EECE 410 Capstone Design I
Electrical and Computer Engineering
Manhattan College

Hydro Power Electric: A Smart, Self-Powered Water Monitoring System

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Abstract

Water is one of the most important natural resources on earth. Although Earth's surface consists of almost 70% of water, only a small part of it is drinkable. Because of this reason, this resource is very limited. Clean water is the basic necessity of all living beings on Earth that is why it must be checked and tested before use. Water resources must be monitored regularly to check if the water is healthy to drink or not. Contaminated water degrades the environment and threatens the whole ecosystem. Most of the diseases are due to the poor quality of water and over 200 million cases about it are recorded annually all over the world. Water quality plays a vital role in both environmental and economical aspects. This paper presents the design of a water sensor buoy having a long-lasting battery which can be placed in water for a long time, it gathers data from the water which can be used to enhance the quality of water.

Keywords: *Water, Natural Resources, Drinkable, Clean Water, Contaminated Water, Environment, Ecosystem, Water Quality, Water Sensor Buoy, Long-lasting Battery*

Acknowledgement

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1. Introduction

1.1 Problem Statement

Figure 1: A man taking a sample of water to measure the water quality

A water sensor buoy is a floating device with sensors that monitor water quality factors including temperature, pH, dissolved oxygen, and conductivity. These measurements are wirelessly transferred to a data logger or computer for processing and interpretation. A water sensor buoy may be used to monitor water quality and analyses the effects of pollution, climate change, and water management methods in a lake, river, or marine environment.

Water sensor buoys are an important tool for monitoring the health and quality of water bodies, such as lakes, rivers, and oceans. By continuously measuring a range of water quality parameters, these buoys can provide valuable insights into the effects of pollution, climate

change, and water management practices on aquatic environments. This data can be used to inform decision-making and develop strategies for protecting and improving water quality.
Water covers over 70% of the Earth's surface and is utilized by millions of humans as well as billions of marine species [7]. Climate change raises the need to monitor water quality and conditions to protect the safety of not just humans but also marine life. As a result, we decided to create a system that would produce energy to power a buoy equipped with sensors to monitor and report water quality.

We would not be able to make this happen without our industry partner and a grant from The U.S. Department of Energy for the Marine Energy Collegiate Competition: Powering the Blue Economy. Our industry partner is Duro UAS (Unmanned Autonomous Systems) which is an environmental organization that is based in the Bronx that creates unmanned autonomous systems for data collection in water bodies. With their help, we may learn more about the current and future critical measures required to guarantee that water quality data is gathered and shared, not only for our personal safety, but also for the safety of future generations. We are committed to working closely with Duro UAS to ensure that our technology is developed in a way that benefits not only humans, but also the billions of marine species that depend on healthy water environments.

1.2 Need

Marine buoys are used for a variety of purposes, including navigation, warning of hazards, making boundaries or restricted areas, and collecting data about the marine environment. Research on marine buoys is therefore important for improving their design and functionality, as well as for understanding their impact on the marine environment and the organisms that live there.
Safe drinking water is a fundamental necessity for good health, and it is also a basic right of humanity. Fresh water is already a restricted resource in many places of the globe. In the upcoming years, it will become much more restricting because of the growing population, urbanization, and climate change. Drinking water quality is a relative word that links the

composition of water with impacts of natural processes and human activities. Deterioration of drinking water quality originates from entry of chemical compounds into the water supply system via leaks and cross connection. The World Health Organization claimed that up to 80 % of all ailments and diseases in the world are caused by poor sanitation and dirty water. Diseases related to contaminated water and poor sanitation have more than 200 million cases and it becomes the reason for millions of deaths all over the world [1].

The present water quality problem highlights the necessity for a water sensor buoy with a long-lasting battery. A device that can be put in a body of water for a long length of time to gather data that may be utilized to enhance water quality is required. Researchers and water managers will be able to monitor water quality over time and discover trends and patterns thanks to the water sensor buoy with a long-lasting battery [2]. This data may be utilized to build and execute water quality protection and improvement programs.Therefore, research on marine buoys can help improve the accuracy and reliability of this data, as well as the best methods for collecting and transmitting it.

A long-lasting battery in a water sensor buoy would not only save money and data collecting, but it would also assist to prevent plastic pollution. When water sensor buoys need to be replaced, the old ones are often discarded, contributing to the rising amounts of plastic pollution in our seas. However, if these buoys had long-lasting batteries, they might be reused numerous times, lowering the quantity of plastic pollution they contribute to dramatically. Overall, research on marine buoys is important for improving their design and functionality, as well as for understanding their impact on the marine environment and the organisms that live there.

1.3 Objective Statement

Designing and creating a system that not only collects data but also powers and recharges the sensors necessitates the use of electrical, computer, and mechanical experts. This multidisciplinary system will need particular information from all areas relevant to this issue in order to produce a system that not only lives up to its full potential, but also benefits people. The primary goal of this project is to design, evaluate, and develop a prototype that can convert enough hydrokinetic energy from flowing water into electricity to power a buoy equipped with various sensors for monitoring and collecting water quality data. In order to produce a successful prototype, we will need to carefully consider a range of factors, including the type and size of the sensors that will be used, the amount of power they require, and the efficiency of the hydrokinetic energy conversion system. This prototype should be designed to be cost effective, both in terms of the materials and components used and in terms of the overall cost of maintaining and operating the system. Our team will also consider the environmental factors that the system will be exposed to, such as water currents and temperature, and design the system to withstand these conditions. In addition, this prototype should be able to efficiently collect and transmit data from the sensor, with minimal loss of data due to transmission errors or other issues.

Some of the goals that were considered were the sensors' capacity to interface with a remote database so that a user or administrator could access live data of the water temperature, ph, and other characteristics. The device should also be able to transmit the current battery status to the user. Consequently, having a user-friendly interface that allows our users or administrators to easily access and interpret the data collected by the sensors. Thereby, the device must be capable of obtaining sufficient charge from the battery, which must be charged utilizing the water current surrounding it. As a result, the buoy is kept operational for as long as feasible by extending the intervals between maintenance and battery replacement. This prototype should be able to efficiently collect and transmit data from the sensors, with minimal loss of data due to transmission errors or other issues.

1.4 Background and Survey

The goal of this project is to design, construct, and test a buoy equipped with sensors and powered by a marine energy harvester that employs piezo strips. The sensor suite must be capable of measuring a variety of oceanographic characteristics such as water temperature, salinity, pH, and dissolved oxygen. The sensing suite's power needs are quite minimal; nonetheless, the energy harvester must be configured to create enough power to operate the data logger and sensors. The harvester must be able to function in a variety of sea conditions and must be built to be as efficient as feasible. The buoy's data will be utilized to better understand ocean health and the effects of human activities on the marine ecosystem.

The most current extant project, published on July 20, 2021, focuses on a wireless maritime buoy system powered by a saltwater battery. This study was supported by a grant from the Ministry of Science's National Research Foundation of Korea (NRF) [3]. One benefit of their method is that it employs an environmentally friendly wireless sea buoy system. However, the usage of lithium-ion batteries poses substantial environmental contamination concerns, and there has been little study on the saltwater battery. Another significant disadvantage was the utilization of LTE and GPS. These two technologies consumed the battery quicker than expected, resulting in longer charging times and frequent connection failures [4]. This can result in longer charging times and frequent connection failures, which can reduce the reliability of the system. Overall, while the wireless maritime buoy system has some benefits, it also has some significant limitations that need to be addressed in future research.

A wireless sensor network (WSN) is a type of system that uses sensors to measure various properties of water. It can sense the physical and chemical properties of water and transmit the information wirelessly to a communication module. This transmits the data wirelessly to a central location. It consists of pH sensor, temperature sensor, biological oxygen demand (BOD) sensor and chlorophyll sensor, and currently WSN is using GPIB (general-purpose interface bus) and USB (universal serial bus) communication protocols. However, it has some drawbacks like GPIB protocols are not suitable for small devices and USB protocols can sometimes become extremely complicated and difficult to handle [5]. This can limit the effectiveness of the WSN system.

Another existing system used is the Water Quality Monitoring System Based on IOT. It is a system that uses sensors to measure various parameters of water quality, such as pH, temperature, and dissolved oxygen. These sensors are connected to an Arduino board, which acts as the core controller of the system. The Arduino is used to access the values from the sensors and process them to transfer the information using Wi-Fi network. The whole design of this system is based on IOT which is an advanced concept, this system is inexpensive and fast, it measures the precise and accurate water quality in real time. But it consumes a lot of battery, its battery must be charged after a short period of time, and this is the main drawback of this system [6]. Further, the system may not be able to measure certain water quality parameters that are not monitored by the sensors, which can limit its usefulness in some situations.

1.5 Project Selection

		Smart Water Fountain	Water Quality Monitoring Buoy	Water Quality Pipe Sensor
Cost	0.06	0.23	0.24	0.11
Battery	0.56	0.15	0.62	0.21
Communication	0.26	0.25	0.32	0.22
Looks	0.12	0.34	0.28	0.19
Score		0.24	0.37	0.18

Table 1: Analytical Hierarchy Process Table

Table 1 is the AHP table for the many alternatives or initiatives. We had two further projects in mind: a Smart Water Fountain and the continuation of a Water Quality Monitoring System embedded into the pipes. We compared both to our chosen project in order to illustrate why we picked it.

The Smart Water Fountain, which would include a water filter and sensors, was the initial alternative project. This fountain would enable users to monitor how much water they consume and the quality of the water they drink using a smartphone app. We picked our proposal over this one because the fountain would take a great amount of electricity [8]. Ultimately defeating the purpose of this project.

The next alternative project was the continuation of a Water Monitoring System that was installed directly into the pipes. We did not choose this project because of its appearance and communication methods. This project would have exposed pipes, which is not suitable in an educational setting, where it is now placed. Looking at the chart, our product seemed to be the winner owing to a variety of variables including a smaller battery, cheap cost, and the freedom to customize how it appears to the user.

Overall, we found that the Water Quality Monitoring Buoy aligned with our objectives and goals. By choosing this project we are essentially lowering costs, improving water quality for the development of marine life, and powering a future where people use cleaner and safer energy. Referring to the AHP table, it scored higher than the other two alternative projects which finalized our decision to pursue this project.

1.6 Proposed Approach

Our solution will presently employ an ESP 8266 Node MCU microcontroller, which is quicker, lighter, and more power-efficient microcontroller than the competitor's LTE and GPS microcontroller. In the future, the plan is to replace the ESP 8266 Node MCU with a bespoke microcontroller that uses the LoRa communication standard, similar to our industry partner. The use of LoRa will provide us with a great range of LTE while also allowing us to employ low power consumption like Bluetooth. Like the previous project, we will utilize a lithium-ion battery to power the sensors and microcontroller. This battery, on the other hand, will be charged by a harvester that uses Piezoelectric strips rather than Photovoltaic cells.

Piezoelectric strips can generate electricity even when the sun is obscured by clouds, whereas photovoltaic systems cannot. When compared to a solar device, the usage of piezoelectric strips greatly reduces the total cost (photovoltaic). This also provides us with an edge owing to the expected total uptime.. The most significant benefit of our suggested system is the inclusion of sensors for measuring various factors such as pH, ORP (oxidation-reduction potential), temperature, and others. This will allow the system to monitor the water quality in real time and provide accurate and reliable data. Overall, the proposed approach offers a number of advantages over previous systems, but it may also have some limitations that need to be considered.

1.7 Global and Societal Impact

Our team believes that the use of clean and safe energy sources is crucial for the future of our planet and its inhabitants. As a result, we are committed to developing a prototype that can harness the power of hydrokinetic energy and convert it into electricity in a reliable and efficient manner. We believe that our prototype has the potential to be a game-changing technology that can help to reduce our reliance on finite energy resources, such as fossil fuels, and contribute to the development of a more sustainable future.

To develop our prototype into a commercial product, we want to perform thorough testing and refining to guarantee that it is market-ready. We will also collaborate extensively with Duro UAS to learn their unique wants and expectations, and we will design our product to match those demands.We believe that our technology has the potential to be used in a wide range of applications, including the power and recharge of buoys used for water quality monitoring and data collection.

By providing a reliable and clean source of energy, our technology can help to reduce the need for maintenance and battery replacement, and improve the overall performance and efficiency of these systems. In addition to providing clean energy, we also believe that our technology can help to improve water quality and support the development of marine life. By reducing the amount of pollution and waste generated by traditional energy sources, our technology can help to create healthier and more sustainable aquatic environments.

2. Design Requirements Specifications

2.1 Marking Requirements Survey

The market for water quality monitoring has always been robust and will continue to be so. Pollution and climate change are threatening the very water we have on our world, and they will be a primary market driver in increasing the need for systems that monitor water quality. As a result, there is an increasing demand for systems that can monitor water quality and provide accurate reliable data. According to multiple research and analyses, the market would grow by 1.21 billion USD by 2026, reaching an all-time high capital of 7.8 billion USD by 2028 [9]. This growth is being driven by several factors, including the COVID-19 pandemic, which has highlighted the importance of clean and safe water, and the need for better wastewater treatment.

Thus, the recent COVID-19 epidemic is a major element in the demand for water quality monitoring systems. As a result of the epidemic, the World Health Organization (WHO) has recommended expanded water testing with additional factors to be checked. International organizations such as the Environmental Protection Agency (EPA), the European Drinking Water Directive, the Australian Drinking Water Criteria, and China's GB3838-2002 have implemented comparable water testing guidelines [10].

The growing need to treat and monitor wastewater is another important factor driving the market for water quality monitoring. As more and more industrial operations generate wastewater, there is an increasing need to treat this water to remove contaminants and make it safe to reuse. This is particularly important in emerging and developed nations, where the use of drinking wastewater as a result of increased industrial operations. [11]. Monitoring the quality of wastewater is crucial, because water that is contaminated with germs and other harmful substances can cause illnesses such as polio, cholera, and typhoid. By monitoring the water quality, it is possible to identify any contaminants and take steps to remove them, ensuring that the water is safe for reuse.

In addition to the need to treat and monitor wastewater, there is also a growing demand for systems that can monitor the quality of other water sources, such as rivers, lakes, and streams. As the quality of these water sources continues to decline due to pollution and other factors, there is an increasing need for systems that can provide accurate and reliable data on the water quality. This will help to protect public health and ensure that the water is safe for drinking and other uses.

2.2 System Requirements

Marketing Requirements

In recent years, companies have raised their standards for water quality testing and monitoring. Water quality has never been more vital, from underdeveloped to developed countries. From the COVID-19 epidemic to the effects of climate change, people all across the world are rushing to find safe drinking water [12]. Clean water is not only helpful to people, but it is also critical for all marine species that lives in the sea. The most essential aim for today and the future is to have a system that can monitor water quality without damaging marine life.

The ultimate goal of this research is not simply to monitor water quality, but also to develop a system that is self-sustaining and harmless to the ecosystem around it, reducing the need for human intervention. These parameters distinguish this system from other devices on the market, resulting in a cheaper cost and more self-sufficient system. The following are some of the system's features:

1. The system should be powered by currents in the water
2. The device should recharge on its own
3. The system should be able to transmit and receive data from base
4. The device should be able to sustain water current and wind conditions
5. The system should require limited maintenance

Engineering Requirements

The engineering requirements are as follows:

1. The device must have a self-sustainable way to recharge a battery with a capacity of 50-70 Ah.
2. The battery must operate for a minimum of 4 hours before automatically recharging.
3. The device must communicate to a database every 30 seconds.
4. The device must be able to withstand an average current of 5 knots.
5. The device must not have a rotation in the water greater than 15 degrees.

Engineering Requirements: Justification

The Justification of our engineering requirements are as follows:

1. This power range represents the amount of energy that can be extracted from the battery at a given time
2. Achievable with the type of battery we intend to use.
3. Past trials on device communication demonstrate that this is a reasonable time
4. Achievable by placing counterweights at the bottom of the buoy
5. Studies on weather condition at sea show that this is a reasonable rotation angle

Marketing Requirements	Engineering Requirements	Justifications
1, 2	The device must have a self-sustainable way to recharge a battery with a capacity of 50-70 Ah.	A battery that can recharge will allow the system to work independently from other power sources
1, 2, 5	The battery must operate for a minimum of 4 hours before automatically recharging.	Allows for limited human interaction in swapping out batteries
3	The device must communicate to a database every 30 seconds.	The system must have a quick response to transmit collected data to warn of possible contamination
4, 5	The device must be able to withstand an average current of 5 knots.	Allows for less human interaction to fix if toppled over
4, 5	The device must not have a rotation in the water greater than 15 degrees.	Allows the sensors and harvester to work properly

Table 2: Engineering Requirements

Engineering - Marketing Tradeoff Matrix

				Eng Req.			
			Battery Capacity	Operation Time	Dimensions	Data Transfer Rate	Stability

			+	+	-	-	+
	Type of Battery	+	↑↑	↑↑	↑	↓	↓↓
Market Req.	Communication	+	↓	↓	↑	↑↑	↓
	Looks	-	↓	↓		↓	↑
	Cost	-	↑↑	↑	↑	↓	↑↑

Table 3: Engineering Marketing Trade Off Matrix

Important characteristics must be addressed on both the Marketing and Engineering sides of this system. Table 3 compares their rankings to one another. On the marketing side, we have costs that should be reduced in order to boost the system's attractiveness in terms of selling and marketability. The next consideration is appearance, which is less significant since it will be submerged and not visible to the public. Finally, we have Communication and Battery Type. The communication type is significant since it determines the operating time and other battery-related parameters. The kind of battery must be given special consideration since it must meet the most standards. On the technical side, the battery capacity must be sufficient to power and recharge the whole system. Next, we have Operation Time, which must be high in order for there to be no latency or downtime on the servers and sensors. Following Operation Time, we have Dimensions, which must be large enough to accommodate the batteries, sensors, and other equipment but not so huge that it is too heavy to take into the sea by boat. The Data Transfer Rate is next, which has enough slack to not be a top priority since we only require the data from the sensors to be delivered every 30 seconds. Finally, we have stability, which is quite important. By increasing stability, we can assure that the system can stand and float on its own without toppling over. This reduces the amount of human contact required to maintain the system.

Engineering - Engineering Matrix

		Battery Capacity	Operation Time	Dimension	Data Transfer Rate	Stability
		+	+	-	-	+
Battery Capacity	+		↑↑	↑	↑	↓↓
Operation Time	+				↑↑	↓
Dimension	-					↑↑
Data Transfer Rate	-					
Stability	+					

Table 4: Engineering - Engineering Matrix

Because it is anticipated to be orthogonal, the engineering matrix in Table 4 is greyed out across the diagonal. The remainder of the criteria seem to have a positive link with battery capacity. Increasing it will enable the system to operate for a longer period of time before requiring a recharge, since the communication protocol is not as confined by battery use. However, it has a negative link with stability since increasing the size of the battery requires additional support to balance the system, such as counterweights to ensure one side is not tilting more than the other. The system's size or dimensions have a negative sign since one of the aims of this project is to produce a lightweight, low-cost system that is comparable to others presently on the market.

2.3 Needs Identification

2.3.1. Analytical Hierarchy Process

Rankings of Needs

	Cost	Battery	Communication	Looks	Weighted Sum	Criteria Weights	
Cost	0.06	0.08	0.05	0.04	0.23	0.0569	4.0403
Battery	0.40	0.56	0.79	0.61	2.36	0.5579	4.2223
Communication	0.28	0.19	0.26	0.37	1.10	0.2633	4.1757
Looks	0.17	0.11	0.09	0.12	0.49	0.1219	4.0357
λ Max	4.1185						
C.I.	0.0395						
C.R.	0.0439						
	Criteria Weights						
Cost	5.69%						
Battery	55.79%						
Communication	26.33%						
Looks	12.19%						

Table 5: Ranking of Criteria

The weights and rankings of our criteria are shown in Table 5. For our project, we prioritized cost, battery, communication protocol, and looks in this chart. We were able to conclude that the Battery had the greatest weight of roughly 0.6 after evaluating these factors against each other, making it our most essential criterion. Since the battery must power all of the sensors and be rechargeable. The communication protocol was the second most significant criterion. This is because we need to communicate data to a wireless database in real time while using as little energy as possible.

Project Requirement Ranking

	Functional Design	Database	Sensors	Harvester Method	Weights
Functional Design	1	3	5	7	0.60
Database	1/3	1	7	1	0.19
Sensors	1/5	1/7	1	1/7	0.05
Harvester Method	1/7	1	7	1	0.11

Table 6: Project Requirements

The weights for the project requirements are shown in Table 6. We compared functional design, database, sensors, and harvesting approach in the table. The most significant requirement, according to the weights, is functional design. This is owing to the fact that we need the systems to be fully operating. If one component fails, the whole system will not function properly. The Database is followed by functional design, with the harvester technique a close second. The database will enable us to see what data is being gathered and will also be used to validate the sensors. The harvester technique is ranked third since it will be its own component, and in comparison, to the rest of the system, it is not as critical as a functional database and an overall functional system.

2.3.2. Objective Tree

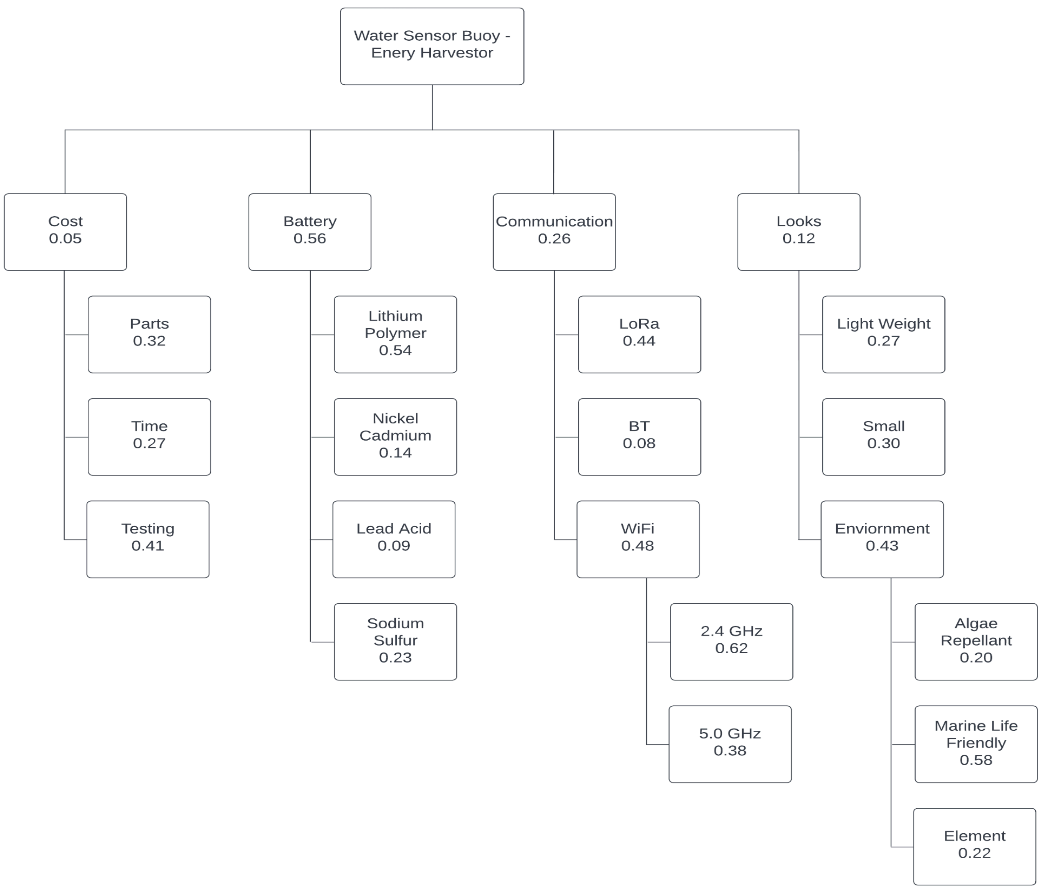

Figure 2: Objective Tree for Needs

In order to understand and prioritize the different components that make up our system, we constructed an objective tree (Figure 2) that shows the hierarchical relationships between these components. The objective tree is a useful tool for visualizing the overall decision-making process, and can help us to identify the most important factors that need to be considered when designing and developing our system. The four primary branches of the object tree are:

1. Cost: This branch represents the financial considerations of our system. The sub-requirements of this branch include cost of parts, time, and testing.
2. Battery: This branch represents the power storage ranking the batteries based on the capacity and efficiency of the batteries, and the ability to recharge them using hydrokinetic energy. The sub-requirements of this branch include all the options we took into consideration.
3. Communication: This branch represents the data transmission and networking systems of our system, including the ability to transmit data wirelessly, and the ability to connect to a remote database or network. The sub-requirements of this branch include the different options.
4. Looks: This branch represents the visual appearance and design of our system, including the shape, size, and the overall aesthetic appeal of the system. The sub-requirements of this branch include the compatibility with the surrounding environment.

Overall, the objective tree helps us to understand the complex relationships between the different components of our system, and to prioritize the requirements and sub-requirements that are most important for the success of our project. By carefully considering these factors, we can develop a system that meets the needs of our users and the environment in which it will be deployed.

3. System Design

3.1 Theory

Our system consists of three main components, the Energy Harvester, Battery PCB, and our main PCB. As shown below in Figure 03, the energy harvester will provide power to charge our battery PCB using piezoelectric strips and an interference cylinder. The interference cylinder will disrupt the basic flow of the river allowing us to capture the wake that occurs. To make sure we capture the greatest amount of wake, each strip will have a small vibrator to induce oscillation. To fully incorporate this into our system, the buoy that holds all the sensors will act as the interference cylinder and the piezoelectric strips will then be attached to the side, extending outward from the buoy. The constant disruption of the water flow should provide a consistent bend and movement in the piezoelectric strips to generate a voltage.

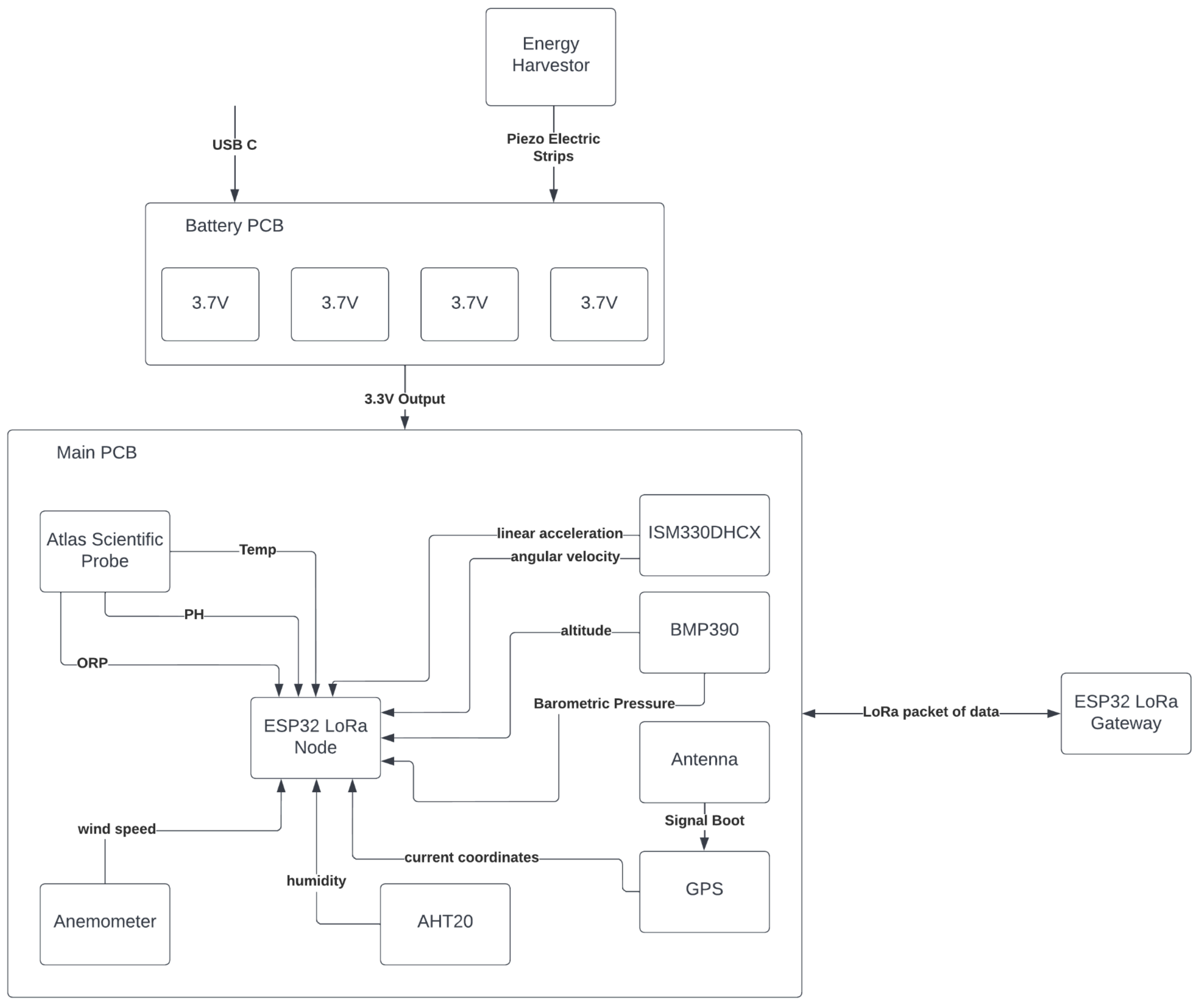

Figure 03: Whole System Flow Chart

The piezoelectric equation is fundamental to the main energy harvesting system since it gives a baseline of the relationship between polarization and stress [19]. The equation is as follows:

$$P = dX$$

Equation 01: piezoelectric equation

Where P is the polarization, d is the piezoelectric coefficient, and X is the stress. The next equation that will help develop the first equation further is that of the electrostatic equation of a capacitor.

$$Q = CV$$

Equation 02: electrostatic equation of a capacitor

Where Q is the charge, C is the capacitance, and V is the voltage. With these two equations we can simplify the equation to:

$$Q = dF$$

Equation 03: electrostatic with respect to piezoelectric

Where Q is the charge, d is the piezoelectric coefficient, and F is the force. This equation shows that the force we apply to the piezoelectric strip, no matter how big or small the strip is, we will obtain the same voltage. In our application, we need to measure and use the voltage of the strip, so we need to further derive the equation with respect to the voltage.

We can substitute equation 2 into equation 3 and after simplifying the equation we are left with:

$$V = \frac{dF}{C}$$

Equation 04: Voltage of piezoelectric with respect to capacitance

Where V is the voltage, d is the piezoelectric coefficient, F is the force, and C is the capacitance. However, the equation is not complete due to the capacitance and its value being determined by the permittivity of the material under free stress.

$$C = \frac{\epsilon_r \epsilon_o A}{t}$$

Equation 05: Capacitance of the Material

Where C is the capacitance, ε subscript r is the relative permittivity, ε subscript o is the vacuum permittivity, A is the area and t is the thickness.

When we combine equation 4 into equation 5 we are left with:

$$V = \frac{dFt}{\epsilon_r \epsilon_o A}$$

Equation 06: Voltage of Piezoelectric

Where V is the voltage, d is the piezoelectric coefficient, F is the force, t is the thickness, ε subscript r is the relative permittivity, ε subscript o is the vacuum permittivity, A is the area. This final equation tells us that as the area of the piezoelectric strip increases, the voltage that is generated decreases. This will allow us to determine the size and count of how many strips we would need to power our system with enough voltage and also enough voltage left over as a backup.

This harvester system will feed into our Battery PCB which has a USB-C connector for a service and test connection. This PCB contains 4, 3.7V lithium-ion polymer batteries connected in parallel. These batteries will provide a output of 3.3-5V depending on the final layout to our main PCB which houses all the main sensors. In our main PCB, we have a suite of sensors and some we have to calibrate to obtain accurate results. The Atlas Scientific Industrial PH, Temp, and ORP Probe is an example of a sensor that has to be calibrated before use.

In order to calibrate the pH, the probe needs to be dipped into 3 different types of buffer solutions [20]. These solutions are in the following order; Mid, Low, and High point, each with different pH values. The first step includes rinsing the probe in deionized water and drying the probe tip. Next dip the probe into the first soilution until the pH reading is constant, making a note of the value compared to the value labeled on the solution bottle. Repeat for the last 2 solutions. Since the probe is industrial grade, the pH can't be set on the probe directly but instead will utilize a calibration curve which will be defined in the software portion when obtaining the data.

The theory behind the pH value comes from literally, the potential of Hydrogen and measuring the hydrogen ion activity in any liquid. In the probe being used, there is a glass membrane which is used to separate the larger ions from the smaller ions. The difference of this concentration creates a small current which can be used to determine the level of pH [21]. The equation for this is:

$$E = E^0 + \frac{RT}{F} ln(\alpha_{H+}) = E^0 - \frac{2.303RT}{F} \rho H$$

Equation 07: Current from Hydrogen Ion

Where R is the ideal gas constant, T is the temperature in Kelvin and F is the Faraday constant. This equation predicts the values of the current that is generated from hydrogen ion activity providing a more accurate reading of pH.

The same probe uses a platinum RTD sensor to measure the temperature of the water using the measured resistance [21]. The equation for this probe is:

$$T = - \frac{\sqrt{(-0.00232(R) + 17.59246)} - 3.908}{0.00116}$$

Equation 08: Resistance to Temperature

Where T is the degrees in Celsius and R is the resistance measured from the PT-100 temperature probe.

One last part of our theory was the machine learning model called GRU or Gated Recurrent Unit which is a type of recurrent neural network (RNN) that is commonly used for sequential data processing tasks. It is a variation of the LSTM (Long Short-Term Memory) model but with fewer gates, making it computationally more efficient.

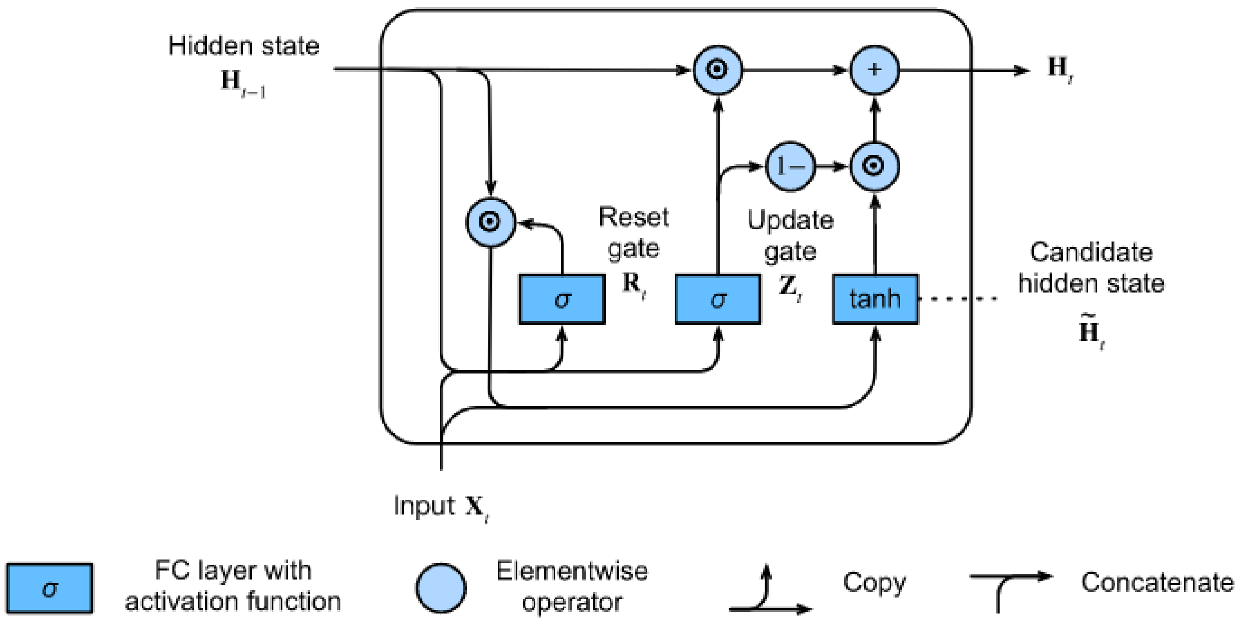

Figure 04: Gated Recurrent Unit Gate Diagram Overview

With the GRU as pictured above in figure 04, we have two main gates, an update and a reset gate. These gates control the flow of information in the network, allowing it to retain important information over long sequences and discard irrelevant information.

In our system, the GRU model is defined using the nn.GRU module from PyTorch. It takes in the input dimension, hidden dimension, number of layers, and output dimension as parameters. The model is trained using the Adam optimizer and the mean squared error loss function (nn.MSELoss). During training, the input data is scaled using MinMaxScaler and then transformed into tensors. The model is trained for a specified number of epochs, and the training loss is recorded. Finally, the trained model is used to predict future pH values, which are then inverse transformed back to the original scale using the scaler. The predicted pH values are printed and saved to a text file which will then be ouputed to the webserver for users to see the next 7 values predicted. This is done for all values, not only pH.

3.2 Functional Decomposition

The functional decomposition is a useful tool for understanding the complexity of a project, outlining both the individual tasks and the overall processes needed to complete the project. It includes both the main function and the essential supporting functions that must be completed in order to complete the main objective. The overview of the buoy system's input to output transformation is shown in Figure 4, starting with Level 0.

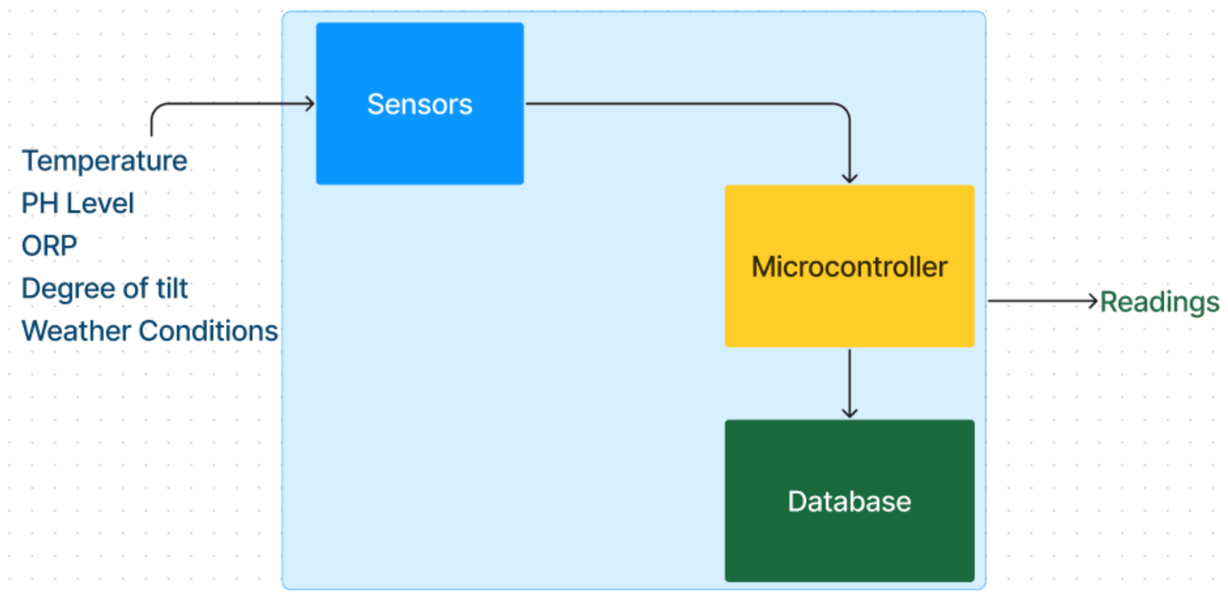

Figure 05: Level 0 of complete system

As shown in figure 5, we have the functional decomposition level 0 block diagram of our complete system which includes the 5 inputs and the output being the reading from the sensors. The main functionality of the system is to send data from our sensors to the database to be displayed on the website. The system shows that the data that is received from the live feed produced by the sensors is processed and outputs readings that will be graphed later on.

Level 1 then dives into more details of the overall transformation process, detailing the individual tasks and sub-tasks in the process. It includes the subsystems that make up the entire system, such as the sensors, the ESP32 microcontroller, Lora Gateway and database.

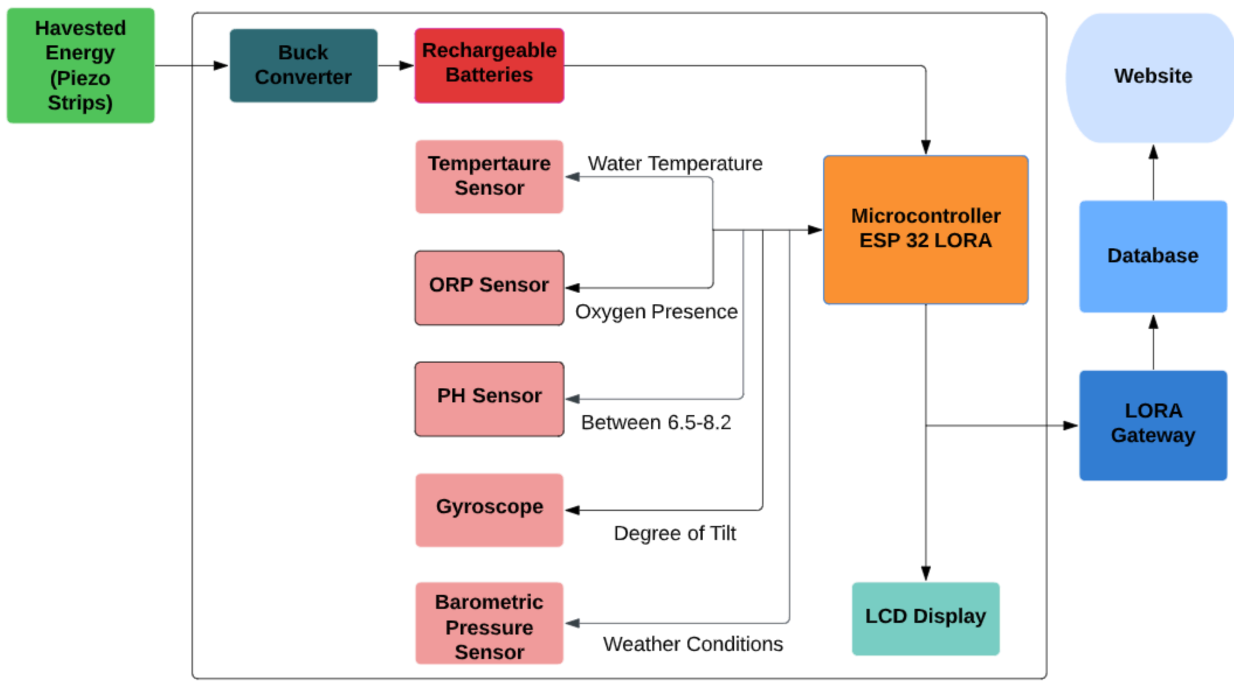

Figure 6: Level 1 of the system

For our level 1 decomposition in figure 6, we have our input which is the harvested energy from the piezoelectric strips which are charging the batteries. The microcontroller will be receiving the data from the sensors which will then be sent to the Lora gateway. Then the data is sent to the database to be processed. It will finally be sent to the website where the user will be able to manage it and keep track for the information.

Our microcontroller module will be able to retrieve the data from the sensors and send them to the gateway for processing. The implementation of several sensors will detect the conditions of the water for water quality monitoring.

Here we have the functional decomposition of our energy harvester which will be providing the energy to our entire system.

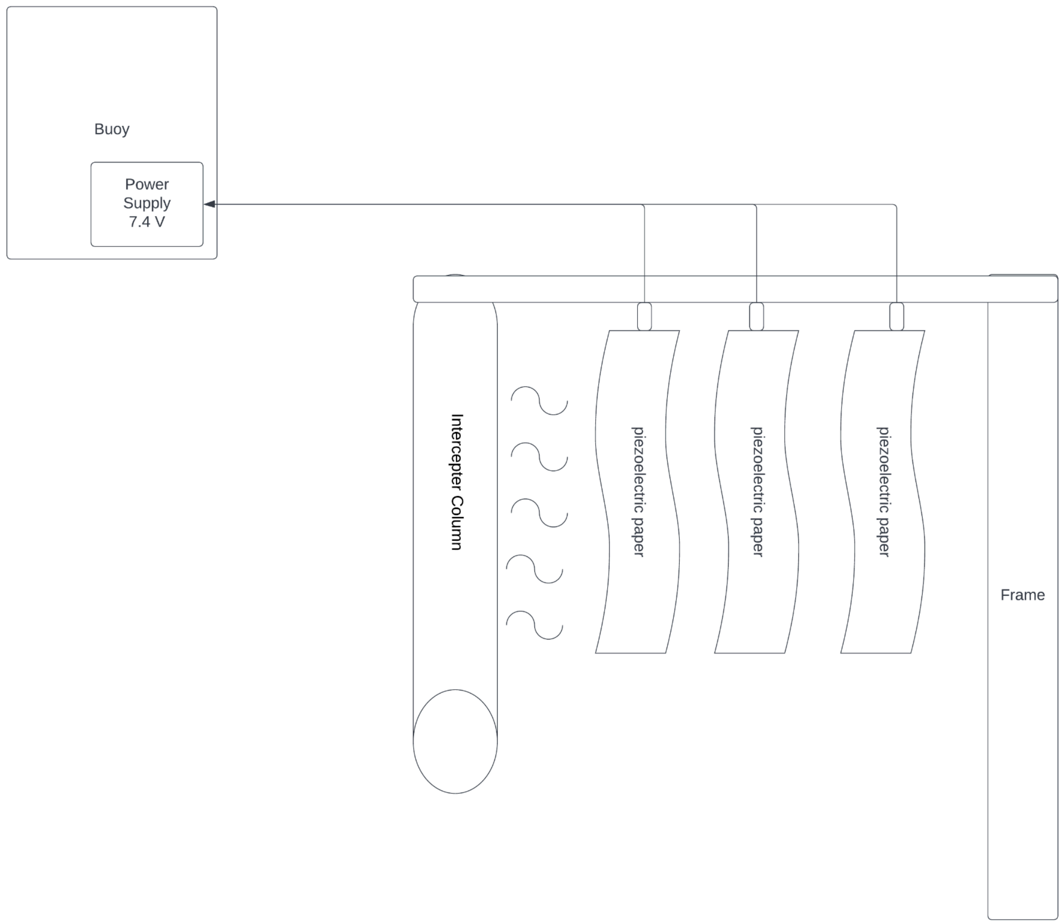

Figure 7: Harvester Functional Decomposition

Harvester Design

Working with mechanical engineers, we designed an energy harvester that operates using a self-excited mechanism. This mechanism is based on the principles of a spring-mass-damper system and is induced by the flow of fluid. It utilizes vortex-shedding which is a phenomenon where the fluid flow around the object creates unstable vortices. Figure 8, displayed below, depicts the 3D model of the object, known as a bluff body.

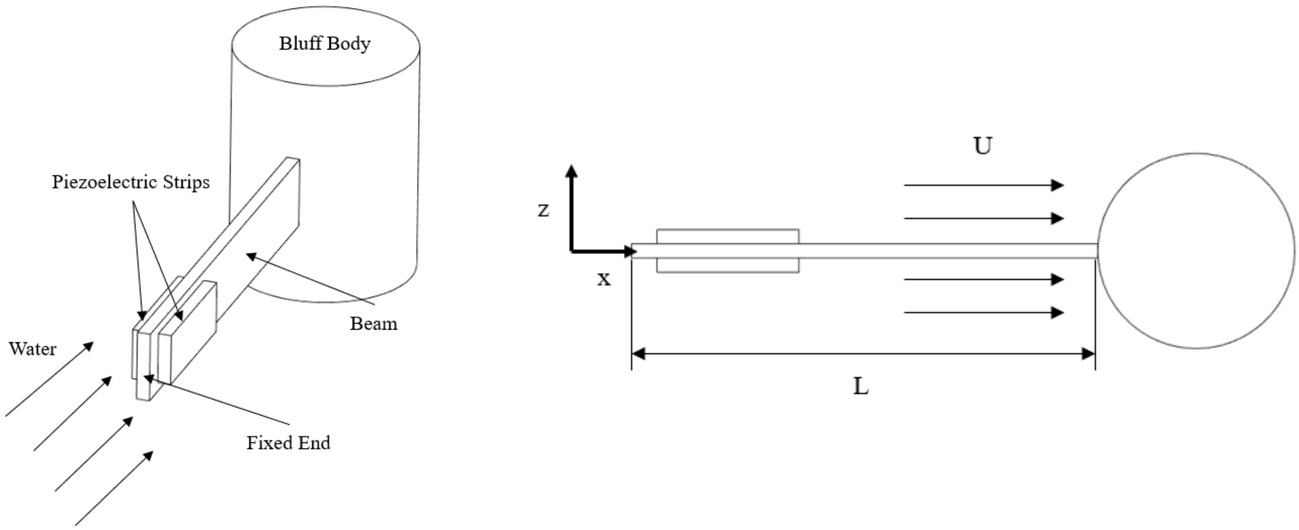

Figure 8: Schematic of the Energy Harvester

As shown on the schematic, we have a bluff body that causes the vortex shedding to generate the energy. As the fluid flows around the bluff body, it induces instability in the system, which in turn causes the energy harvester to vibrate. Another component is the cantilever beam, which is a structural element that is fixed on one end and free to move on the other end. We attached piezoelectric strip materials, shown in figure 9 to the beam to produce an electric charge when subjected to mechanical stress. This is achieved by applying pressure to the material or by bending it.

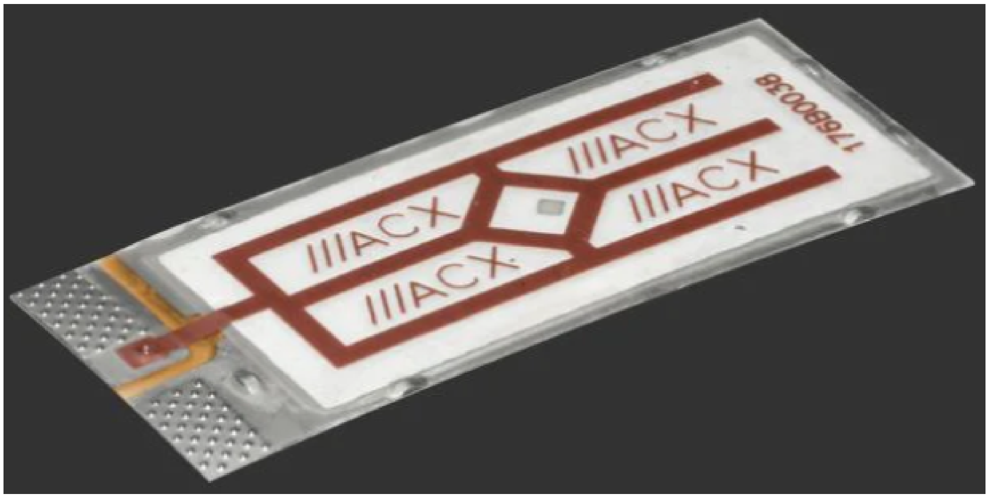

Figure 9: Image of a Piezoelectric Strip Material

Below is an overview of how the system was fabricated and assembled.

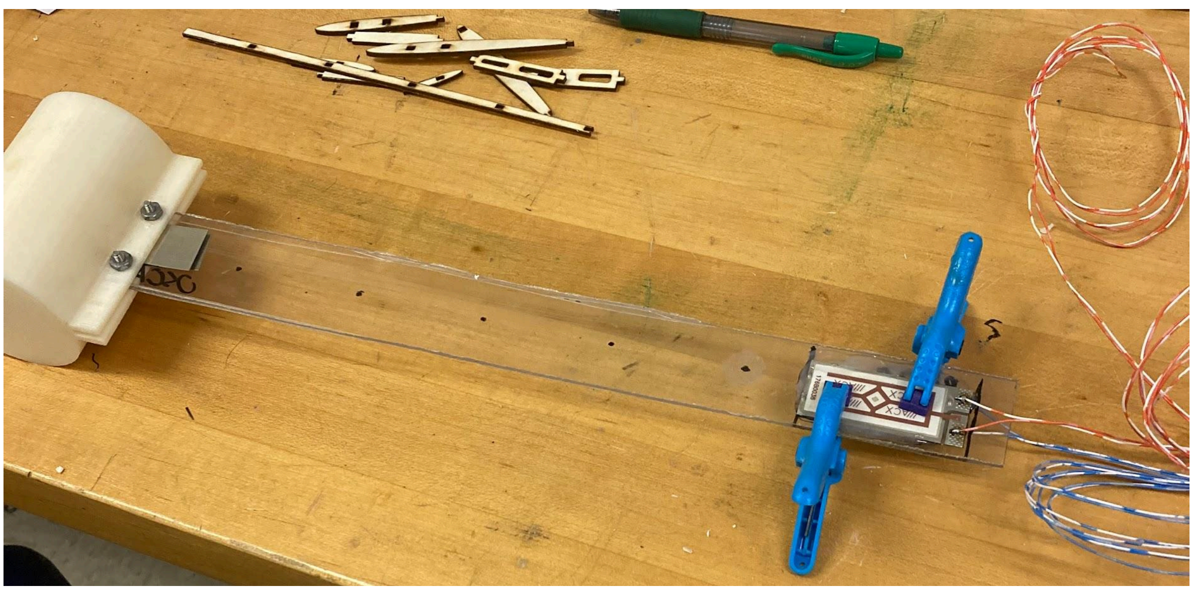

Figure 10: Piezo strips attached to Beam

As you can see, two (2) piezoelectric strips are attached on each side of beam and close to the base to gain maximum voltage output through oscillation of the water currents. We then soldered wires on both the positive and negative layout of the strips to measure their voltage output.
After multiple iterations and testing, we were able to induce a steady oscillation and read voltage produced.

3.3 Behavior Models

The behavior model is a way to bridge the hardware and the software to show how both systems will work together. The key components of this system are shown in Figure 11 in large rectangular cubes with the names. Inside each cube are the subsystems and components that make up the main system. All of these components are connected with each other and the relationship can be seen by the arrows. Some of the components in this system might change depending on the availability and there might be some additions due to future requirements and further testing.

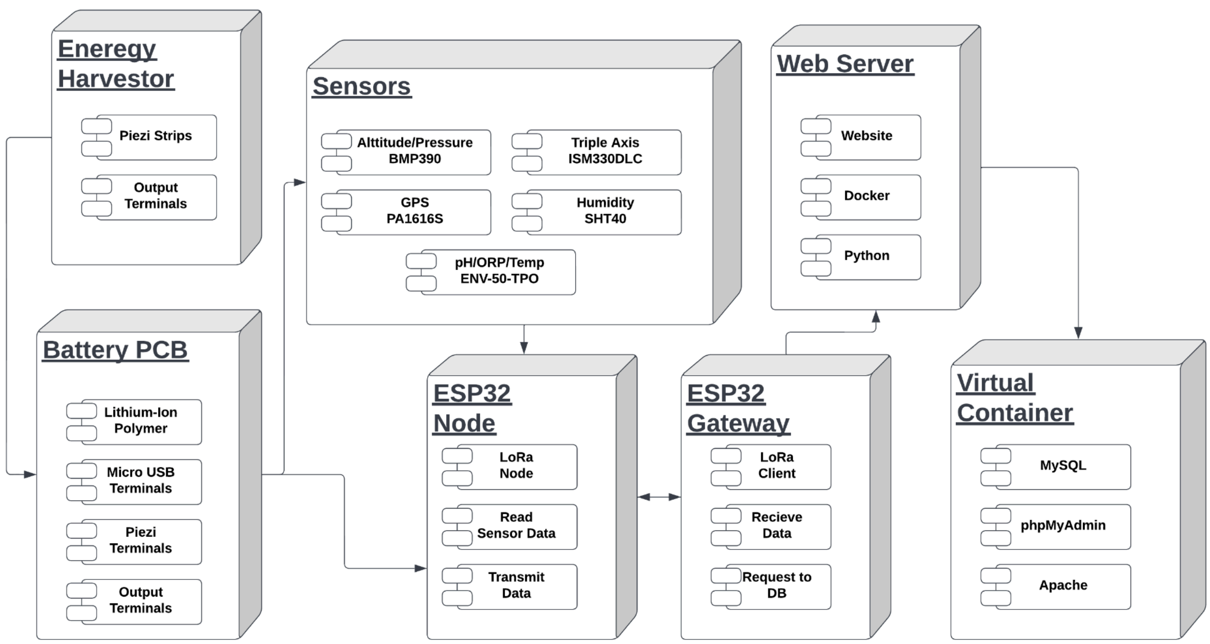

Figure 11: Physical View Behavior Module

The virtual container that is shown as the last component in Figure 11 hosts our main database. This virtual container is hosted on a Synology Disk Station (DS) which is a physical network attached storage (NAS) system that can be used to run a variety of programs and applications such as docker, python, and PHP. Utilizing the Synology DS we were able to spin up a docker instance of both MySQL and phpMyAdmin. The database uses MySQL as the backend with phpMyAdmin as the frontend web UI. MySQL and phpMyAdmin are both open source relational database systems that have greater compatibility with third party services but also a greater compatibility with web development technologies such as PHP.

Shown below in Figure 12 and Figure 13 is the Entity Relationship Diagram of our database tables. Currently we have 6 tables which are subject to change as we add more sensors and more functionality to our website. In Figure 12, the three main tables are users, user_reset, and new_pass. All three tables work together on our website to register a user and validate the credentials to log them in. The users table contains the id, name, email, username, hash_password, and a 4 digit pin. The id is used to quickly check how many rows are in the database as well as the main index which allows us to query the database for results such as the average number of users that join each week. The other values are varchar datatype and a hash_password that uses the built in password_hash function which is described in detail later in the report.

If a user does not remember their password, they can request to reset their password by entering their email and pin they created. When they enter this, the user_rest table will verify these values match the given id in the users table. If this matches, the user is given a one time code in their email which is entered in the form and verified by the new_pass table in the database. When all is verified and correct, the user will set the new password and this password will replace the old password in the main users table.

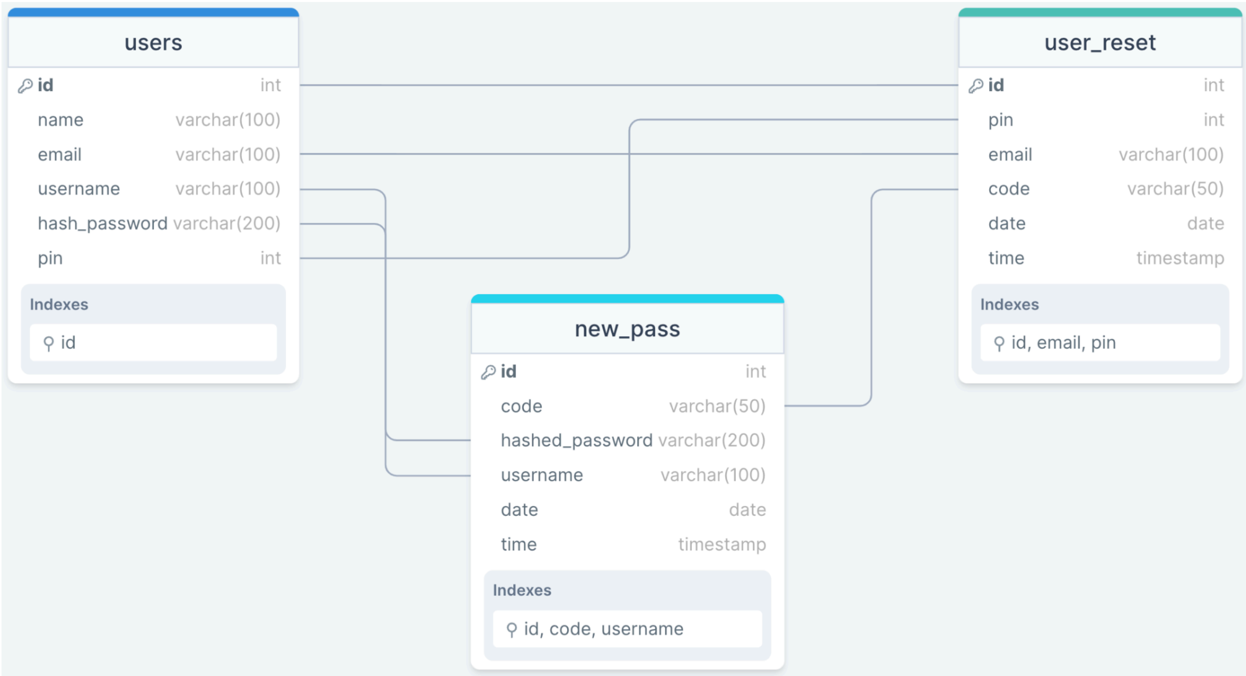

Figure 12: Entity of Users in the Database

In Figure 13, the three main tables are bmp390, ism330_acc, and ism330_gyro. The bmp390 table contains all the sensor values that are sent to the database such as the temperature, pressure, and altitude, along with the RSSI value of the transmission. The ism330 sensor has two tables, one for the acceleration and one for the gyrometer. These two tables below in Figure 10, contain the x, y, and z values which will later be sent to a storage table (not pictured). This storage table will use the values to generate a 3D model of the rotation and movement of the buoy.

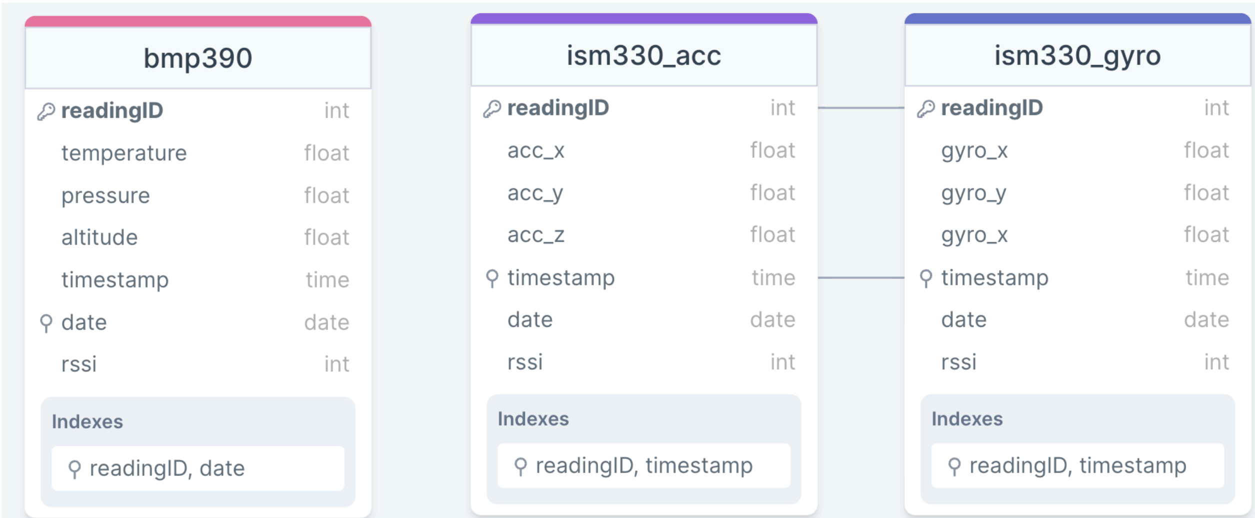

Figure 13: Entity of Sensors in the Database

3.4 Hardware Design and Implementations

The design of an effective water quality monitoring system requires careful consideration of its functional and operational requirements. A particular focus of our system is for it to be energy efficient, autonomous and low maintenance.

The system is also equipped with 6 sensors to measure temperature, Oxidation Reduction Potential (ORP), PH, humidity, degree of tilt of the buoy and pressure. The assembly of the system is done as per the schematic diagram. All the components are mounted on a printed circuit board (PCB). The PCB is designed to minimize the number of connections and maximize the power efficiency of the system. The components are soldered to the board and the ground and power lines are connected.

The system is then tested and calibrated to ensure accuracy and reliability. Finally, the system is programmed and customized according to the requirements. The software is written in C++ and uploaded to the MCU, which is responsible for controlling the system. The software includes the code for reading data from the sensors, communication protocols for wireless access.

3.4.1. Technical Specification and Modules

Sensors

The sensors are essential to the system's design and operation given its intended use.
These are chosen based on their range, precision, and resolution to satisfy the monitoring needs. Additionally, ease of use and integration are taken into account to enable quick and efficient system prototyping. The figures below show the chosen sensors with their corresponding properties as the selection's outcome.

1. As shown in figure 14, the **BMP390** is a high precision digital barometric pressure sensor from Bosch Sensortec that combines a MEMS pressure sensor with an integrated low-power 24 bit ADC. This sensor is capable of measuring pressure up to 1060 hPa with a resolution of 0.18 Pa, and an accuracy of ±0.3 Pa. It features a low power consumption of only 0.3 µA in Sleep Mode and only 5 µA in Active Mode. It also includes an embedded temperature sensor which can measure temperatures from -40ºC to 85ºC with an accuracy of ±0.5°C. The sensor is suitable for applications such as indoor air quality monitoring, altitude tracking and weather forecasting.

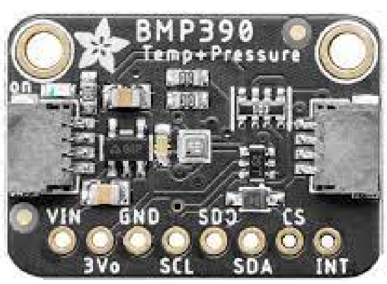

Figure 14: BMP390 sensor

2. The **ISM330DHCX** (see figure 15) features a high-performance 3D digital accelerometer and 3D digital gyroscope tailored for Industry 4.0 applications [16].An accelerometer measures acceleration forces while a gyroscope measures angular velocity. Together, they can measure orientation, velocity and acceleration in three-dimensional space.

Figure 15: ISM330DHCX sensor

Accelerometer Specifications:

• Range: +/- 2g, 4g, 8g, 16g

• Resolution: 8 bit, 10 bit, 12 bit

• Noise: Typically 0.25mg RMS

• Bandwidth: 0-400Hz

Gyroscope Specifications:

• Range: +/- 250, 500, 1000, 2000 deg/sec

• Resolution: 8 bit, 10 bit, 12 bit

• Noise: Typically 0.02-0.03 deg/sec/sqrt(Hz)

• Bandwidth: 0-1000 Hz

3. Atlas Scientific's Industrial **pH/ORP/Temp Probe** sensor is an all-in-one, high-precision probe designed to measure pH, ORP, and temperature in industrial applications. It is designed to work in harsh environments, including high-temperature, pressure, and corrosive solutions. The probe features a stainless steel body, durable and chemical-resistant Teflon cable, and a built-in temperature sensor for precise readings. The probe is also equipped with a double-junction reference electrode and a low-noise amplifier, which are both designed to minimize drift and provide accurate readings. Additionally, the Industrial pH/ORP/Temp Probe sensor is compatible with most popular pH/ORP/Temp meters on the market, making it easy to integrate into existing systems. With its robust construction, precise readings, and reliable operation, Atlas Scientific's

Industrial pH/ORP/Temp Probe sensor is an ideal choice for any industrial application, see figure 16 below.

Figure 16*: Industrial pH/ORP/Temp Sensor Probe*

Technical Specifications:

pH: 0 - 14

ORP: -2000 – 2000mV

Temp: 1 – 99°C

4. The **Anemometer Wind Speed** Sensor with Analog Voltage Output (shown in figure 17) is used to measure wind speed and output a voltage signal. This device uses a rotating-vane type anemometer to measure the wind speed, which is then converted into an analog voltage output. The output voltage is proportional to the instantaneous wind speed and can be calibrated to any desired unit of measure. This device is designed to operate accurately in wind speeds up to 150 m/s, with a resolution of 0.1 m/s. The output voltage range is 0-5V and the operating temperature

range is -30 to 50℃. It is suitable for use in both indoor and outdoor applications and is compatible with multiple voltage sources.

Figure 17: *Anemometer Wind Speed Sensor*

The black wire is used to connect to power and signal ground, the brown wire to 7-24VDC and the analog voltage is measured on the blue wire. The voltage will range from 0.4V (0 m/s wind) up to 2.0V (for 32.4m/s wind speed).

5. The Adafruit **AHT20** Temperature & Humidity Sensor Breakout Board is used to measure temperature and humidity levels. It uses an AHT20 digital temperature and humidity sensor to accurately measure and monitor temperatures up to 80°C and relative humidity up to 100%.

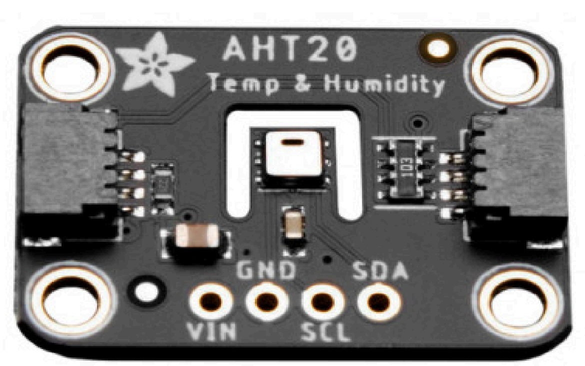

Figure 18: *Temperature & Humidity Sensor*

The board includes a 1200:1 humidity sensing range and ±0.5°C temperature accuracy. As you can see in figure 84, it is powered by an I2C interface and includes a 3.3V regulator, making it easy to use with a variety of boards and platforms.

6. The Adafruit **Ultimate GPS Breakout v3** will be used as our GPS module for this project. It features an integrated active antenna and a dedicated backup battery for ultra-low power operation. It also includes an LED indicator for debugging and locating satellites. The module supports up to 10Hz update rates and up to 10-meter accuracy. The Ultimate GPS Breakout v3 supports a wide range of interfaces, including I2C, SPI, and USB. It also provides precise location tracking, see figure below.

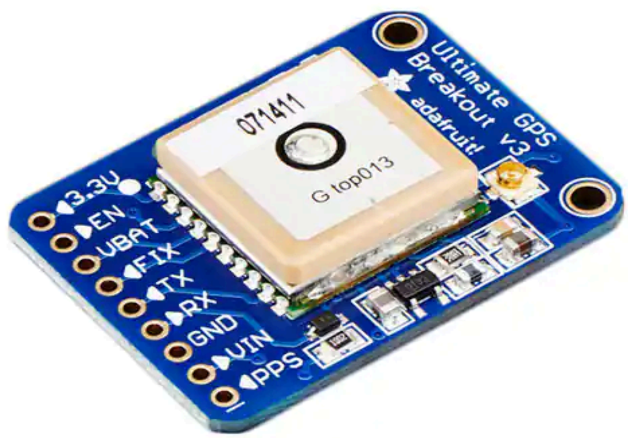

Figure 19: *Ultimate GPS Breakout*

Our system will use an external active GPS antenna to improve GPS signal reception. It is designed to capture the GPS signal from all directions, making it more reliable in areas with weak signal reception.

To hold all the electronic components and PCB devices securely, we needed to make a buoy that could both float and be waterproof. We used Fusion 360, a computer design software, to create the buoy in three separate parts. Then, we 3D printed these parts using white PETG+ filament on an Ender 5 printer.

Fusion 360 is a powerful tool that allowed us to design and refine the buoy in a 3D virtual environment. It helped us ensure the accuracy and precision of the design before moving on to manufacturing. Using this software, we divided the buoy into three parts to make assembly easier and to provide convenient access to the internal components. Each part was designed to fit together and was printed using PETG+ filament because it's known for its strength, durability, and resistance to water and moisture. This made it an ideal choice for a waterproof application like the buoy.

Using the Ender 5 printer was a practical decision. It's a reliable 3D printer with a large build volume, making it suitable for printing the buoy's components. The white color of the PETG+ filament was intentional as it offers better visibility in different lighting conditions and reduces the risk of overheating under sunlight.

Combining the design capabilities of Fusion 360, the properties of PETG+ filament, and the reliable performance of the Ender 5 printer, we successfully created a buoy that effectively housed all the necessary components while meeting our requirements for floating and waterproofing. Below are the 3 parts along with the completed design and flotation device.

Figure 20: 3D Bottom of the Buoy

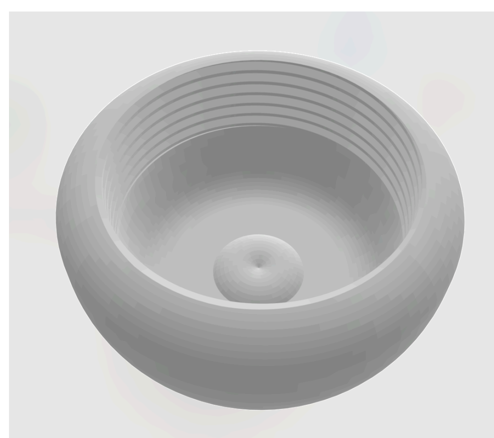

Figure 21: 3D Top of the Buoy

Figure 20 of the buoy design includes an important feature: a hole designed specifically to accommodate the Atlas Scientific probe. This hole ensures that the probe fits snugly within the buoy, providing stability during its operation.

The top part of the bottom piece is designed with threads. These threads allow for easy and secure attachment of the middle section to the bottom section. This design element ensures a tight and reliable connection, preventing any unintended detachment or water leakage. This is the same with the top piece in Figure 21. Below in Figure 22, you will see the middle section which threads to the bottom section and top section. The middle section houses all the electrical compients snuggly ensuring there is no movement.

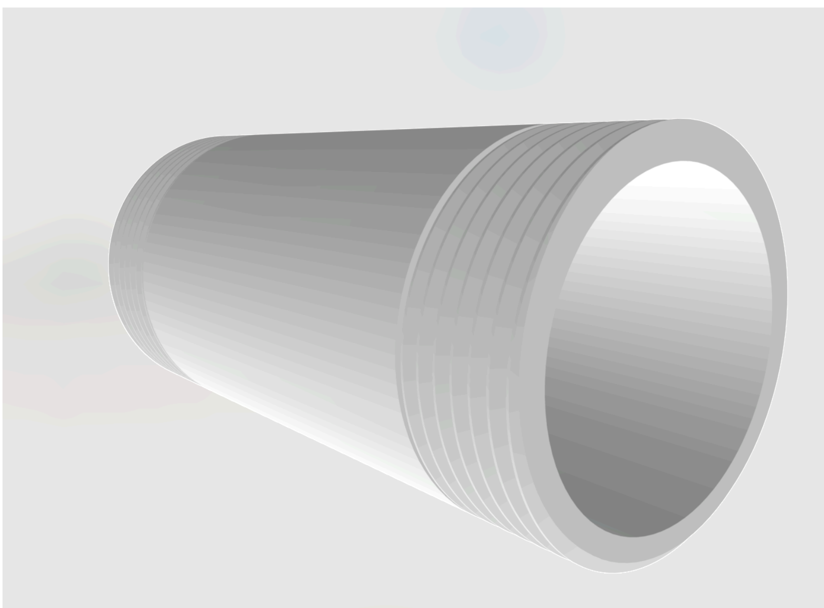

Figure 22: 3D Buoy Middle Section

3.4.2. The Proposed Communication Methodology

The hardware design is composed of two ESP32 LoRa microcontrollers with one acting as the Gateway and another acting as a Node. There is a suite of sensors as well as the physical servers running the virtual containers.

Based on Figure 23, the sensor suite contains sensors that will transmit pH, ORP, Temp, Angular Velocity, Wind Speed and more to the Node MCU. This Node will receive the data from multiple sensors and will combine the data into a LoRa packet which is sent to the Gateway. The gateway will search for the LoRa packet and once it finds it, the data will be transmitted to the Server which will parse and transform the data into the SQL database. This database will send the data to the web server for further processing and analysis.

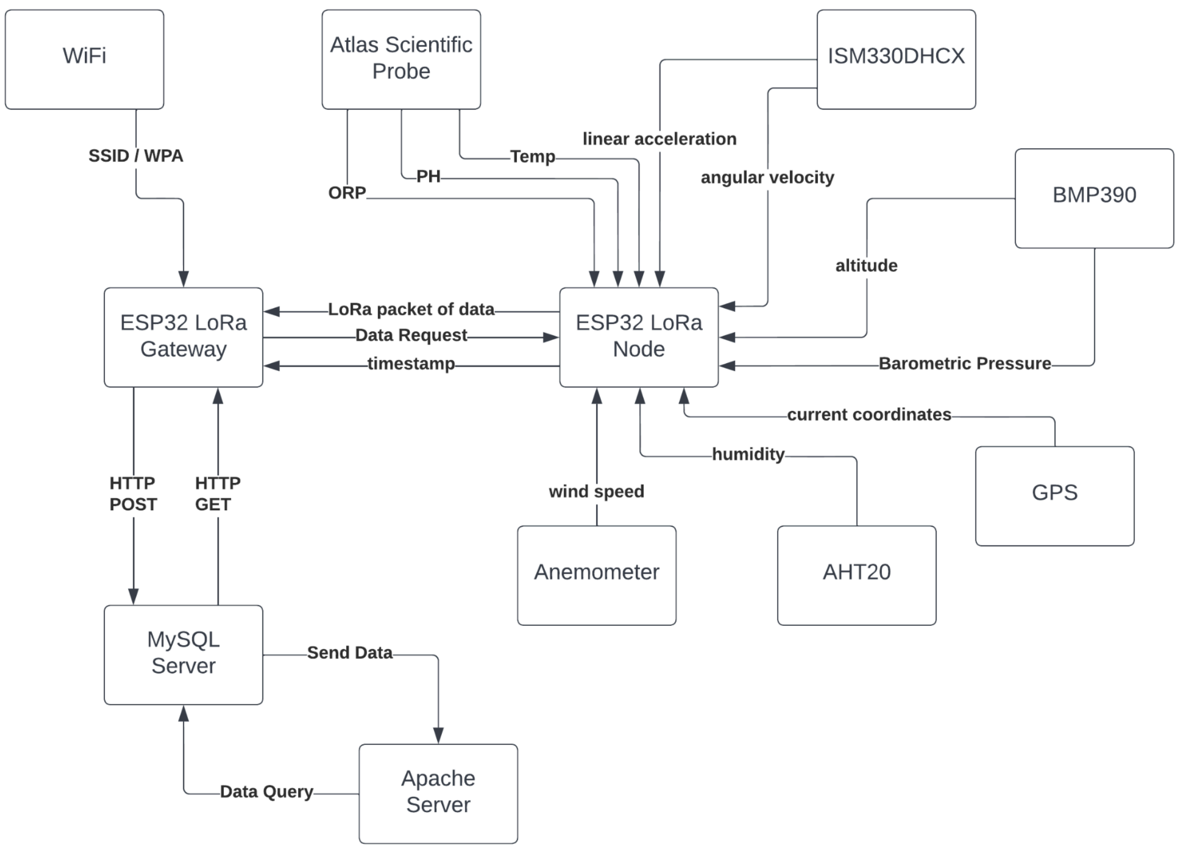

Figure 23: Proposed Communication Methodology Between Hardware

3.4.3. Description of Hardware Implementation

We completed the unit testing for all of our components and are working on the integration testing at the moment. Below is the latest version of our PCB implementation, shown in Figure 24. The setup consists of the Microcontroller (ESP32), the Temperature and Humidity sensor

(AHT20), the Ultimate GPS, Temperature and Pressure sensor (BMP390), the Accelerometer and Gyroscope (ISM330DLC), Anemometer, and Temperature strobes. Currently, the sensors are successfully sending data to the microcontroller and the system is running properly. The website will be used to monitor the data.

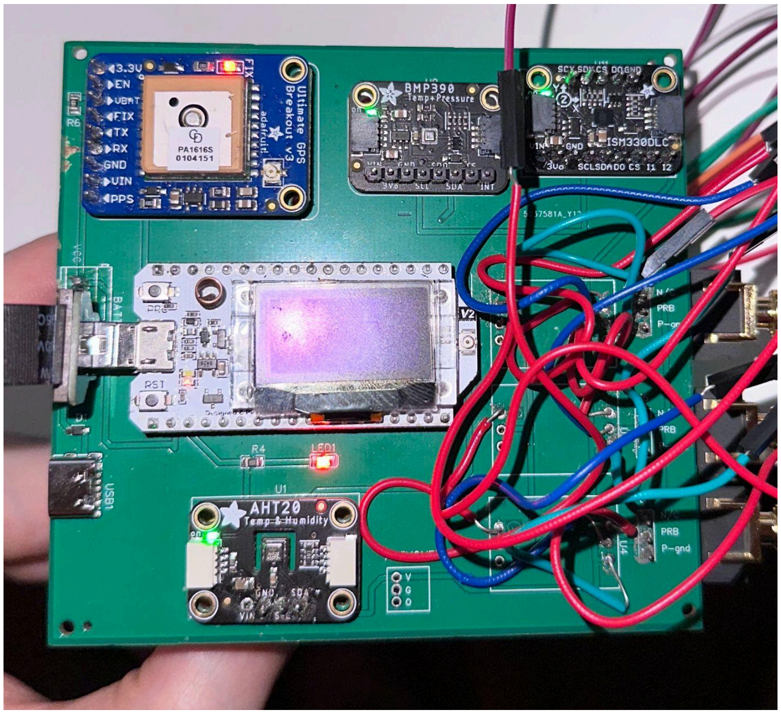

Figure 24: Complete PCB System

Lora Gateway

We also have an IP65 waterproof box that contains our ESP32 lora microcontroller, seen in Figure 25, acting as the gateway with an antenna on the side to communicate with the node. A LoRaWAN gateway for the ESP32 microcontroller and is based on the SX1276 transceiver. It has a built-in LoRaWAN module, support for LoRaWAN Class A and Class C, and a UFL antenna connector. It also supports LoRaWAN nodes with 868, 915, and 433 MHz frequencies. The gateway also has a built-in OLED display, which can be used to display LoRaWAN messages. The gateway can be used to transmit LoRaWAN packets to and from other LoRaWAN devices in the same LoRaWAN network.

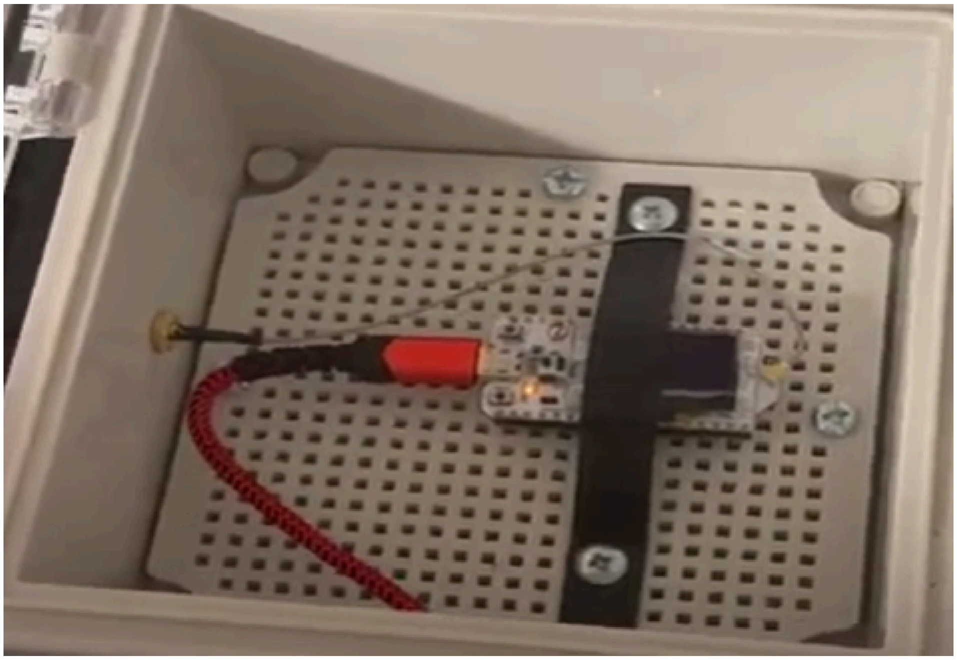

Figure 25: Lora Gateway

For our node, we also have an ESP32 Microcontroller that uses the lora communication attached to the sensors and will send the data received to the lora gateway to be sent to the database to provide real-time information on the state and evolution of the waterbody, as well as tracking changes over time

PCB Design

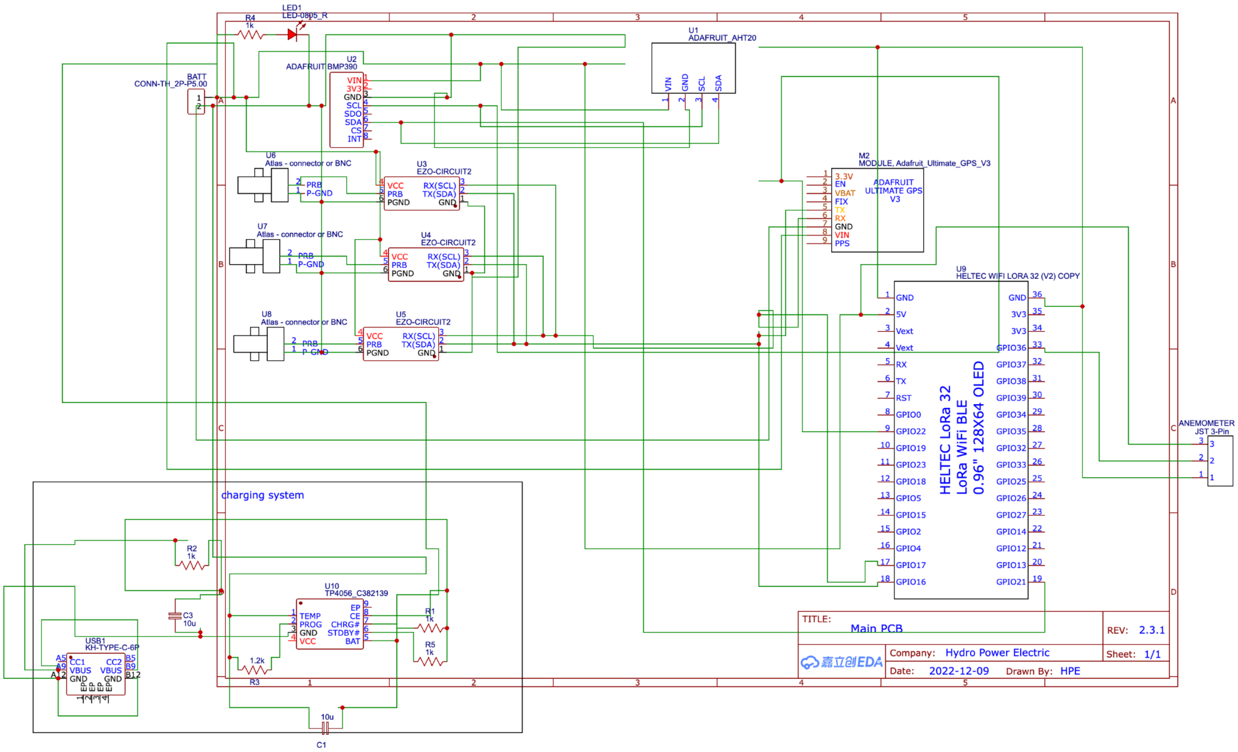

Figure 26: PCB Schematic

This PCB board schematic contains several sensors we will be using, a ESP32 Lora microcontroller and a charging system to use the energy harvested from the piezoelectric strips. The sensors are used to measure various aspects of the environment, such as temperature, humidity, pressure, and weather conditions. U3, U4 and U5 which are EZO circuits that will be connected to the probes of the industrial sensor and have a connector at the other end that will connect to electrically isolated EZO carrier boards stacked on top of one another (refer to figure 26). They will be connected to the pH, ORP and temperature probes respectively. The collected data is then processed by the ESP32 Lora microcontroller, which is an ultra-low-power, powerful microcontroller with Wi-Fi and Bluetooth capabilities. The microcontroller is also capable of transmitting data over long distances via LoRa communication, making it ideal for our project. We also have a GPS module which has an external active antenna to boost it, BMP390 sensor which measures the temperature and pressure and ISM330DHCX sensor equipped with an accelerometer and gyroscope. Additionally, we have a battery terminal and a USB port to charge the board. With the combination of sensors and the ESP32 Lora microcontroller, this PCB board schematic can be used to monitor the quality of the water in the East River (see figure 24 for a 3D layout of the board). We will be performing more iterative testing on this PCB to ensure its functionality.

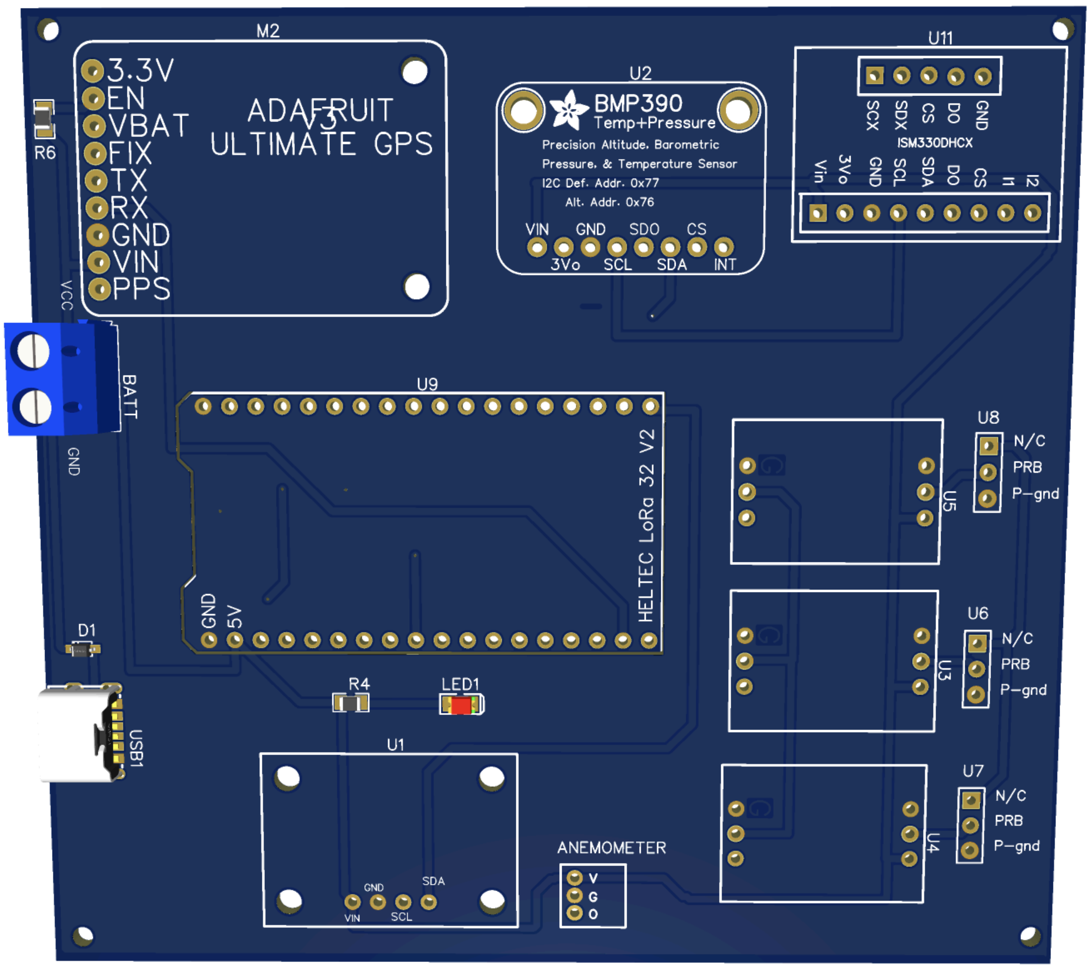

Figure 27: 3D PCB Layout

Battery PCB Design

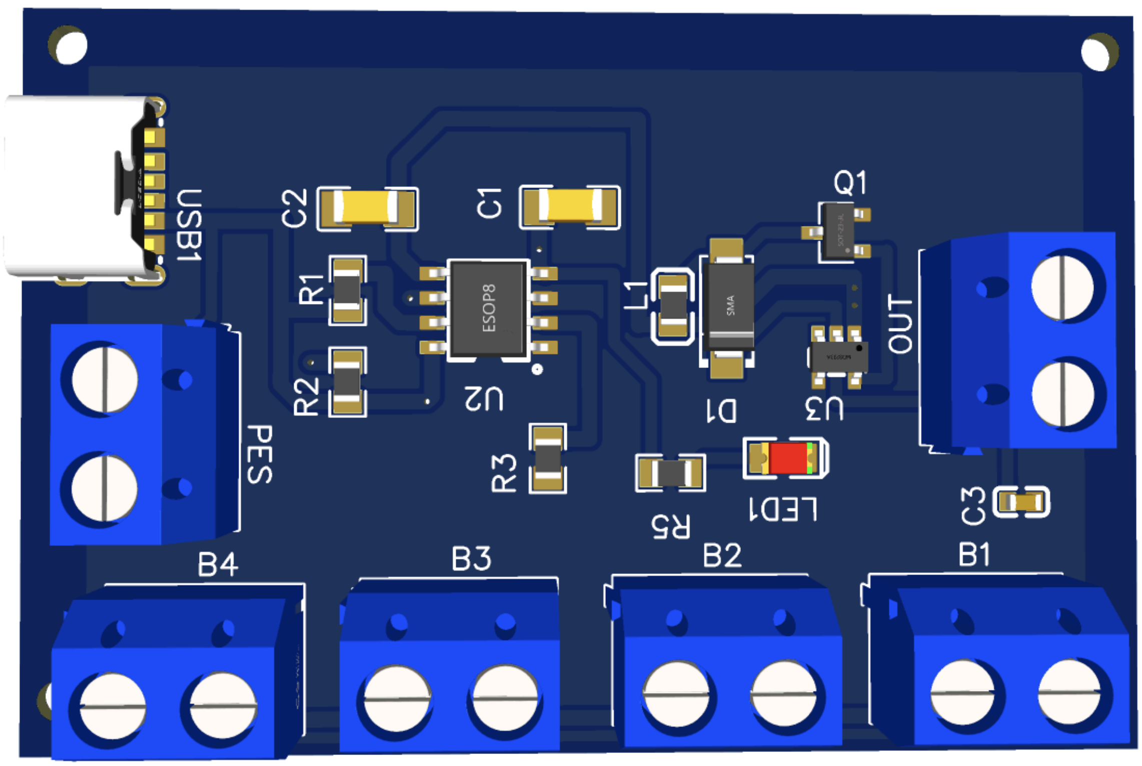

Figure 28: Battery PCB Design

In reference to Figure 28, our battery PCB design will feature 4 3.7V batteries connected in parallel, which will allow for a larger capacity and a longer runtime. The batteries will be connected in a way that all of their voltage will be added together, resulting in a total voltage of 15V. This voltage will then be regulated to 5V output with a voltage regulator, making it suitable for powering a variety of electronic devices. The battery PCB design will also feature protection circuitry that will prevent overcharging and over-discharging of the batteries, which will ensure their longevity and reliability. Additionally, the board will have a simple interface and will be easy to use, making it ideal for a variety of applications. The board will also feature two terminals; one to charge the batteries using piezoelectric strips, and the other to charge the batteries using a micro USB connector.

3.5 Software Design and Implementations

Behind this whole system and behind all the hardware, there has to be software running to make sure everything is operational and everything is communicating how it should be. From machine learning algorithms, PHP, and HTML; everything comes together as one. For this system the main website is coded in PHP with HTML and CSS. The sensors are programmed using the Arduino IDE and the two main microcontrollers are also programmed with the same IDE.

3.5.1. Design Setup

Our main system will run on two main platforms, virtual and physical. Our virtual platform will be used to combine our web server which will include our website and main database. The physical platform is separated into two parts, the server side and the microcontroller side. All of these platforms will work with each other to produce a system that is smart, efficient, and evolving.

The virtual platform can't exist without the server sided physical environment. This environment is mainly the Synology DS 720+ which is the Synology DiskStation. The 7 indicates that the drive bays can be expanded to a total of 7 and the 20 indicates the year it was released, in this case 2020. The Synology DS is a compact Network Attached Storage Solution or NAS. This specific NAS has a 4 core 2.0 GHz CPU with a burst of 2.7 GHz. The total RAM (Random Access Memory) is expandable up to 8GB and has 2 drive bays for hard drives.

Our system currently utilizes both drive bays with a 8TB NAS hard drive in each. However, we only have access to 8 out of 16GB since we have the storage in a RAID system. RAID (Redundant Array of Independent Disks) is a data storage system which uses at least 2 drives in an array system to store a copy of the data on each drive. This ensures that if one drive fails, the user has enough time to replace it without losing any data as the entire system is already copied onto the other drive. This is especially important for us since we are storing a large database which currently has over twenty thousand data points with an estimated increase of twenty thousand each week as the system is running on a constant basis.

On this NAS, the main program that is running is Docker. Docker is an open source platform that makes it easy to deploy software in a container. This container is a package of software that can be re-deployed in a different environment without the need for changes in the original container. There can be multiple containers running the same software. For our system, the main containers that we have running in Docker are Portainer, MySQL, phpMyAdmin, and an Apache Web Server.

Portainer is a management tool that is used to manage Docker containers, images, and networks with a simple web interface. This web interface allows us to create a stack for our database and webserver all in one place without having to create multiple containers. A stack when talking about containers is a group of services that you want interrelated with each other. For our system, we need apache and php so we created a stack that pulls an apache image along with the latest PHP version and then deploys it under one container for easy management.

MySQL and phpMyAdmin is our choice of database based on its sheer ease of usability and the ability to integrate it with almost any provider. Since we are storing large amounts of constant data, we needed a storage solution that would provide access to third party services such as HTTP requests and also the ability to connect the database to our web application.

3.5.2. The Workflow of the Proposed Algorithm and the Implementation

The setup consists of the main ESP32 microcontroller acting as the LoRa gateway and another ESP32 acting as the child or the LoRa Node. Attached to the Node are all the sensors which use I2C communication to transmit the data from the sensor to the microcontroller. In the main program we have three participants which are the Gateway, Node, and the BMP390 sensor. Over time there will be more participants once we obtain all the other sensors but the main setup will be mirrored to the other sensors.

Referenced in Figure 26, we can see the three participants and the setup function that happens at the same time between the Gateway and the Node. The setup function in Figure 23 starts with the

Gateway by starting the LoRa communication. Since this is running on the gateway, the microcontroller will connect to the WiFi that is referenced to in the main code configuration. Once the gateway is connected to the WiFi, the setup function is complete and the Gateway will continue to the Loop function. As the Gateway is performing the setup, the Node is also performing its own Setup function. In this function, the Node is starting the sensor by providing 3.3V of power which will indicate to the sensor to being the I2C function using the SDA and SCL pins. SDA (Serial data) and SCL (Serial Clock) act as data transfer lines between devices. When the sensor receives power from the Node, the SDA pin is used to send the data to the Node and the SCL pin is used to tell the Node that there is new data that has been sent over.

In the background, the sensor will begin to set the Oversampling for the Temperature, Pressure, and Altitude. Oversampling the data is simply the number of times the sensor gets a measurement before getting a single result. For these sensors, this is necessary in order to obtain accurate results. Once this is complete, the Node will begin its LoRa communication and will move onto the Loop function.

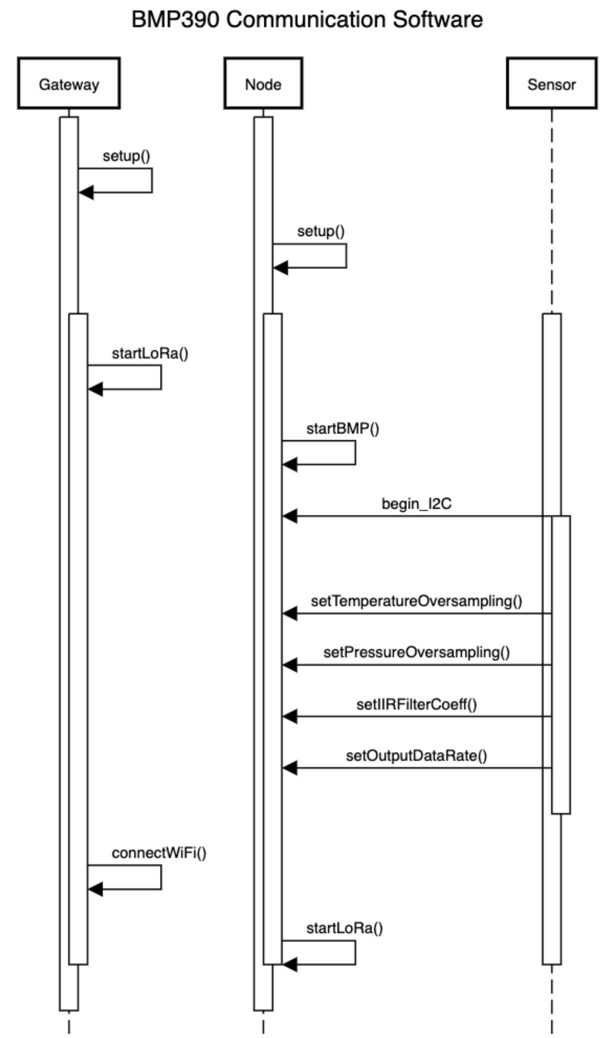

Figure 29: Setup Function of Main Code

In Figure 30, we see the same three participants but instead of Setup, the participants are running the Loop function. The Loop function will run whatever sub functions that are inside it over and over until either there is no power, no data, or the communication protocol fails.

For the Gateway, the loop function begins with obtaining the LoRa data from the Node and at the same time, in Figure 30, we can see that the Node is running its getReadings function which will wait for the SCL pin to send the signal that new data has been sent over. When this signal is received, the Node will send these readings over to the Gateway as a LoRa packet. Once the Gateway receives this packet of data, it will be parsed and sent to the database using HTTP requests.

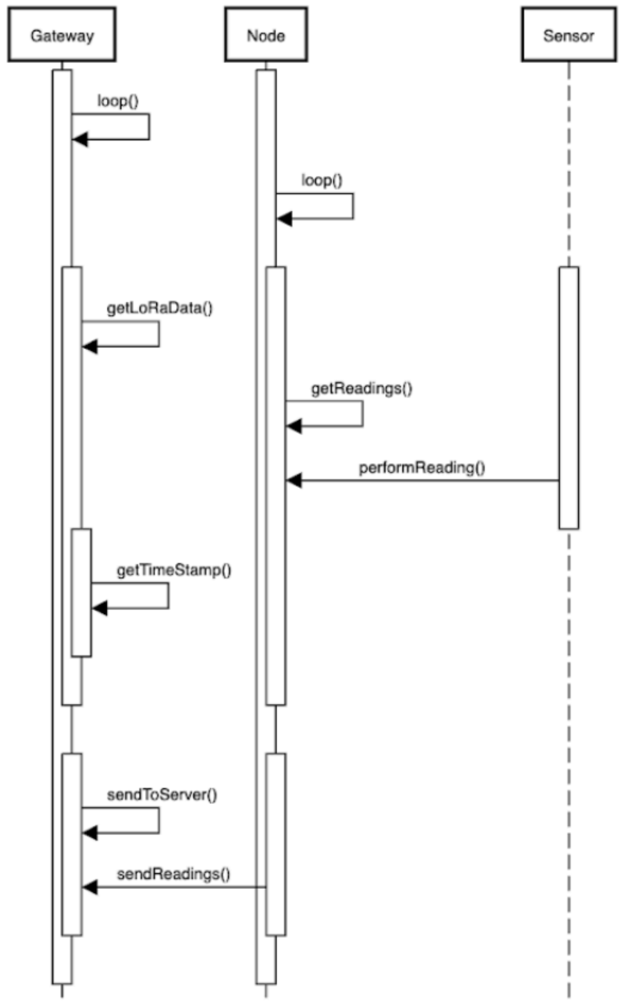

Figure 30: Loop Function of Main Code

The two types of HTTP requests that we are using are HTTP Post and a HTTP Get protocol. The HTTP Post protocol, sends the data to the database by inserting the data into a form in the body of the webpage. In Figure 31, we can see the diagram of how these two requests integrate with the gateway and the node. We use the POST request to submit the data into the database while the GET request will send back a code to the gateway with a response. We aim for a 200 response code which indicates that the data was successfully submitted. These two types of HTTP requests are used in a variety of applications especially in PHP heavy environments.

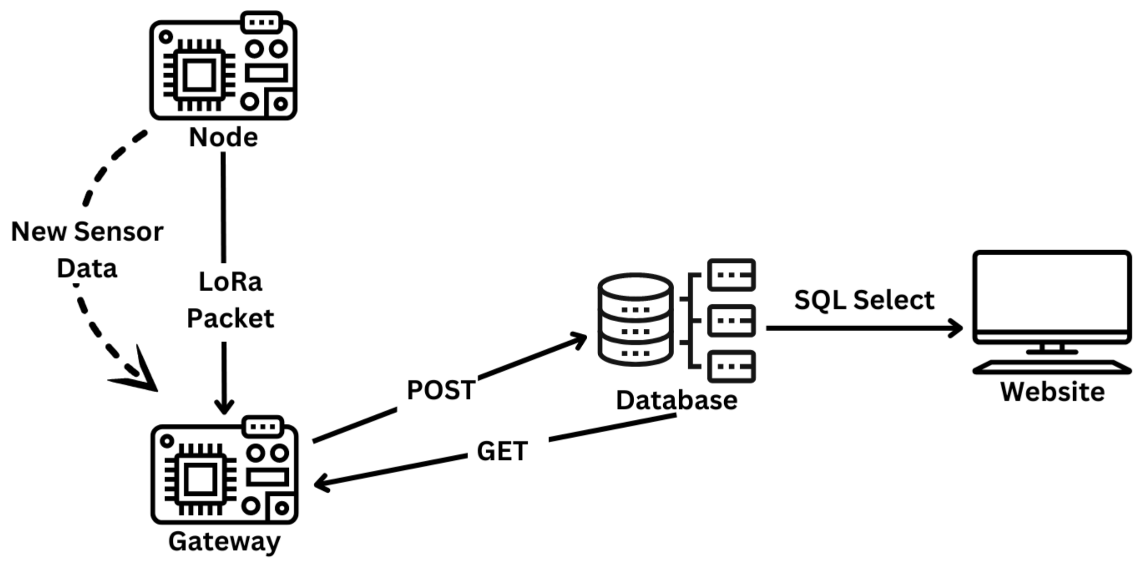

Figure 31: HTTP POST/GET Diagram

3.5.3. Description of Software Implementation

For the main portion of the software, we begin with the website which has user account access such as registration and login credentials. We also have a data page which will show a chart of the latest 40 entries of the sensor, roughly the last twenty minutes. There is an about page which describes the project goal as well as the team members, their roles and responsibilities.

In Figure 32 we can see a login screen which uses PHP, HTML, CSS, and JS to render and run the backend of the webpage. The main PHP code is used to query the database and establish the connection between the website and the users table in the database. When the user fills in the username and password fields, the backend process of the page will query a result to see if their is a match. Once a match is found, the website redirects the user back to the home page.

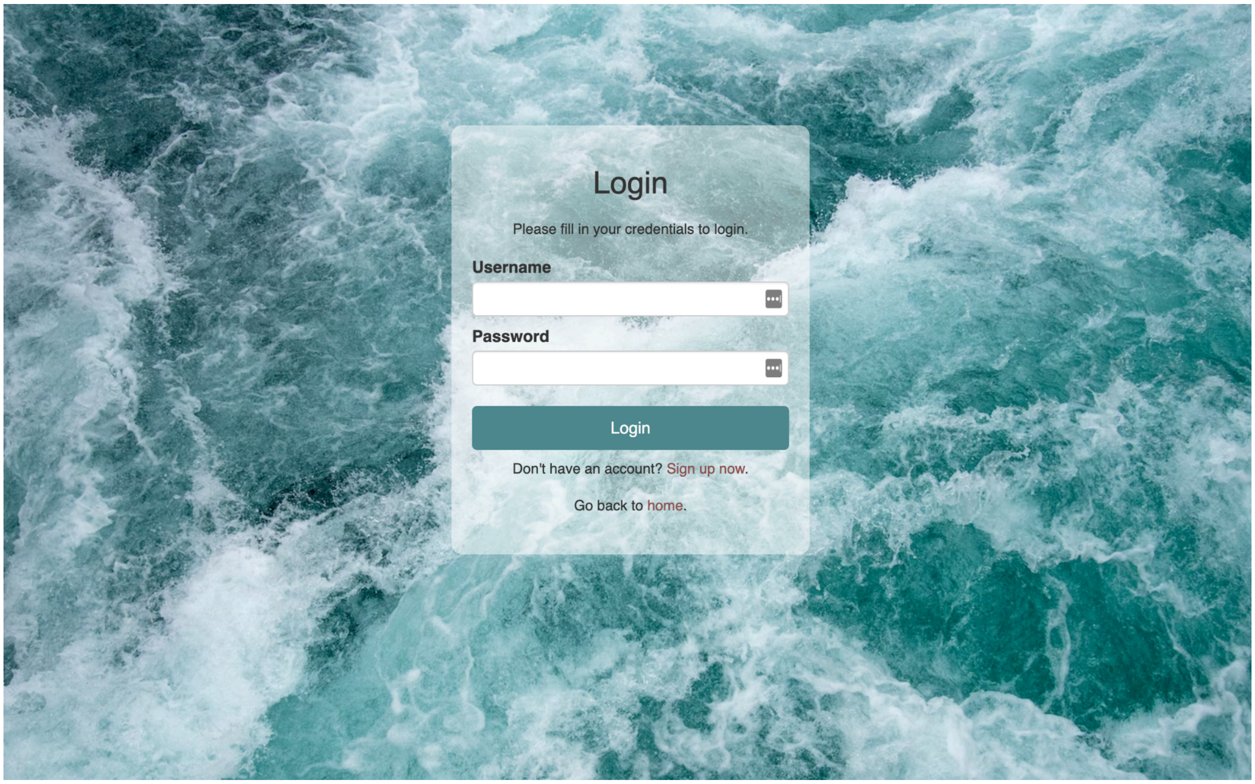

Figure 33: Login Page

If a user does not have an account, they can register as seen in Figure 33. The registration page requires the user to type their name, a username, email address, password, a password confirmation, and a pincode. If a user chooses a username or email address that is already in the database, they will be presented with an error message shown in Figure 34. Once the user is successfully registered, they will get a redirect to the login page and will be allowed to sign in with their credentials they just made. From here they can explore the main data pages on the site.

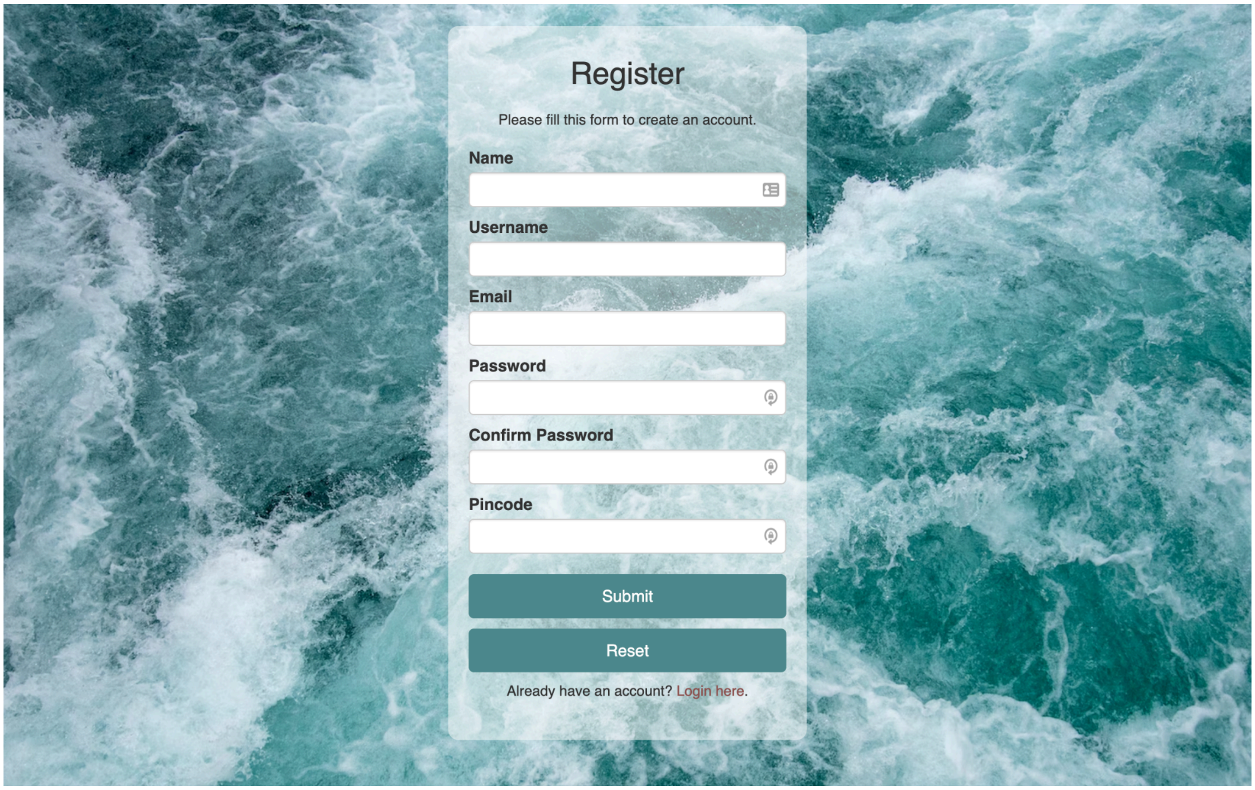

Figure 33: Registration Form

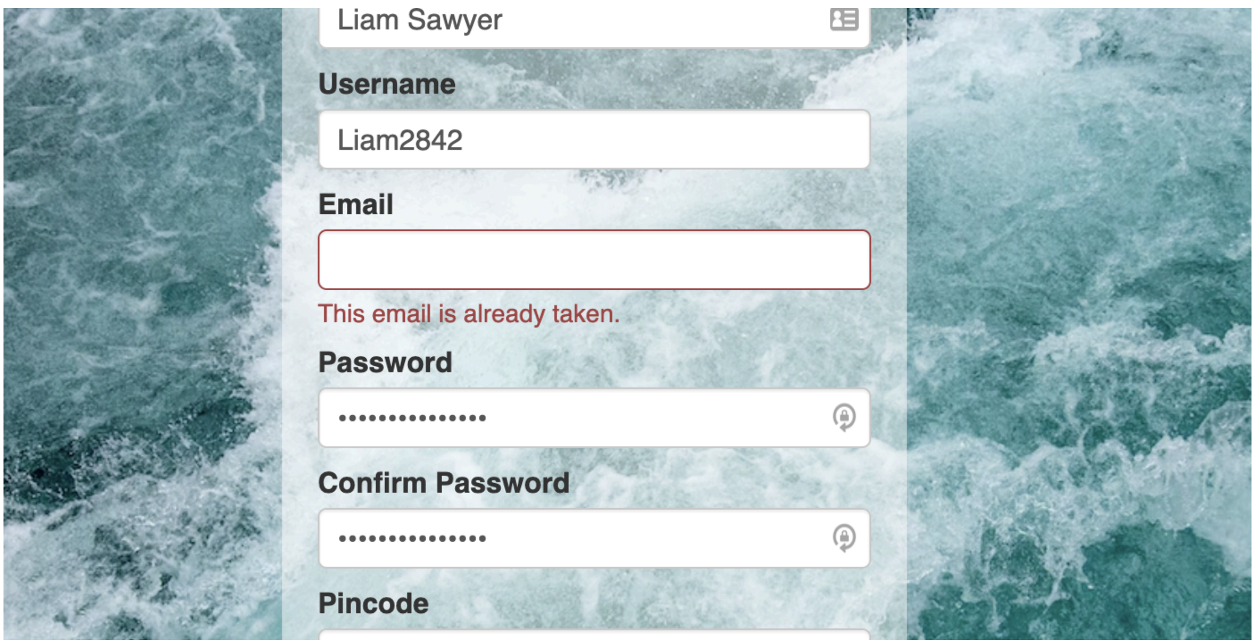

Figure 34: Email Taken Error Message

The main section of the website is the live data feed. All three values of the Atlas Scientific sensor are shown in a simple to view graph as seen in Figure 35. All the charts are mobile friendly so viewing on a mobile device is no problem and the charts will automatically resize to fit the screen. Since these charts are querying the data live from the database, the webpage automatically refreshes every 1 minute with a simple PHP code in the backend.

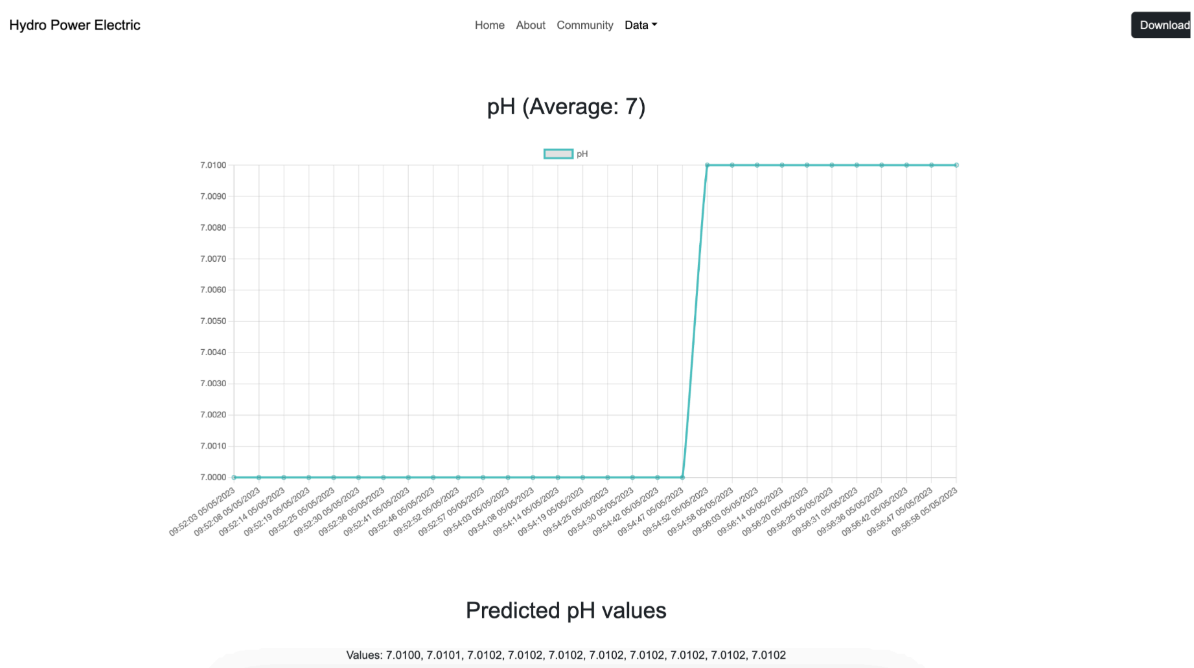

Figure 35: Data Page

The Atlas Scientific pH sensor is a type of digital sensor that measures the pH level of the water surrounding the buoy. The current pH value is displayed on the y-axis as it is being measured in real-time, while the x-axis represents the time elapsed since the start of the measurement. Tracking the pH fluctuations over time is important for monitoring water quality and detecting any changes that could indicate pollution or other environmental factors. pH is a critical parameter because it directly affects the health of aquatic organisms and can indicate the presence of harmful substances in the water. By collecting pH data over time, the system can identify trends and patterns, allowing for the implementation of appropriate measures to maintain or improve water quality. For instance, if the pH level becomes too acidic or alkaline, the system can trigger alerts or activate corrective mechanisms to restore the optimal pH range. This ensures the buoy's components and the surrounding ecosystem are protected and allows for efficient and timely response to changes in water conditions.

As shown in Figure 35, the pH starts at 7.00 and increases to 7.01, indicating a slight change in the overall water pH.

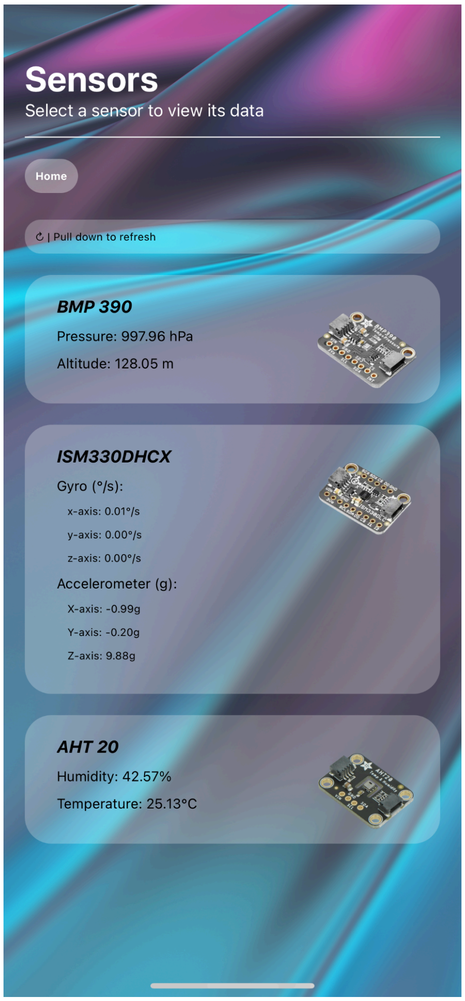

Figure 36: App Data

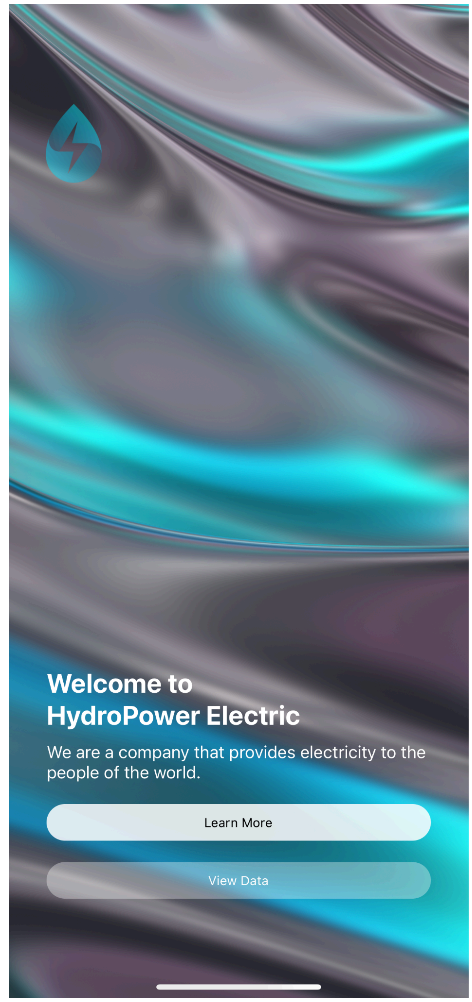

Figure 37: App Welcome

Above in Figure 37 is the Welcome page when you launch the application. It presents our logo and a simple description of what is to come and what the project is about. When you click on the View Data button, we are greeted with Figure 36, the Data page in the app. This page lists the sensors as well as shows an image of the sensor. Each sensor presents the data in real time straight from the database. In the future, you will be able to click on the sensor and it will open a new page with graphical and historical results, as well as a map of where the sensor is located.

3.6 Iterations to Develop Optimal Design

We performed several iterations to develop an optimal design for our project. From testing the printed circuit board (PCB), website, microcontroller, database and several other components, we were able to make gradual changes to the design by testing the results, then making further changes based on the test results. This iterative process allowed us to improve our components and make sure the requirements and specifications are met. For example, when designing the PCB, we made a first draft of the board, then test it to ensure it meets the performance and reliability requirements. Since the first testing failed, we then made changes to the board and continue the cycle until it meets all requirements. This same iterative process is applied to all the components such as the website, microcontroller, database, LoRa gateway, etc. Most of our tests were successful.

Date	Test Case Name	Test ID	Test Type	Failed/Success Action	Corrective Action	Iterations
2/30/23	App Development	APP 01	Unit	Success	Review configuration of the board	1
2/30/23	Microcontroller	MCU 02	Unit	Success	Using the right data cable and connections, the board was recognized by the PC	3
2/20/23	PCB	PCB 03	Unit	Success	Displayed real-time updated information	3
2/18/23	Website	WB 01	Integration	Success	Website was able to deploy with a login feature for user and MCU is recognized	3
12/05/22	Temp + Pressure Sensor	Temp + Pressure 01	Unit	Success	N/A	1
12/05/22	Accelerometer + Gyroscope	Acce + Gyro 01	Unit	Success	N/A	2
12/05/22	Website Test	WB 02	Integration	Success	Able to connect to server and transfer data.	2
12/06/22	Lora Gateway	Lora 01	Integration	Success	N/A	1
12/06/22	Database/ Web Server	Database 01	Unit	Success	The database was created and updated to integrate different sensor	2
12/06/22	Microcontroller	MCU 01	Unit	Success	Board was able to communicate with sensors	1
12/06/22	Website	WB 02	Integration	Success	Display collected data from the database	1

Table 6: Iterations Table

4. Experiment and Testing

Testing all the components in our system is essential in ensuring the accuracy of our readings. For the first stage, we performed unit testing. During the unit testing process, each hardware component is tested individually to make sure it meets the required specifications and performance criteria. This includes testing the accuracy of the sensors, microcontrollers and PCB. Testing also includes verifying the performance of the database, website and Lora Gateway. The unit testing for each component required a table specifying its setup, the steps to complete the testing, the expectations and final outcome. The unit tables included, shown in Tables 7-11, represent the completed unit testing of the hardware and software components. These components are ready to move on to the integration testing stage.

4.1. Unit Test

Testing Documentation

Test Writer: Bintou Sylla						
Test Case Name: Microcontroller 1			**Type ID:** MCU 01			
Description: ESP32 to server			**Type:** Black Box			
Tester Information						
Name Of Tester: Bintou Sylla, Liam Sawyer, Salvatore Schillace			**Date: 12/04/22**			
Setup: ESP32 will be connected to a computer via USB and a sample program will be written to make sure the microcontroller is getting recognized by the PC						
Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect ESP32 to computer	The light on the microcontroller turn on and the computer recognize the board	✓			MCU was able to connect to the computer and a green light turned on
2	Configure code to allow MCU To send data to database	ESP32 should light up when code is compiled	✓			The MCU was able successfully connected
Overall Test Results: Success						

Table 7: ESP32 Microcontroller Test

Test Writer: Bintou Sylla						
Test Case Name: PCB			**Type ID:** PBC 01			
Description: Connect PCB board to the ESP32			**Type:** Black Box			
Tester Information						
Name Of Tester: Bintou Sylla, Liam Sawyer, Salvatore Schillace			**Date: 12/04/22**			
Setup: ESP32 will be connected to a computer via USB and a sample program will be written to make sure the PCB gets recognized by the microcontroller						
Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect ESP32 to computer	The light on the microcontroller turn on and the computer recognize the board	✓			MCU was able to connect to the computer and a green light turned on
2	Connect PCB to batteries to turn on	PCB should turn on and light should	✓			The PCB was able successfully connected
3	Read data from PCB	MCU will be able to read data from PCB		✓		MCU was unable to read data from PCB
Overall Test Results: Fail						

Table 8: PCB Test

Test Writer: Bintou Sylla						
Test Case Name: Temperature + Pressure Sensor Test			**Type ID:** Temperature + Pressure 01			
Description: Capture data from the Temperature and Pressure sensor using ESP32 microcontroller			**Type:** White Box			
Tester Information						
Name Of Tester: Bintou Sylla, Liam Sawyer			**Date: 12/06/22**			
Setup: ESP32 will be connected to a PC via USB and the temperature and pressure sensor will be wired to the MCU. An online database will be used to record data directly from the MCU and showcase it on a live chart.						
Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect ESP32 to computer	The light on the microcontroller turn on and the computer recognize the board	✓			MCU was able to connect to the computer and a green light turned on
2	Connect the sensor to the MCU	ESP32 should read data from the sensor	✓			The MCU was able to from the sensor
	Configure code to retrieve the data	Result will be displayed on the screen	✓			Data was successfully received by the database
Overall Test Results: Success						

Table 9: Temperature and Pressure sensor Test

Test Writer: Bintou Sylla						
Test Case Name: Accelerometer and Gyroscope Sensor Test			**Type ID:** Accelerometer and Gyroscope 01			
Description: Capture data from the Accelerometer and Gyroscope sensor using ESP32 microcontroller			**Type:** White Box			
Tester Information						
Name Of Tester: Bintou Sylla, Liam Sawyer			**Date: 12/06/22**			
Setup: ESP32 will be connected to a PC via USB and the Accelerometer and Gyroscope sensor will be wired to the MCU. An online database will be used to record data directly from the MCU and showcase it on a live chart.						
Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect ESP32 to computer	The light on the microcontroller turn on and the computer recognize the board	✓			MCU was able to connect to the computer and a green light turned on
2	Connect the sensor to the MCU	ESP32 should read data from the sensor	✓			The MCU was able to from the sensor
	Configure code to retrieve the data	Result will be displayed on the screen	✓			Data was successfully received by the database
Overall Test Results: Success						

Table 10: Accelerometer and Gyroscope sensor Test

Test Writer: Bintou Sylla					
Test Case Name: Microcontroller 1		**Type ID:** MCU 01			
Description: ESP32 to Lora Gateway connection		**Type:** Black Box			
Tester Information					
Name Of Tester: Bintou Sylla, Liam Sawyer, Salvatore Schillace		**Date: 12/06/22**			
Setup: ESP32 inside the buoy will be communicating with the Lora Gateway using the node and antenna					

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect ESP32 to computer	The light on the microcontroller turn on and the computer recognize the board	✓			MCU was able to connect to the computer and a green light turned on
2	Gateway is connected to a power source	ESP32 should sent data from the sensor to the node	✓			The MCU was able to send the data
	Configure code to send the data to database	Result will be displayed on the screen	✓			Data was successfully received by the database
Overall Test Results: Success						

Table 11: ESP32 Microcontroller Test

Integration test and Acceptance test will be performed in the upcoming semester.

4.2. Graphical Data Results

4.2.1. Results from the website

Graphical data is a powerful tool for analyzing and interpreting data, and these three graphs provide a valuable way to quickly understand and visualize changes in temperature, pressure and altitude. Data was obtained from the BMP390 sensor used.

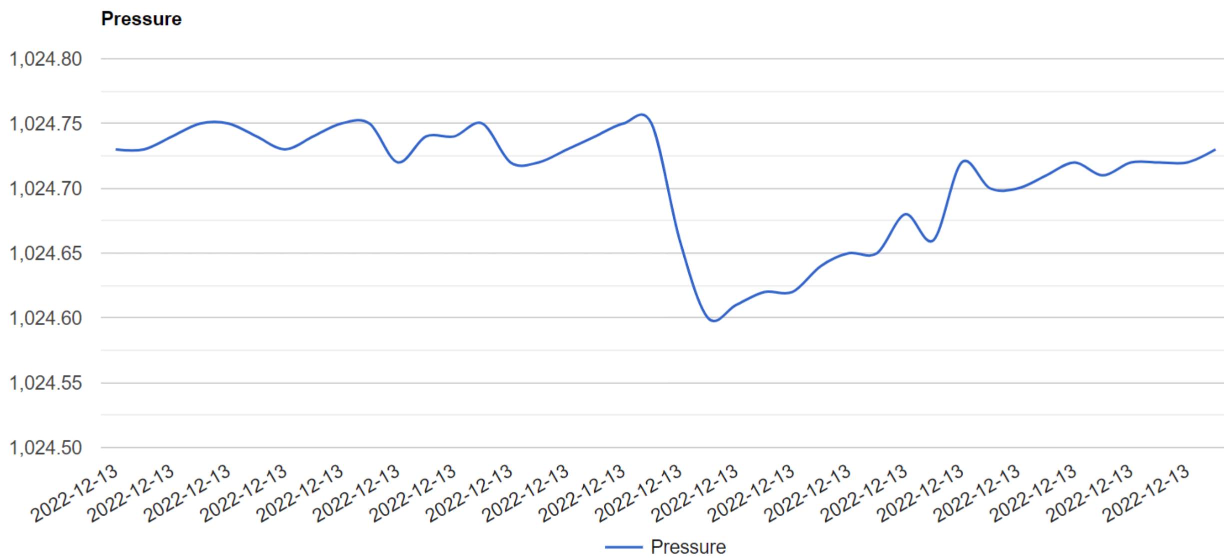

Figure 38: Pressure Readings

Figure 38 shows the graph of the pressure from the BMP390 sensor. It is a visual representation of the barometric pressure readings taken over a certain period of time during the day. It graphs the latest 40 entries of the sensor and displays the overall trend. The x-axis of the graph is labeled with the dates of the readings, while the y-axis is labeled with the pressure readings in hectopascals. The graph allows for a visual representation of the changes in pressure over time and can be used to identify any trends or patterns in the data. The average pressure reading as of 12/13/2022 is 1,023.72hPa, which is good for sea level.

It is essential to take these temperature readings to indicate the buoyancy of the system. If the pressure inside the buoy changes significantly, it can indicate that the buoyancy has changed, which can affect the buoy's stability and its stability to stay afloat. This goes hand in hand with Figure 38, since they are readings from the same sensor, the BMP390. These pressure readings are displayed on the website, where users are able to monitor the temperature and view historical records. The users may use this data for further marine and buoy research. These readings can be helpful to study ocean currents, measuring water depth, monitoring tides, studying waves, etc. Overall, pressure readings are an essential tool for studying the ocean and understanding the complex processes that govern oceanographic conditions.

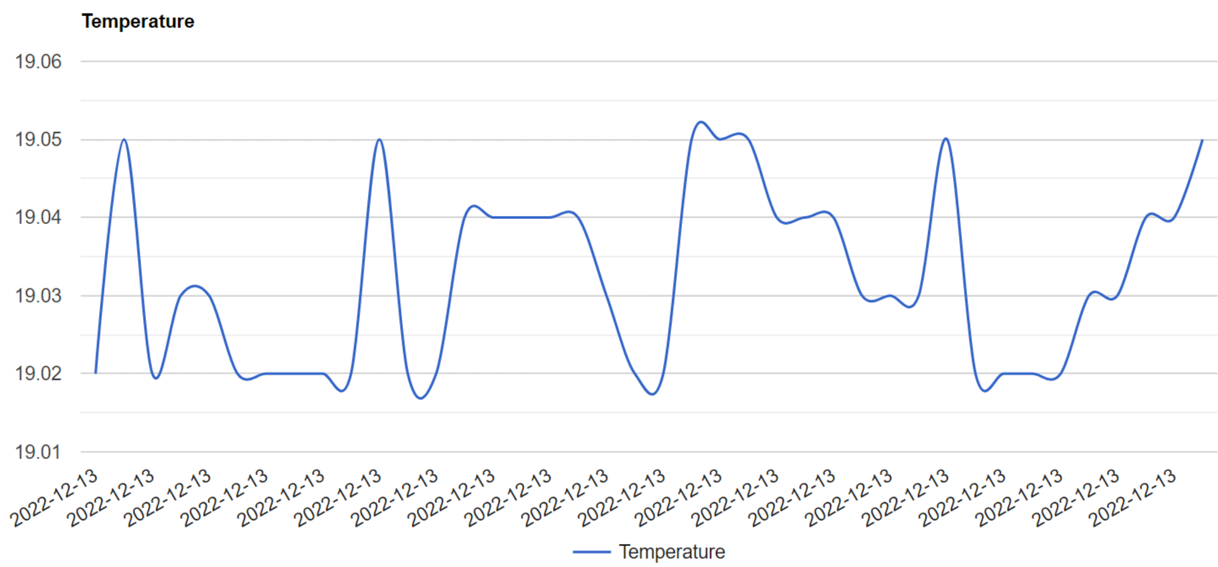

Figure 39: Temperature Readings

This graph in figure 39 shows the temperature from the BMP390 sensor over the course of several dates. The x axis shows the dates, and the y axis shows the temperature in Celsius. The data points on the graph show the temperature measurements taken at different dates. The graph also shows some fluctuations in the readings, which could indicate changes in the weather or other environmental factors that are affecting the temperature readings. The average temperature reading as of 12/13/2022 is 20.70 C (69.26 F).

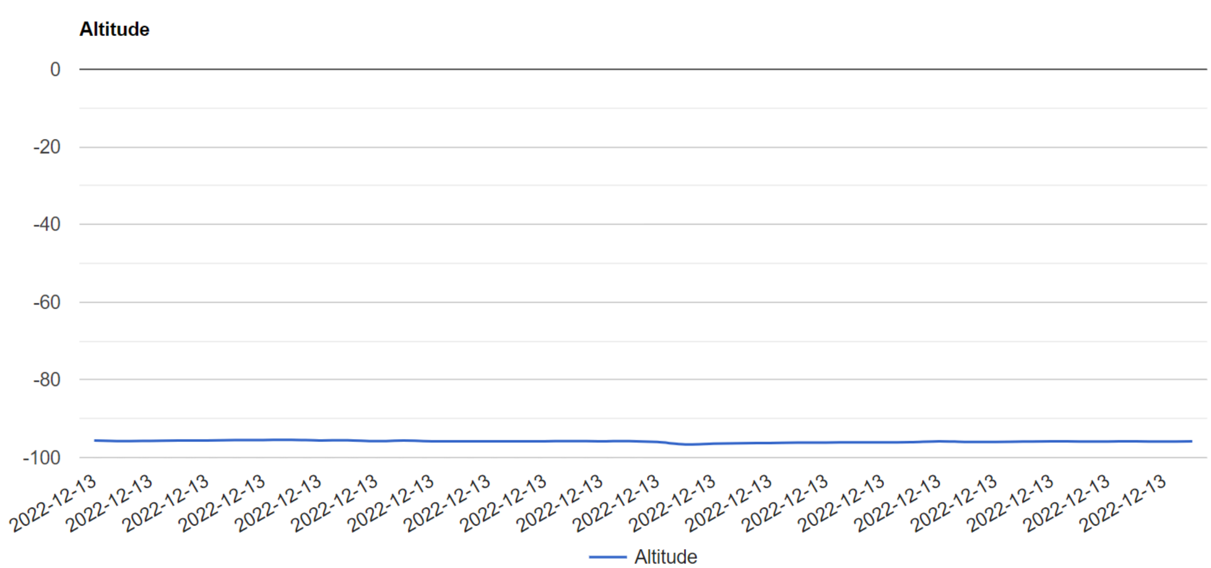

Figure 40: Altitude Readings

The graph of the altitude from the BMP390 sensor has the x axis as the dates and the y axis as the altitude in meters from 0 to -100 (see figure 40). The graph is composed of a series of points, each point representing a distinct date and the corresponding altitude measurement. The graph gives a visual representation of the altitude measurements taken over time. The graph can be used to analyze any changes in the altitude over time, such as the effects of weather and other environmental factors. It can also be used to compare the altitude measurements of different locations.

It is important to measure the altitude of a buoy for navigation, tracking storms, monitoring ocean conditions, etc. For example, the altitude of a buoy can provide information about the height of the water surface, which can be important for monitoring ocean conditions such as sea level rise or tidal changes. In this case, the average altitude as of 5/10/23 is -86.76m. There is a slight decrease in altitude but not significantly. It can be inferred that the sea level is constant throughout the day. Overall, having pressure, temperature, and altitude readings of the inside of a buoy can provide a more comprehensive understanding of the oceanographic conditions around the buoy and can help researchers and oceanographers make more accurate predictions about ocean conditions and their effects on marine ecosystems and coastal communities.

4.2.2. Results on the efficiency of the system

Below is the analysis of the RSSI values captured from our collected data. These values shed light on the strength of the wireless signals we observed. Additionally, we also take a closer look at the time intervals between consecutive readings. This allows us to examine the timing patterns and changes in the signal over time. By examining both the RSSI values and the time differences, we gain a deeper understanding of the signal's quality and how it fluctuates over different time periods. This analysis helps us draw meaningful conclusions and implications from our study.

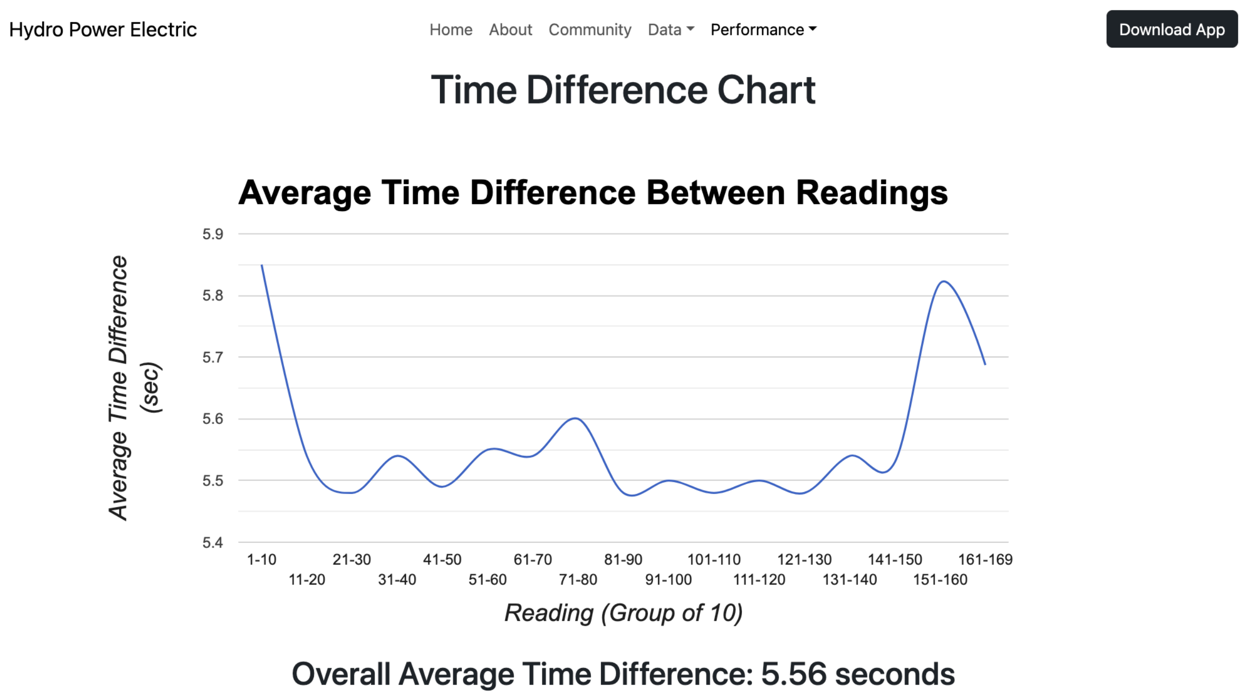

Figure 41: Time Difference Between Readings

In Figure 41, we examine the time difference between each reading in our data. This measurement holds great significance as we aim to ensure that all data transmitted from the buoy to the database occurs approximately every 5 seconds. Upon analyzing the graph, we can observe that the average time difference falls slightly above our target, ranging between approximately 5 seconds and 5.5 seconds. This finding provides us with valuable insights into the efficiency of data transfer and allows us to assess if any adjustments are needed to achieve optimal synchronization between the buoy and the database.

Figure 42 displays the Average RSSI Values derived from our data analysis. The overall average RSSI value registers at -37 dBm, indicating a relatively strong received wireless signal. This suggests that the signal strength remains consistently robust throughout the data collection process.

These findings provide significant insights into the signal quality and reliability within our study. The elevated average RSSI value implies a consistently strong signal, while the exceptional reliability percentage underscores the reliability and trustworthiness of our collected data.

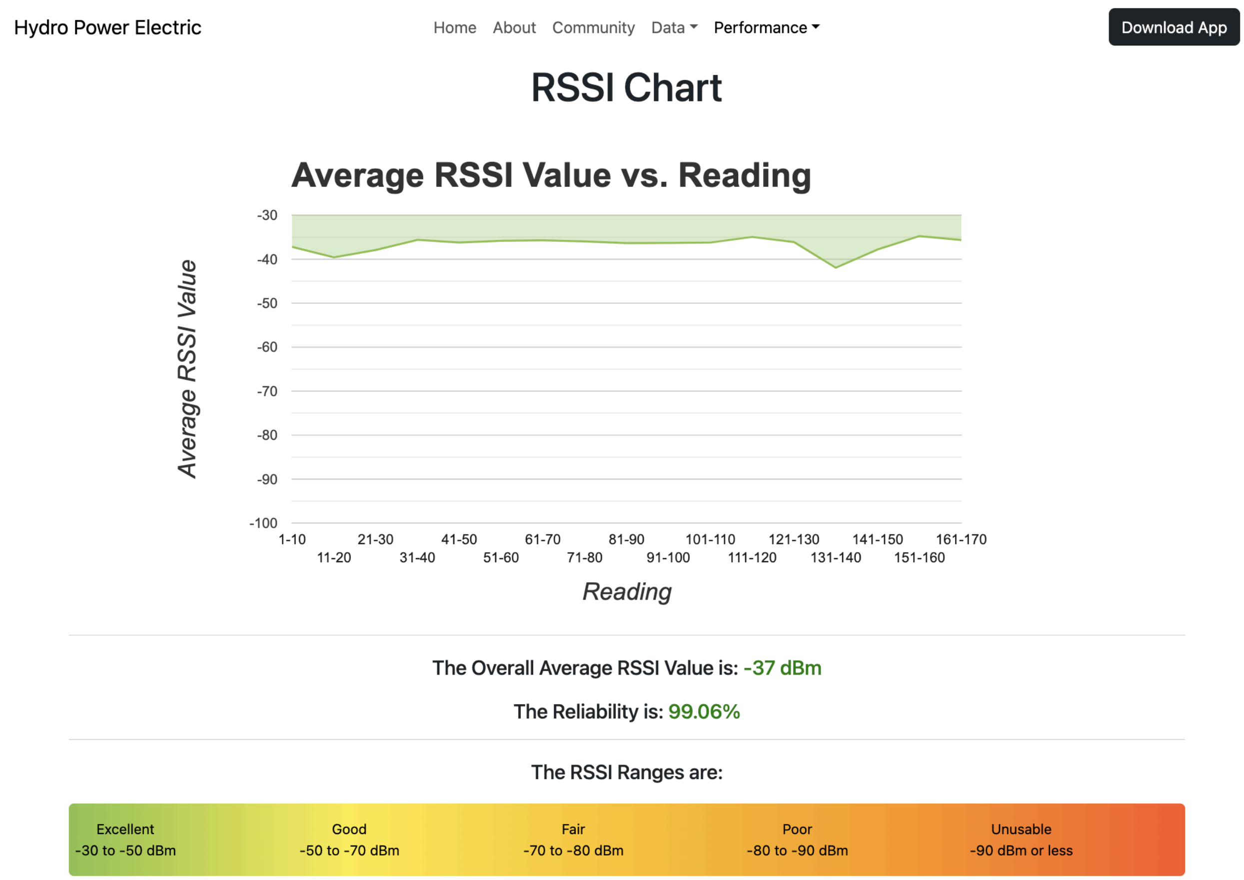

Figure 42: Average RSSI Values

5. Risk Analysis

Our group consists of 4 total members. Three of the members are electrical engineers and one is a computer engineering student. Bintou is assigned Hardware Lead and Salvatore will do both Software and Hardware while Karla has a focus on the hardware side. If someone gets sick for any reason and for any period of time, everyone is well versed in the fields and can easily take over with assignment by the Team Leader, Liam Sawyer. If the team leader is sick for an extended period of time, Salvatore will take over the responsibility until Liam Sawyer is back.

Since this is a multidisciplinary project, we have to include the Mechanical Engineers who will serve as the main point of contact for building of buoy and harvester. They will perform the design layout and reach out with important information such as the specifications of how the device should perform in the water.

6. Project Schedule

Project timeline

We were able to configure the LoRa wireless communication network with an SQL database. We had to set up the LoRa network, including the installation and configuration of LoRa gateways and end devices (such as sensors and actuators). Once the LoRa network is up and running, we connected it to the SQL database resulting in the data being displayed on the website. Now, configuring a LoRa network with an SQL database allows for efficient data collection and analysis, providing valuable insights for our project.

This semester, we are in the final stages of the third version of the main PCB. Tracing has improved, components were relocated, and input was increased from 3V to 5V. In doing this, we are supplying enough power to the microcontroller. Finally, on the app we are able to see the information collected from the sensors such as the pressure, altitude, and temperature readings.

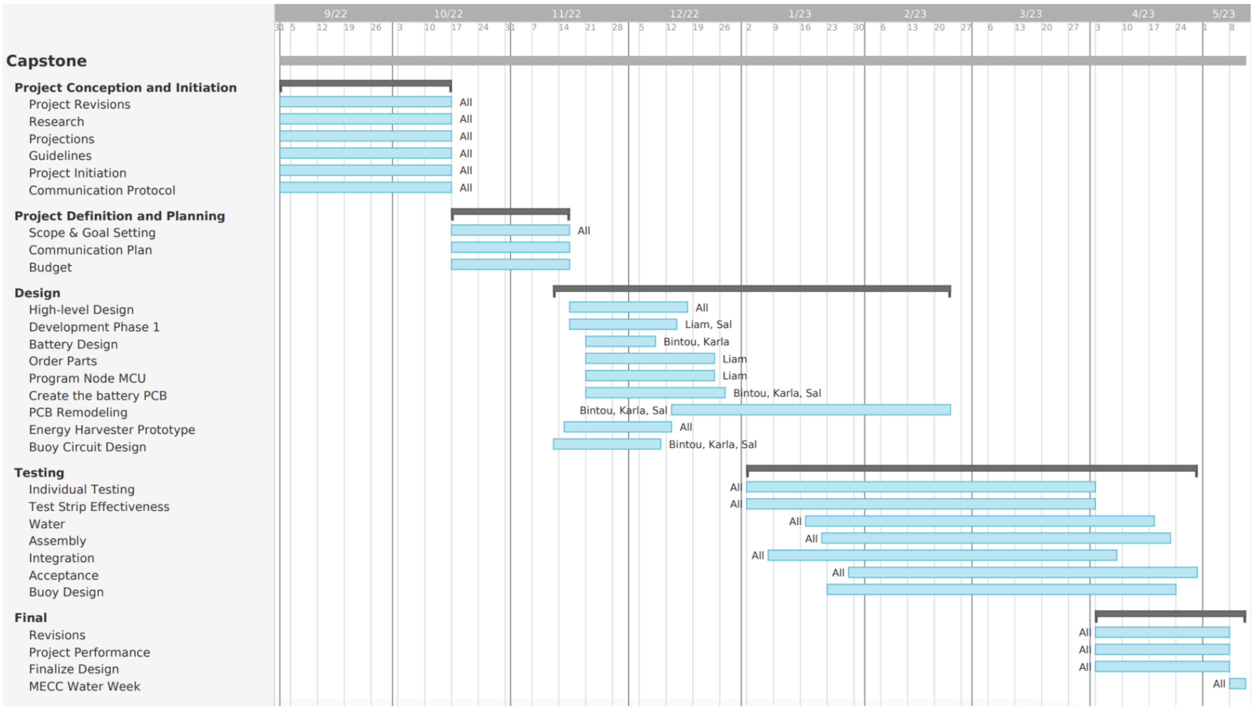

Figure 40: Gantt chart of project

Testing plan

Our project consists of 5 testing phases, Pre-Production, Production, Field, User, and Long-Term Testing.

- Pre-Production

  This phase will ensure to make sure that all the individual components work with not only the microcontroller but with each other. Since the suite of sensors has a wide range, not all the components use the same communication method. Some use UART while others use I2C and can also be piggybacked off of each other.

  Not only will we test the individual sensors, we will also test the integration of the database with the sensors and also with the website. This will ensure that the database is fully setup and the communication between all ends is solidified before moving onto the next phase.

- Production Testing

This phase will begin the production of the PCB boards needed to hold all the components in one area instead of using a breadboard and having wires dangling that can be disconnected in the field. We will allow this phase to span from the beginning of October 2022 to the second week of January 2023 to provide adequate time for the PCB's to be printed, assembled, and tested to ensure they can provide power to the components that will be used.

We will also begin to design the buoy after the PCB is finalized to ensure the proper fittings and also to ensure the device will be able to float in the water. We expect to obtain the final design of the buoy before the end of January with printing to be started the very first week of February 2023.

- Field Testing

  This phase is all about doing testing in the open environment after everything is assembled. We will ensure the device is waterproof and is able to transmit the data from a few miles away due to the device being in the middle of a river. At the end of this phase, we can determine if the design is able to withstand a longer testing phase.

- User Testing

  This phase will be about marketing the device and the website to encourage users to sign up and keep track of the data that will be presented. This will allow us to collect valuable information from a real user on the software and user interface portion of the website and mobile app.
- Long-Term Testing

  Lastly, the long-term testing phase will conclude this project by allowing us to collect 24/7 data which will allow us to gather important information such as the average water temperature, pH, ORP and other key factors mentioned in this report.

Milestone

We have chosen our design and now we are in discussions with our Mechanical engineering team to begin our hands-on design. We will have a functional prototype of the buoy by the end of the fall semester. This prototype will not be the final product, but it will include features that need to be enhanced. The prototype must transmit data to a distant database. During the winter we worked on the battery PCB and completed a working version (Version 3). For the spring we plan to work on the rest of the hardware and publish an app for everyone to download. We need to finish the PCB, connect the device to the harvester, and finish the buoy design.

7. Cost Analysis and Bill of Material

We are lucky enough to have a generous grant of $20,000 dollars from the U.S. Department of Energy's Water Power Technologies Office Powering the Blue Economy for participation in their annual competition. Out of the twenty thousand, we were given five thousand dollars for our portion of the design. Some of the main things that we thought of before making a price breakdown was the quality of the sensors. Since this system will be implemented in a river, we needed sensors and other items that could withstand the different environmental challenges.

One of the most expensive sensors is the Atlas Scientific Probe which is shown in Table 7 alongside with the entire proposed budget. And we have a couple more sensors and battery. We are also planning on attending a conference in April.

Name	**Description**	**System**	**Vendor**	**Part #**	**Quantity**	**Price Per Unit**	**Total Price**
Waterproof Digital temperature sensor	waterproofed (with heat shrink) version of a 1 Wire DS18B20 sensor.	Buoy Sensors	Adafruit	DS18B20	1	$9.95	$9.95
Precision Barometric Pressure and Altimeter	environmental sensing or as a precision altimeter.	Buoy Sensors	Adafruit	BMP390	1	$10.95	$10.95

Accelerometer and Gyroscope	3 degrees each of linear acceleration and angular velocity	Buoy Sensors	Adafruit	ISM330DHCX	1	$19.95	$19.95
Ultimate GPS Module	High-quality GPS module that can track up to 22 satellites	Buoy Sensors	Adafruit	MTK3339	1	$24.95	$24.95
RF Adapter Cable	SMA to uFL/u.FL/IPX/IPEX	PCB	Adafruit	RG178	1	$3.95	$3.95
GPS Antenna	External Active Antenna - 3-5V 28dB 5 Meter SMA	PCB	Adafruit	RG174	1	$19.95	$19.95
Wire Housing Pack	DIY Jumper Cables	Accessories	Adafruit		1	$1.95	$1.95
Industrial ph/orp/temp probe	This probe features a flat bulb for pH and a gold disk for ORP. The built-in PT-1000 temperature sensor	Buoy Sensors	Atlas Scientific	ENV-50-TPO	1	$457.99	$457.99
EZO™ Carrier Board	connect to one Atlas Scientific circuit to your CPU	Buoy Connectors	Atlas Scientific	ISCCB-2	3	$28.99	$86.97

EZO™ pH Circuit	read pH with the same accuracy and capabilities	Buoy Connectors	Atlas Scientific	EZO-pH	1	$45.99	$45.99
EZO™ ORP Circuit	Atlas Scientifics EZO-ORP circuit makes taking high accuracy ORP readings easy.	Buoy Connectors	Atlas Scientific	EZO-ORP	1	$45.99	$45.99
EZO™ RTD Temperature Circuit	Atlas Scientific EZO-RTD Circuit makes taking high accuracy readings from a platinum RTD probes easy.	Buoy Connectors	Atlas Scientific	EZO-RTD	1	$32.99	$32.99
ESP32 LoRa 32 (V2), ESP32 Development Board	One is used to send messages and one is used to receive messages	LoRa	Amazon	B076MSLFC9	2	$26.19	$52.38
IP67 Project Box 150x150x90mm	Made of high-quality ABS	LoRa	Amazon	B089K6Z567	1	$20.99	$20.99
Pin Header Connector Assortment Kit	breakaway male and female pin headers	Accessories	Amazon	B07CWSXY7P	1	$13.79	$13.79
600pcs M6 M5 M4 M3 Nuts and	Hex Socket Cap Nut & Bolt	Accessories	Amazon	B09NN72Y84	1	$25.95	$25.95

Bolts	Assortment Sets 600pcs						
USB LiIon/LiPoly charger - v1.2	This is a Lithium Ion and Lithium Polymer battery charger based on the MCP73833	Battery	Adafruit	MCP73833	2	$12.50	$25.00
DC/DC Step-Down (Buck) Converter	Can output 1 Amp at 5V with up to +60°C ambient temperature without the need of any heat-sink or forced cooling.	Battery	Adafruit	TSR12450	2	$14.95	$29.90
Lithium Ion Polymer Battery - 3.7v 500mAh	This battery has a capacity of 500mAh for a total of about 1.9 Wh.	Battery	Adafruit	LP-523334	4	$7.95	$31.80
Domain Name	Custom .com domain for the website and other coding components	Web Dev	Google	DNS	1	$12.00	$12.00
Digital Isolators	3.75 kV uni- and bi-directional isolator	PCB	Skyworks	SI8606AC-B-IS1	3	$7.85	$23.55
PCB Prototype	Prototype PCB board with connection	PCB	EasyEDA	PCB	5	$13.40	$67.00
PCB Assembeled	Fully assembled	PCB	EasyEDA	PCB	2	$86.50	$173.00

	PCB						
TOPPOWER TPE0505S	Plugin Power Modules ROHS	PCB	TopPower	TPE0505S	3	$1.98	$5.94
Conference	Attend a conference	N/A	N/A	N/A	1		
PCB Re-Design Allowance	Allow for PCB errors and mistakes to purchase new ones	PCB	EasyEDA	PCB	1	$500.00	$500.00
							$3,742.00

Table 7: Cost Estimation

8. Codes, Standards, Constraints

One of our main goals for this project is to help the environment. When building our project we will be following the IEEE code of ethics to ensure that we are making educated decisions that will not negatively affect the environment and the people in it. During this project we used different codes, standards and were limited by these constraints.

Standards

LoRa: The Long Range (LoRa) Wide-Area Network (WAN) is a low-power, wide-area networking solution that is specified in the IEEE 802.15.4g standard. LoRa enables devices to communicate over long distances with little power, making it ideal for battery-operated devices and sensor networks [13]. The LoRa WAN specification defines the physical layer and media access control layer for LoRa WAN networks. The LoRa Alliance is a nonprofit technology alliance that is working to standardize LoRa WAN technologies.

TCP/IP: The TCP and IP standard is the basis for all data communication over the internet. The TCP protocol is responsible for breaking down data into packets and routing them to their destination, while the IP protocol is responsible for addressing and delivering these packets. Together, these two protocols provide a reliable and efficient way for data to be transferred between computers.

Wi-Fi: The Wi-Fi standard is the 802.11 family of standards developed by the IEEE for wireless local area networking (WLAN) [14]. The Wi-Fi standard includes several different types of standards, each covering different frequencies, data rates, and modulation types.

pH: The EPA standard for pH in water is 6.5-8.5.

Constraints

The project has certain constraints which cause problems when building the project. The first is the LoRa. LoRa was found to be a better alternative for us than using WIFI but it still has a limited range. Next there is the high cost of the parts, this makes it hard to replace broken or defective parts. These parts also take a long time to get to us, so it will extend the time needed for completion. The last major constraint is the size and weight of the buoy. We have to make sure that anything we design will fit in the buoy and will not affect how it floats.

9. Ethics Analysis

Ethical issues are the main reason we choose this project. We will be able to create a system that will significantly reduce the waste from batteries. The code we will be abiding by is the IEEE code of ethics. This states that we will prioritize safety and make sure to have dignity and honor and not manipulate our data. Some Ethical issues are environmental issues/human error, inaccurate measurements,and power issues. Environmental issues/human error deals with the device being in different animals' habitats so the device being there cannot cause damage to those and the device must not be in a location where a human will break it and cause debris to pollute the water. Next is inaccurate measurements which will cause misleading information about the water quality so if it reads good but is bad, then no work will be done and the pH level will stay off and vice versa. Lastly if the power fails then the harvester will have to be replaced and then there is no purpose of the device.

10. Conclusion and Future Work

The development of this project is critical for the future of our water resources. The goal is to create a buoy that is equipped with sensors that can measure various parameters of water quality, such as pH, temperature, and dissolved oxygen and a piezoelectric-powered harvester. This project will address the need for a reliable and cost-effective way to monitor water quality in real time.

The sensor buoy will be easy to deploy and recover, and it will require minimal maintenance. The main advantage of this system is that it will provide a reliable and cost-effective way to monitor water quality in real time. The sensor buoy will be easy to deploy and recover, and it will require minimal maintenance. The data collected by the sensors will be used to improve our understanding of water quality patterns and to identify potential sources of contamination. If the project is successful, it will offer a flexible and cost-effective water quality monitoring system that can be used in a wide range of applications.

The project team is optimistic that the initiative will be successful, and they believe that it will have a wide-reaching impact. By providing a dependable and cost-effective way to monitor water quality, the project will help to protect public health and ensure that our water resources are safe and sustainable. This will benefit not only the local community, but also the broader environment.

In the future we are going to be focused on connecting the proobs to the PCB, SARIMAX/LSTM for the software as well as designing the buoy. When the buoy is completed, we will be testing in a river and a water channel to see if we will be able to gather accurate results in both environments.

11. Team-Centered Behavior & Individual Contributions

Bintou and Karla worked on designing the Printed circuit Board and found the proper sensors for the device. This includes running the needed test to make sure everything is properly working. Salvatore assisted Liam with the software portion, as well as helped put together the device. Sal worked on setting up the hardware, as well as drilling and soldering. Liam worked on all the software portions of this project. He created the database, website, and configured ESP 32 microcontrollers. Sal and Bintou worked with Piezoelectric strips researching and measuring the maximum output. The team meets together with the Business team and the Mechanical team biweekly on fridays. This allows for clear communication among practices. During these meetings all updates and questions are shared. Since each team has specific strengths and weaknesses we rely on each other to have continuous progress on the buoy. Also any disagreement is discussed among all team members when there is a larger scale issue. Smaller issues are dealt with at the team level.

12. Engineering Complexity of the Project

The project has three major groups of engineers focusing on different parts of the project. The three disciplines are Computer engineers, Electrical engineers, and Mechanical engineers. The breakdown of responsibilities allows each group to use their expertise. Computer engineers are tasked with Machine Learning, programming the gateway connection, and programming each sensor so we will be able to receive the data. The Electrical engineers are tasked with all the hardware portions of the project, including the circuitry and PCB boards. Lastly the Mechanical engineers are building the energy harvester device. With the three major disciplines working together there must be good communication or else if someone changes their design, it will negate any of the progress made.

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14. Bibliography

Team members introduction and roles

Liam Sawyer - Computer Engineering

- Role: Team Leader, Hardware, Software
- Expertise: Coding, Database Structure
- Interests: Cybersecurity, IoT, HomeLabs

Salvatore Schillace - Electrical Engineering

- Role: Hardware, Software
- Expertise: Electronics, Power Systems
- Interests: Bulk Power, Energy Systems

Bintou Sylla - Electrical Engineering

- Role: Hardware Lead
- Expertise: Electronics, Bioelectrical Engineering
- Interests: Sustainable Energy, Computer Vision

Karla Quizhpi - Electrical Engineering

- Role: Hardware, Logistics
- Expertise: Electronics, Computer Vision
- Interests: Design Process, Construction