master node that will be communicating with all others and storing the data, is organized to find any potential regressions. Since the hardware and software are going to be directly working together, it is crucial that both are reliable as well as stable.

5.6 Acceptance Testing

We will ensure that our design requirements, both functional and non-functional, are being met by creating a spreadsheet with all of our test cases and requirements. This will be used to keep track of the testing status and results. It will also ensure that all team members have somewhere to see what functionality to consider outside of their own assigned work. We will involve our client in the acceptance testing process by creating prototypes for them. We'll ask them to use them and tell us what they think so that we can revise our design to fit their needs better.

5.7 Security Testing

Security testing isn't necessarily important to our project. The data that is being sent over our network isn't sensitive as it is simply sensor data, and commands used to start and stop recording data. The mesh network framework from Espressif also implements the same security features one would expect from any other Wi-Fi device, such as WPA2 encryption.

5.8 Results

For the hardware side, our goal was to find a way to relate the output voltage of our circuit to a resistance value. Included, Figure 5.8.1, shows a polynomial fit equation that relates our voltage to a resistance. The results we got were the results that were desired but due to a new requirement from our client, we will have to slightly redesign our circuit to meet a new range of resistance values that the sensor can output.

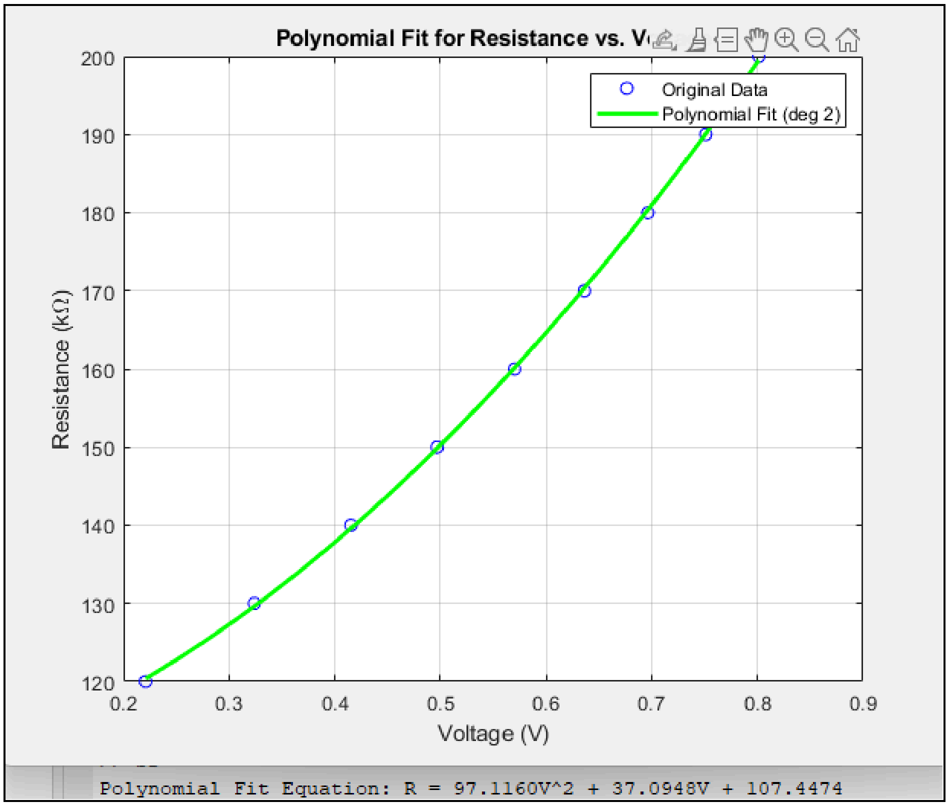

Figure 5.8.1: Voltage vs Resistance Graph

After our final circuit is complete the next step is to print a PCB and test it to verify that it still meets the design requirements of our client. Following the PCB design, our team will combine all our components, which include the PCB, the microcontroller, the master node, and our power supply. Finally, we will further test our project as a whole in a corn crop field, to verify we are receiving the desired data and make sure it is being organized in a way that the client and users can easily understand.

6 Implementation

The integration phase of our project is still in development, with the detailed implementation plan yet to be fully solidified. However, we have established a general approach for how the integration process should proceed. At this stage, most of the individual circuit components have been selected, and we are refining their specifications. Once the designs and testing of these components are finalized, we will move forward with comprehensive system testing. Our current unified circuit with all components present is in Figure 6.1.1. Following successful testing, the next step will be the design and fabrication of a custom PCB to house the circuit components, which will take place in the upcoming semester. Concurrently, we have developed a strong understanding of the software requirements, ensuring that the integration of the hardware and software components will be seamless.

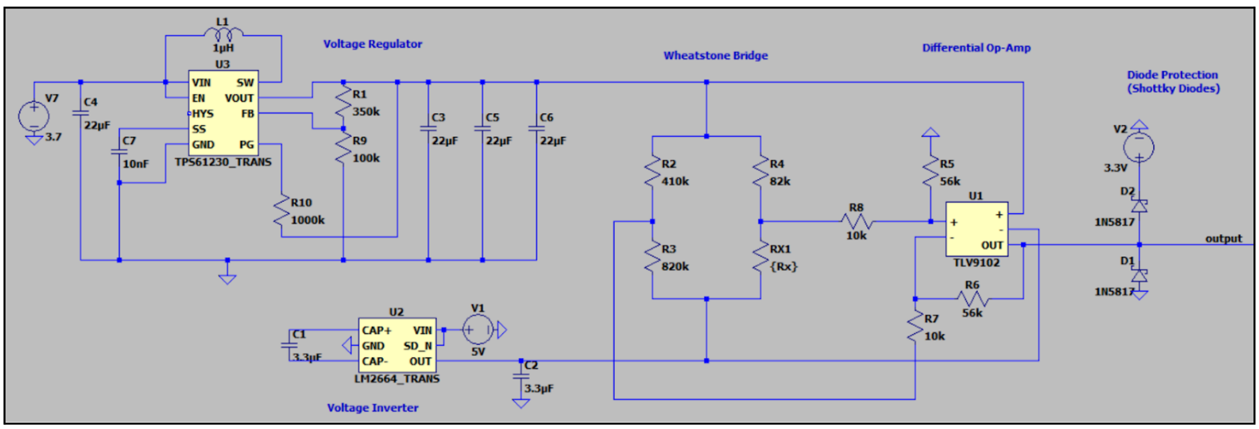

Figure 6.1.1: Unified Circuit Design

7 Ethics and Professional Responsibility

7.1 Areas of Professional Responsibility/Codes of Ethics

This discussion is with respect to the paper by J. McCormack and colleagues titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012 [9]

Area of Responsibility	Definition	Corresponding IEEE Ethics Code	Team Interaction
Work Competence	Deliver high-quality work with integrity, timeliness, and professional expertise	6) Maintain and improve our technical competence and undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations	Our team ensured that all tasks were carried out with the highest quality, adhering to timelines, and maintaining professional competence, while also ensuring that any limitations were fully disclosed and addressed
Financial Responsibility	Provide products and services that offer tangible value while ensuring they are delivered at a cost-effective price	5) Seek, accept, and offer honest criticism of technical work, acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others	Our team ensured that the products and services delivered were of realistic value and cost-effective by actively seeking and incorporating honest feedback, correcting any errors, and maintaining transparency in claims and estimates based on available data
Communication Honesty	Provide accurate, transparent, and clear reports of work to stakeholders, ensuring no deception or misrepresentation		Our team maintained clear and honest communication with all stakeholders, ensuring that technical work, progress, and estimates were reported accurately while acknowledging the contributions of all members and addressing any errors transparently
Health, Safety, Well-Being	Actively reduce risks to the safety, health, and overall well-being of all stakeholders	1) Hold paramount the safety, health, and welfare of the public, strive to comply with ethical design and sustainable development practices, protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment	Our team primarily focused on the technical development of the wireless mesh network, ensuring that the project met the functional requirements while minimizing risks where possible
Property Ownership	Respect the property, ideas, and information of clients and others by ensuring their proper use and protection	9) Avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors, or any other verbal or physical abuses	Our team has maintained a focus on the technical aspects of the project while ensuring respect for the property, ideas, and information provided by the client
Sustainability	Safeguard the environment and natural resources at both local and global levels	1) Hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and disclose promptly	Our team has made efforts to ensure the project adheres to ethical design practices by considering the environmental impact of pesticide applications and aiming to improve the efficiency of spray distribution

Social Responsibility	Develop products and services that positively impact society and contribute to the well-being of communities	factors that might endanger the public or the environment	Our team has considered social responsibility by ensuring that the wireless mesh network for pesticide monitoring is designed to improve agricultural efficiency, with an emphasis on minimizing environmental impact through precise pesticide application

Table 7.1.1: Mapping Area of Responsibilities

Our team is performing well in the area of social responsibility by focusing on developing a system that benefits society and communities. Our project addresses the critical need for sustainable food production by reducing pesticide waste and environmental contamination through precise monitoring and data collection. We are creating a scalable, user-friendly system that empowers farmers to make informed pesticide application decisions, ultimately improving resource efficiency and minimizing environmental impact. This approach upholds our ethical and professional responsibilities by ensuring data accuracy, enhancing sustainability, and providing equitable access to technology for diverse agricultural communities.

One area in which our team needs to improve is sustainability, specifically in protecting the environment and natural resources both locally and globally. While our project aims to optimize pesticide application and reduce environmental damage by preventing overuse and minimizing pesticide drift, our current focus is primarily on precision through IDE sensors and a wireless mesh network for efficient pesticide spray measurement. To enhance sustainability, we should consider optimizing energy use in our system, selecting more sustainable materials for our sensors and components, and accounting for the long-term environmental impacts, including how we manage and dispose of equipment. This would not only make our solution more eco-friendly but also contribute to more sustainable agricultural practices.

7.2 Four Principles

	Beneficence	Nonmaleficence	Respect for Autonomy	Justice
Public health, safety, and welfare	Increase crop yield and accessible food sources.	The design will ensure certain foods are not oversaturated with pesticides.	Enables individuals to feed themselves despite the population growth.	Positive outcomes will affect all individuals evenly and fairly.
Global, cultural, and social	Promote a culture of affordable and sustainable food.	The FDA will further govern to protect from negative impacts once brought to the public.	Some anti-pesticide culture could be infringed on.	Since we're in the research stages, public opinion can still be taken into consideration.
Environmental	Pesticides are directly	Avoidance of	Some concern for	Ensure design does

	applied to plant life.	oversaturation and therefore damage.	crops applied with pesticide.	not interfere with the health and layout of crops.
Economic	Affordable food due to high yields from even pesticide distribution.	Design is simple and affordable.	Will enable small farmers to have high yield crops.	Simplicity of design will make it affordable to small farmers.

Table 7.2.1: Four Principles for Pesticide Design

One important broader context-principle pair for this project is Public health, safety, and welfare - Nonmaleficence. The project aims to develop a system that ensures pesticides are distributed efficiently and evenly within targeted crop canopies, avoiding oversaturation that could lead to harmful pesticide residues in food or environmental contamination. This promotes public health by reducing the risks associated with improper pesticide application, such as health issues in consumers and environmental damage. To ensure these benefits, the design will prioritize accurate, reliable measurements from IDE sensors and robust data transmission to a centralized node. This will enable stakeholders to make informed decisions about pesticide application rates and methods, minimizing unintended harm.

Conversely, the project currently lacks in the Global, cultural, and social - Justice area. While the system promotes efficient pesticide use, it may not fully account for the diverse perspectives and cultural practices of anti-pesticide communities. These groups may feel marginalized or see the project as a challenge to their values. However, this limitation is counterbalanced by the project's broader positive impacts, including increased food accessibility and sustainability. To address this gap, our team could engage with diverse stakeholder groups, including those skeptical of pesticide use, to incorporate their feedback. This could involve designing the system to be adaptable for use with organic or alternative pest control methods, ensuring the project aligns with a broader range of cultural values.

7.3 Virtues

3 Virtues Important to the Team

Integrity

<u>Definition</u>

Upholding honesty, transparency, and ethical behavior in all project-related tasks and interactions.

<u>Actions to Support</u>

- Ensure clear and honest communication within the team and with stakeholders, reporting progress truthfully and acknowledging limitations or errors.
- Commit to ethical design practices, prioritizing environmental and societal impact alongside technical functionality.

- Foster accountability by encouraging team members to take ownership of their tasks and responsibilities.

Collaboration

Definition

Working effectively as a team by valuing diverse perspectives, leveraging individual strengths, and maintaining mutual respect.

Actions to Support

- Hold regular team meetings to share updates, brainstorm solutions, and provide constructive feedback.
- Promote open dialogue and equal participation to ensure all voices are heard, regardless of discipline.
- Use collaborative tools like shared project management platforms to track tasks and foster transparency.

Excellence

Definition

Striving for high-quality outcomes through diligence, professionalism, and continuous improvement.

Actions to Support

- Set clear goals and timelines, ensuring the team meets project milestones with attention to detail and precision.
- Review and test designs rigorously to ensure the final product meets or exceeds client expectations.

Virtues Important to Team Members

Henry

Demonstrated Virtue: Broad Perspective

- **Importance:** All team members, especially those in leadership roles, must be able to "zoom out" their view of the project in order to understand the full scope of the project better in order to make proper design decisions and do their work with the rest of the system as a whole in mind.
- **What I Have Done:** My major, Computer Engineering, has given me a broad exposure to engineering topics from Electrical Engineering to Computer Science. This has allowed me to, at least partially, understand every part of our project and make proper decisions on our system design.

Undemonstrated Virtue: Sociability

- **Importance:** Ultimately, engineers are human and thus social. A team of friends is more likely to be successful and productive than a team of strangers. The rest of my team were already friends before our project and I hadn't met any of them before this semester.
- **What I Could Do:** In the coming semester I will likely need another member of our team to help me with the mesh network aspect of our project which will give me an opportunity to socialize with my team instead of simply only interacting for the purpose of farthing our project.

Ashley

Demonstrated Virtue: Communication

- **Importance:** Healthy, productive, and consistent communication is fundamental to a team structure. It is imperative that we speak to our accomplishments, shortcomings, and areas needing improvement.
- **What I Have Done:** I have acted at the group liaison between our team and our advisor. I also ensure tasks are actively assigned so that we are all on the same page. Open communication has allowed us to avoid the trap of unclear responsibilities.

Undemonstrated Virtue: Confidence

- **Importance:** It is important to maintain respect for oneself in all situations. Confidence allows us to be less easily toppled by challenges, and enables us to be unafraid of failure.
- **What I Could Do:** I could work on asking more questions and being comfortable vocalizing confusion. I need to trust my capabilities and accept shortcomings with optimism rather than defeat.

Drew

Demonstrated Virtue: Altruism

- **Importance:** Altruism emphasizes contributing to the greater good, fostering collaboration, and advancing projects for the benefit of all.
- **What I Have Done:** Actively assisted team members with tasks, such as troubleshooting code and discussing project strategies.

Undemonstrated Virtue: Eloquence

- **Importance:** Eloquence enables clear, impactful communication, especially when explaining complex technical concepts and ensures ideas are conveyed effectively, fostering understanding and collaboration with clients and team members.
- **What I Could Do:** Focus on presenting ideas clearly and confidently in team meetings and client interactions and prepare well-organized talking points and practice delivering explanations in a concise, understandable manner.

Hector

<u>Demonstrated Virtue: Adaptability</u>

- **Importance:** The ability to adapt to any shift regarding any new client demands, small problems, or working around the schedules of each member is important when working as a team.
- **What I Have Done:** I have helped the hardware team create a circuit that meets the needs of our client. As a team we had to redesign our circuit numerous times to fit the needs of our client as well as be as efficient and accurate as possible.

<u>Undemonstrated Virtue: Creativity</u>

- **Importance:** Creativity is important because it allows us to improvise and act in innovative ways to solve problems.
- **What I Could Do:** When the team faces a problem, I could help the team by thinking outside of the box to hopefully find a solution for the problem that arose.

Yok

<u>Demonstrated Virtue: Perseverance</u>

- **Importance:** It is important to help me to solve the problem and make a better version that will fit into our design.
- **What I Have Done:** When I need to troubleshoot and change the value of the Wheatstone bridge, our team keeps changing the design of the Wheatstone bridge since the first couple weeks till now, even though some of the design is within the range, I would like to get a better range.

<u>Undemonstrated Virtue: Proactivity</u>

- **Importance:** It helps us to identify the potential problems that I will meet in the future. This is make the progress of our project become more smoother
- **What I Could Do:** After the PCB is designed, I will create a plan of the fabrication, assembly parts and testing to share with the team. By sharing the plan we will align our goal and make sure we meet the project deadline.

Wesley

<u>Demonstrated Virtue: Collaboration</u>

- **Importance:** Collaboration is essential in team-based projects to leverage diverse skills and perspectives, especially when designing complex systems like a mesh network.
- **What I Have Done:** I have actively participated in team meetings, shared insights, solutions, and contributed to collective problem-solving.

Undemonstrated Virtue: Initiative

- **Importance:** Initiative encourages proactive problem-solving and taking on responsibilities without waiting for direction, which can move the project forward efficiently.
- **What I Could Do:** When the hardware portion of our project is completed, I will need to take charge and find a way to contribute on the software side of our project.

8 Closing Material

8.1 Conclusion

Our team has made significant progress on this project, starting with project planning, meeting with clients to set clear goals and objectives, researching different topics on microcontroller, communication protocols and hardware components.

Hardware Progress

The hardware team designed, simulated, and tested circuits, including a Wheatstone bridge, voltage regulator and differential amplifiers. The design of the Wheatstone bridge will go through a differential amplifier before entering to the Analog-Digital-Converter (ADC). The Wheatstone bridge will provide the clients to have a better accuracy of the data (resistance) measurement.Some of the testing has been implemented to ensure the circuit is working properly, including worst-case analyses to provide the client a better understanding of the output range based on different data. Voltage regulator and inverter will be included in the circuit to provide the targeted voltage supply

Software Progress

The software team has been configuring the development environments. We have successfully set up the FreeRTOS for the ESP32 programming in C. We have developed, debugged, and tested the ADC functionality to capture and transmit the data (resistance value).We will be using the ESP-Now and protocol 801.11LR to create the mesh network. The team also created a software to enable data logging into the SD card for the backup purpose; in the meantime all the data will be transmitted to the base station microcontroller). We are also able to set up communication between the nodes and ensure the data collection and transmission is stable.

In the future iterations, we might change the Wheatstone bridge design with a firmware that will let us choose which circuit we will be using based on the resistance we get from the sensor to get a better accuracy of the data. We will start to design a PCB for the circuit that we designed such as the Wheatstone bridge, voltage regulator, and inverter. On the software side, we will need to combine all the coding for the ADC reading and the mesh network communication. Besides this, we will need to synchronize the clock for each ESP32 to make sure we are able to get the data for the same time from the field.

8.2 References

[1] "IEEE SA - IEEE Standard for Information Technology--Telecommunications and information exchange between systems--local and metropolitan area networks--specific requirements part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications amendment 10: Mesh Networking," IEEE Standards Association, https://standards.ieee.org/ieee/802.11s/4243/ (accessed Dec. 5, 2024).

[2] "IEEE SA - IEEE Standard Profile for use of IEEE 1588 Precision Time Protocol in Power System Applications," IEEE Standards Association, https://standards.ieee.org/ieee/C37.238/4609/ (accessed Dec. 5, 2024).

[3] "IEEE SA - IEEE standard for Telecommunications and information exchange between systems - LAN/man - specific requirements - part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (wpans)," IEEE Standards Association, https://standards.ieee.org/ieee/802.15.1/1180/ (accessed Dec. 5, 2024).

[4] Esp32-C6 series, https://www.espressif.com/sites/default/files/documentation/esp32-c6_datasheet_en.pdf (accessed Dec. 5, 2024).

[5] Esp32-C6, https://www.espressif.com/sites/default/files/documentation/esp32-c6_technical_reference_manual_en.pdf (accessed Dec. 5, 2024).

[6] "Waspmote," Libelium, https://www.libelium.com/iot-products/waspmote/ (accessed Dec. 5, 2024).

[7] "IMETOS 3.3," METOS® by Pessl Instruments, https://metos.global/en/imetos33/ (accessed Dec. 5, 2024).

[8] "IEEE SA - IEEE standard for design and verification of low power integrated circuits," IEEE Standards Association, https://standards.ieee.org/ieee/1801/4189/ (accessed Dec. 7, 2024).

[9] L. J. McNeill and M. M. Bellamy, "Contextualizing professionalism in capstone projects using the IDEALS professional responsibility assessment," International Journal of Engineering Education, vol. 28, no. 2, pp. 416–424, 2012.

[10] R. Kumar and M. P. Singh, "Wireless Sensor Networks for Precision Agriculture," IEEE Communications Magazine, vol. 54, no. 3, pp. 34-40, March 2018.

[11] S. P. Mohanty, U. Choppali, and E. Kougianos, "Everything You Wanted to Know About Smart Agriculture: Sensors, Systems, and Applications," IEEE Transactions on Consumer Electronics, vol. 62, no. 1, pp. 45-54, Feb. 2019.

[12] J. Smith, P. Lee, and R. Patel, "IoT-Based Pest Monitoring and Control Systems in Agriculture," IEEE Internet of Things Journal, vol. 6, no. 2, pp. 1234-1242, April 2020.

8.3 Appendices

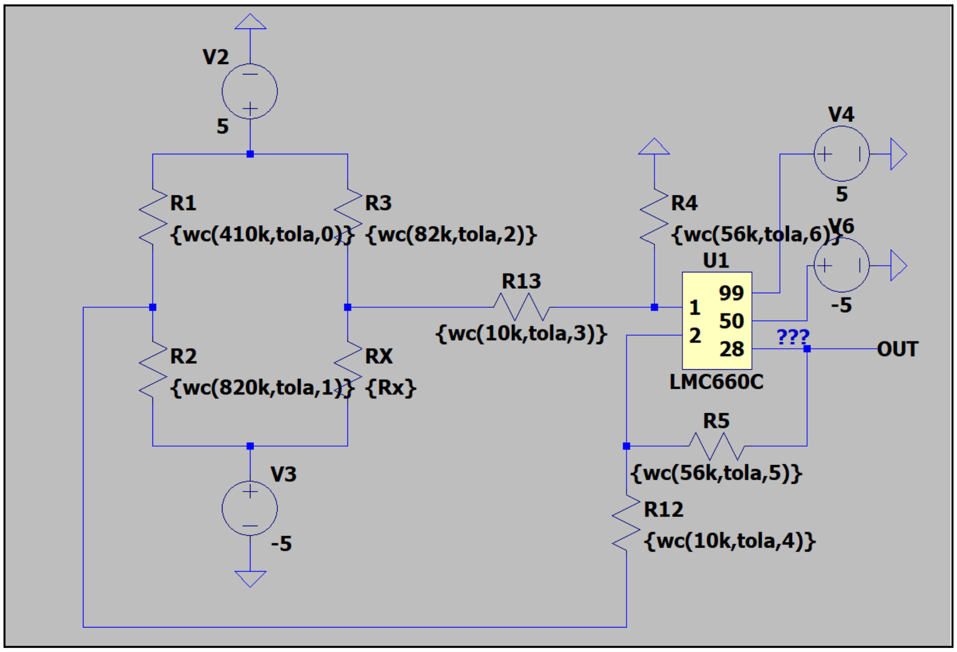

Figure 8.3.1: Wheatstone Bridge Circuit

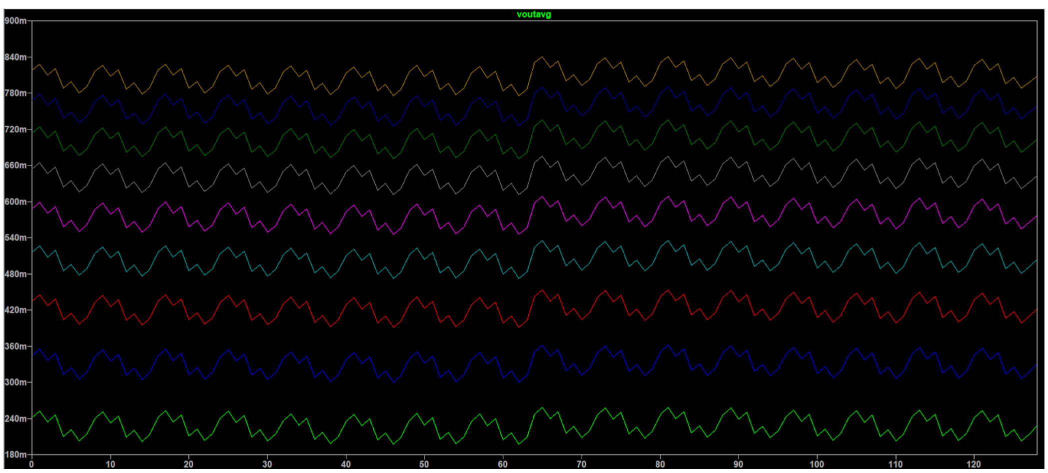

Figure 8.3.2: Wheatstone Bridge Circuit with tolerance of 1%

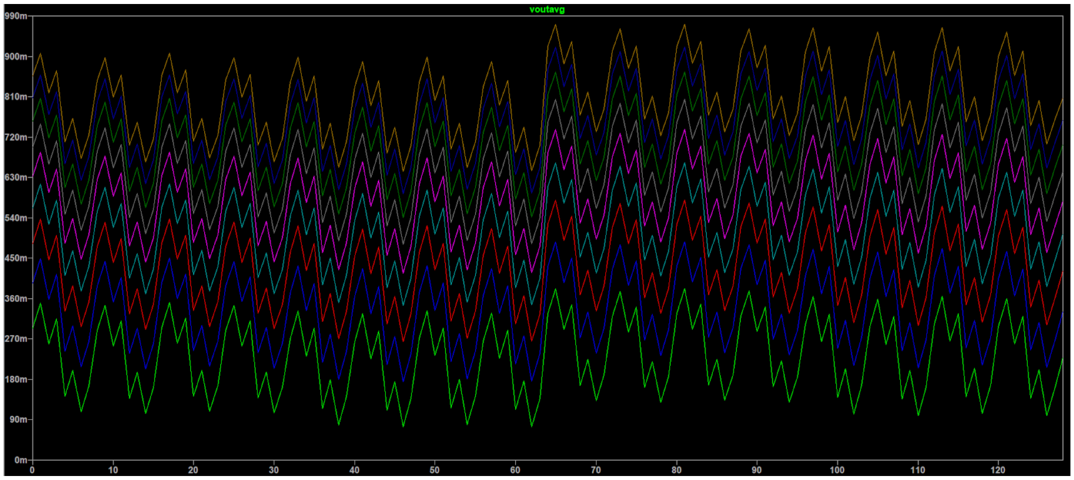

Figure 8.3.3: Wheatstone Bridge Circuit with tolerance of 5%

9 Team

9.1 Team Members

1.) Ashley Falcon	2.) Drew Scheidler
3.) Wesley Smith	4.) Henry Hingst
5.) Yok Quan Ong	6.) Hector Perez Prieto

9.2 Required Skill Sets for Our Project

Embedded Systems and Microcontroller Programming

- Proficiency in C/C++ for programming ESP32-C6 microcontrollers.
- Familiarity with Arduino IDE or ESP-IDF for microcontroller development.
- Knowledge of ADC (Analog-to-Digital Conversion) for reading the analog signals from the Wheatstone bridge and IDE sensors.
- Experience with low-level hardware programming and interfacing sensors.

Wireless Communication and Networking

- Expertise in Wi-Fi protocols (especially for ESP32-C6, which uses Wi-Fi for communication).
- Understanding of wireless mesh networking principles, particularly for creating a robust communication system across multiple ESP32-C6 devices.
- Familiarity with IEEE 802.11s (Mesh networking standard) and IEEE 802.15.4 for low-power wireless communication.

Analog Circuit Design

- Experience with Wheatstone bridge circuits to measure changes in resistance, particularly for sensors like IDEs.
- Knowledge of voltage regulators, inverters, and power management circuits to ensure stable voltage levels for sensors and microcontrollers.
- Understanding of sensor interfacing to translate physical measurements (like pesticide spray intensity) into readable electrical signals.

Sensor Technology and Signal Processing

- Understanding of Interdigitated Electrode (IDE) sensor technology and how to calibrate and interpret their readings.
- Experience with signal filtering and noise reduction techniques to ensure accurate sensor data.
- Familiarity with data acquisition systems and the conversion of analog signals to digital form for analysis.

Power Management and Battery Optimization

- Knowledge of battery-powered system design, with a focus on maximizing battery life.
- Understanding of low-power modes in microcontrollers and optimizing communication to reduce energy consumption.
- Familiarity with energy harvesting techniques (e.g., solar panels) to extend the operational time of remote sensor nodes.

Software Development and Cloud Integration

- Experience with Wi-Fi-based communication protocols for transmitting sensor data to a central base station.
- Familiarity with cloud integration (e.g., storing data on a cloud server, visualizing data via web dashboards).
- Knowledge of real-time data processing and data visualization tools for monitoring spray efficiency.

System Integration and Testing

- Expertise in system integration to ensure all components (hardware, software, sensors) work together seamlessly.
- Experience with debugging hardware and software issues during testing and deployment.
- Proficiency in performance testing and data validation to ensure the network's reliability and accuracy.

Project Management and Documentation

- Skills in project management for planning, scheduling, and coordinating tasks.
- Ability to document designs, code, and procedures clearly for future development or collaboration.
- Proficiency in writing reports and presentations, particularly when sharing results with stakeholders or for academic purposes.

9.3 Skill Sets Covered by the Team

Ashley Falcon: Project Management, Embedded Systems, Microcontroller Programming, Testing
Drew Scheidler: Software Development, Embedded Systems, Microcontroller Programming,
Wesley Smith: Power Management, Analog Circuit Design, System Integration
Henry Hingst: Software Development, Wireless Communication and Networking
Yok Quan Ong: PCB design, Circuit Design, MCU Programming, Documentation, Signal Processing
Hector Perez Prieto: Power Management, Analog Circuit Design, Testing

9.4 Initial Project Management Roles

Ashley Falcon: Software Engineer
Drew Scheidler: Software Engineer
Wesley Smith: Hardware Engineer
Henry Hingst: Team Leader & Software Lead
Yok Quan Ong: Hardware Engineer
Hector Perez Prieto: Hardware Lead

9.5 Team Contract

Team Name sdmay25-04

Team Members:

1) Ashley Falcon　　2) Drew Scheidler
3) Wesley Smith　　4) Henry Hingst
5) Yok Quan Ong　　6) Hector Perez Prieto

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
    a. Face-to-face
    b. Team meeting: tentatively Mondays, 2:15 - 3:05 pm @ Parks Library
        i. Main expectation: team meeting 1x per week
    c. Advisor meeting: Wednesday, 2:15 - 3:05 pm @ Parks Library or SICTR

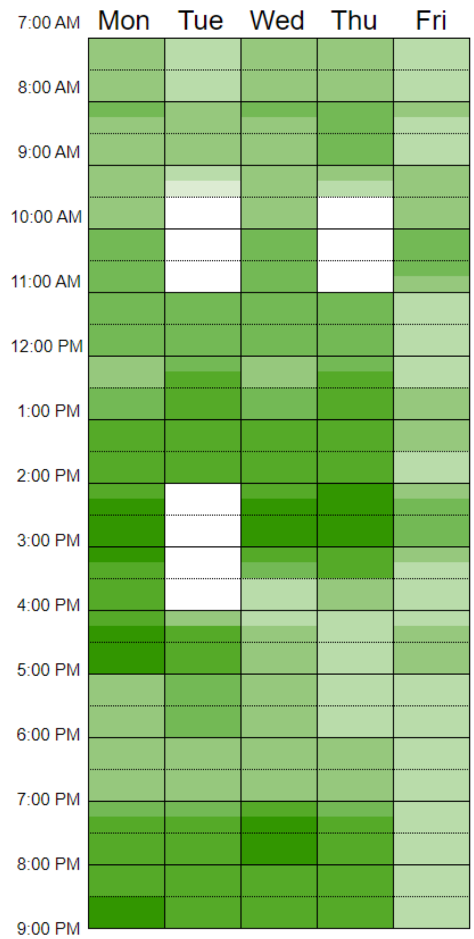

Figure 9.5.1: Time Map to Help Organize Team/Advisor Meeting

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
    a. Phone (Snapchat Group Chat)
    b. Discord Server
    c. Face-to-face at our weekly meetings.
3. Decision-making policy (e.g., consensus, majority vote):
    a. Majority vote (4/6 members agree)
    b. Ideally a compromise should be made prior to vote
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
    a. Project Report done weekly
    b. Notes made by Wesley kept in shared Google Drive folder

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
    a. 100% attendance expected, notify of absence ASAP via group chat

    b. Respect for other group members' time
    c. Assigned tasks should be completed, and any roadblocks should be reported
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    a. Timelines, responsibilities, and deadlines should be clear before the end of team meetings
    b. Roadblocks should be reported promptly
3. Expected level of communication with other team members:
    a. Face-to-face communication once a week
    b. Track progress in the Google Drive folder for team reference
    c. Communicate issues ASAP
4. Expected level of commitment to team decisions and tasks:
    a. See "Decision-making policy."
    b. Before anything is turned in, all members must approve (unless assignment due date reached)

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
    a. Client/Advisor interaction (Emailer): Ashley Falcon
    b. Professional Note Taker: Wesley Smith
    c. Other roles will be assigned to other group members when project advancements are made
2. Strategies for supporting and guiding the work of all team members:
    a. Breaking off into groups that are dedicated to specific tasks could be useful
    b. Regular team meetings to address issues and progress
    c. Encouraging questions
    d. Reaching out to Professor Neihart with daily questions
3. Strategies for recognizing the contributions of all team members:
    a. Documented tasks assigned
    b. Giving positive feedback to team members

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.
    a. Drew: Software expertise and interfaces
    b. Henry: Networking. Experience with microcontrollers in previous internship.
    c. Wesley: Power distribution, basic microcontroller knowledge from HABET
    d. Hector: Basic microcontroller knowledge and Power distribution knowledge from previous internships.
    e. Ashley: Experience with microcontrollers and hardware testing in previous internships. Good communication skills. CAD experience.
    f. Yok: PCB design (KiCAD), basic microcontrollers knowledge
2. Strategies for encouraging and supporting contributions and ideas from all team members:

    a. Open discussion at group meetings
    b. Set time aside for questions and kudos for other team members
3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)
    a. Set aside kudos time will ensure team members feel comfortable
    b. Open and prompt communication is preferred
    c. Ashley can be a mediator
    d. Make expectations clear to avoid a lack of team member contributions

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    a. Wireless chip set to chosen and drivers written
    b. Schematic of PCB done by the end of the semester
    c. Part number for ESP32 (microcontroller) picked out and blink test complete
2. Strategies for planning and assigning individual and team work:
    a. Allow team members to communicate what they most want to do
    b. Delegate tasks from advisor/client meetings to specific individual/team
3. Strategies for keeping on task:
    a. All members should be ready to contribute any research regarding the project found during weekly meetings
    b. Maximize efficiency during times we meet

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
    a. Handle infractions as a team
    b. Preferably communicate infractions before they happen
2. What will your team do if the infractions continue?
    a. Discuss continued infractions to Senior Design TAs
    b. Intervention with the team member

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*
b) *I understand that I am obligated to abide by these terms and conditions.*
c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) Ashley Falcon DATE: 9/17/2024
2) Drew Scheidler DATE: 9/17/2024
3) Wesley Smith DATE: 9/17/2024
4) Henry Hingst DATE: 9/17/2024
5) Yok Quan Ong DATE: 9/17/2024
6) Hector Perez Prieto DATE: 9/17/2024