Drain Defenders

Product: WATT 3000

(Water Analyzer and Turbidity Tester 3000)

Members: Andy Freshnock, Brandon Oddo, Jackson Foster, Micah Hoover, Phillip Disidore

Monitor to Protect

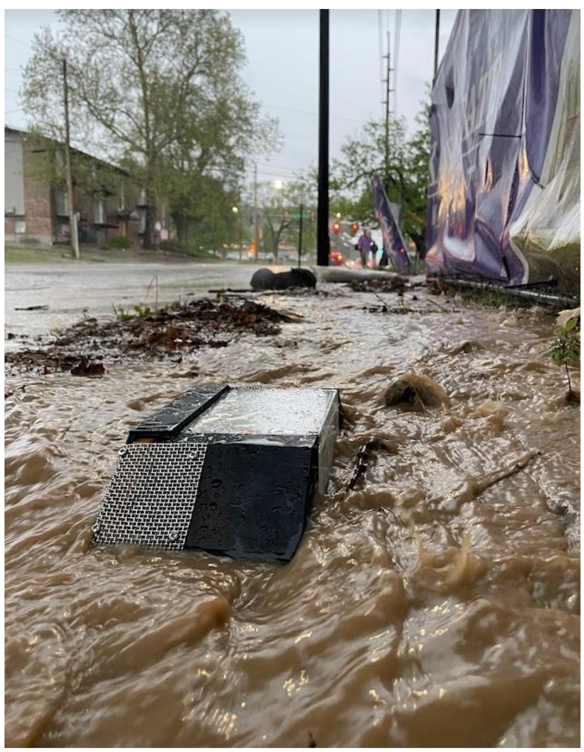
5/7/2024

EXECUTIVE SUMMARY

This innovative system focuses on monitoring pollution in storm drains, specifically addressing a gap in existing water monitoring solutions for monitoring soil erosion due to water runoff. The primary objective is to hold construction companies and other entities accountable for polluting storm drains and, consequently, the environment with runoff soil. Unlike conventional water quality monitoring systems, this project activates only when water is present, offering precise location data by positioning sensors near potential polluters.

The system records and transmits sensor data to users, allowing them to identify and address potential sources of pollution. Other products in the market primarily focus on monitoring drinking water, industrial processes, or natural bodies of water. This project concentrates on individual storm drains, providing a targeted approach for accountability.

The project encompasses electrical, embedded, and software components. The electrical systems include a sensor array, power supply, and internet communication capabilities. By transmitting data to the communication system, the embedded software functions as a controller and data acquisition system for the sensors. The software system is comprised of network communications, a database, and a data analysis tool.



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PROJECT DESCRIPTION

Background and Motivation

This system aims to monitor pollution – specifically soil erosion – in storm drains. Its purpose is to hold construction companies and other entities accountable for polluting storm drains and the environment. The system will record and transmit sensor data to a user who can utilize this information to identify potential polluters.

While water quality monitoring is not a novel concept, most products on the market primarily concentrate on monitoring drinking water, industrial processes, or natural bodies of water. Monitoring storm drains enables a system that activates only when water is present, offering a more precise location since the sensors would be positioned near potential polluters.

This project is innovative as it addresses a gap in water monitoring systems currently unaddressed by other solutions. Some products are designed for stormwater management, but they primarily address downstream issues such as flooding and flow rate. Our design would concentrate on individual storm drains and the pollutants entering them. This positioning enables our project to be located near potential polluters for accountability purposes.

The project will comprise electrical, embedded, and software components. The electrical systems will include a sensor array, a power supply, and internet communication capabilities. The embedded software will function as both a control system for the sensors and a data acquisition system, transmitting data to the communication system. The software system will include network communications, a database, and a data analysis tool.

Problem Statement

Water runoff from construction sites causes soil erosion, and there is not currently a method of measuring this type of pollution on a smaller scale. Our aim is to create a product that monitors this water runoff to ensure that construction sites are held accountable for what they put down the drain.

Project Requirements

To determine the project's success, below is a table of requirements we will adhere to. For our project to be considered successful we must test each requirement and prove that each requirement is satisfied. Included in the project requirement table are functional requirements, design constraints, and design goals/objectives.

The following table describes our requirements:

ID #	Title	Description
0.1	Cost	The cost of the unit shall be fit within the project budget
0.2	Designed for Environmental Wear and Tear	The unit shall be robust in outdoor conditions (To include underwater conditions)
0.3	Ease of Install	The unit should be easily installed.

0.4	Data Gathered	The unit shall provide relevant water quality metrics.
0.5	Rough Size Requirement	The unit shall be discrete and unintrusive for construction sites.
0.6	Ease of Use	The unit should be intuitive and easy to use for consumer use.
0.7	Coding Standards	The unit should comply with MISRA coding standards.
0.8	Operating Life	The unit shall remain powered for a portion of the length of a small construction project (5 months)
0.9	Follow EPA Standards	The unit shall follow EPA standards outlined in title 40.125 and 40.127.
0.10	Data Gathered Is Accessible	The unit shall send gathered data to a central unit
1.1	Cost of System	The system BOM shall not cost more than $250.
1.2	Turbidity Data Gathering	The system shall offer data sensing for turbidity. (Frequency of gathering TBD)
1.3	Temperature Data Gathering	The system should offer data sensing for temperature. (Frequency of gathering TBD)
1.4	Flow Rate Data Gathering	The system should offer data sensing for water flow rates. (Frequency of gathering TBD)
1.5	Conductivity of Water Data Gathering	The system should offer data sensing for water conductivity. (Frequency of gathering TBD)
1.6	Tolerance on Readings	The system should offer readings within a 10% tolerance range.
1.7	Life of System	The system shall be able to remain powered for 5 months.
1.8	Size Requirement	The system shall fit into a sit nicely at the corner of the mouth of the drain at street level (10” x 9” x 6”)
1.9	Weight Requirement	The system shall weigh less than 1 Kg (to be refined)
1.10	Power Requirement	The system shall use 5V and 3.7V
1.11	Data Goes to a Central Hub	The system shall send gathered data to a central hub

Validation and Acceptance Tests

To meet our requirements and validate that our product meets customer needs, we will need to employ many different validation and testing methods. Analysis is our first method of validation. In analysis, we can use mathematical modeling, analytical techniques, and simulation to validate that our product meets requirements. Another method of validation is demonstration that the product meets the specified requirement. Third, there is inspection to validate the physical design of the product. Finally, there is validation by testing. Testing will allow us to verify performance by obtaining detailed data gathered by the product.

We plan to perform analysis of materials to verify that our costs fit the allotted budget while also meeting EPA standards. Furthermore, we can verify that our product meets size, weight, and power (SWaP) requirements and follows coding standards through Inspection. Demonstration will be used to validate things such as ease of use and ease of installation. Finally, we will use testing to validate requirements dealing with functionality of the product such as power usage, battery life, and data gathering. We will also test to see if the product can survive in the harsh outdoor conditions that our product will be in.

Verification and Validation Matrix

Level	ID #	Title	Description	Analysis	Inspection	Demonstration	Test
0	0.1	Cost	The cost of the unit shall fit within our project budget	x			
0	0.2	Designed for Environmental Wear and Tear	The unit shall be robust in outdoor conditions (To include underwater conditions)				x
0	0.3	Ease of Install	The unit should be easily installed.			x	
0	0.4	Data Gathered	The unit shall provide relevant water quality metrics.				x
0	0.5	Rough Size Requirement	The unit shall be discrete and unintrusive for construction sites.			x	
0	0.6	Ease of Use	The unit should be intuitive and easy to use for consumer use.			x	
0	0.7	Coding Standards	The unit should comply with MISRA coding standards.		x		

0	0.8	Operating Life	The unit shall remain powered for the length of a small construction project (1-14 months)				x
0	0.9	Follow EPA Standards	The unit shall follow EPA standards outlined in title 40.125.	x			
0	0.10	Data Gathered Is Accessible	The unit shall send gathered data to a central unit		x		
1	1.1	Cost of System	The system BOM shall not cost more than $250.	x			
1	1.2	Turbidity Data Gathering	The system shall offer data sensing for turbidity.				x
1	1.3	Temperature Data Gathering	The system should offer data sensing for temperature.				x
1	1.4	Flow Rate Data Gathering	The system should offer data sensing for water flow rates.				x
1	1.5	Conductivity of Water Data Gathering	The system should offer data sensing for water conductivity.				x
1	1.6	Tolerance on Readings	The system should offer readings within a 10% tolerance range.	x			
1	1.7	Life of System	The system shall be able to remain powered for 5 months.				x
1	1.8	Size Requirement	The system shall not be larger than 9” x 8” x 6”		x		
1	1.9	Weight Requirement	The system shall weigh less than 1 Kg		x		
1	1.10	Power Requirement	The system shall use 5V and 3.7V				x
1	1.11	Data Goes to a Central Hub	The system shall send gathered data to a central hub		x		

TECHNICAL DESIGN

Pre-Conceptual and Conceptual Design/Solution Descriptions

POSSIBLE SOLUTIONS AND DESIGN ALTERNATIVES

During the preconceptual design process, three possible solutions arose. After receiving feedback and reviewing our requirements, a fourth design was created. The following details a basic overview of how each design alternative would function and includes some advantages and disadvantages for each.

THE PASS-THROUGH

Possible solution one, dubbed “The Pass-Through," functions as a single unit located on the entrance to a storm drain. It has a water intake, from which it will utilize a flow rate sensor and turbidity sensor, with room for other sensors to be added if desired. After measurements are taken, the water leaves through the outtake and enters the drain. This design has the advantages of being a single unit, easy data transmission from being outside the storm drain, and robust durability. The Pass-Through is, however, prone to blockage from debris and will require the use of concrete screws to anchor the unit.

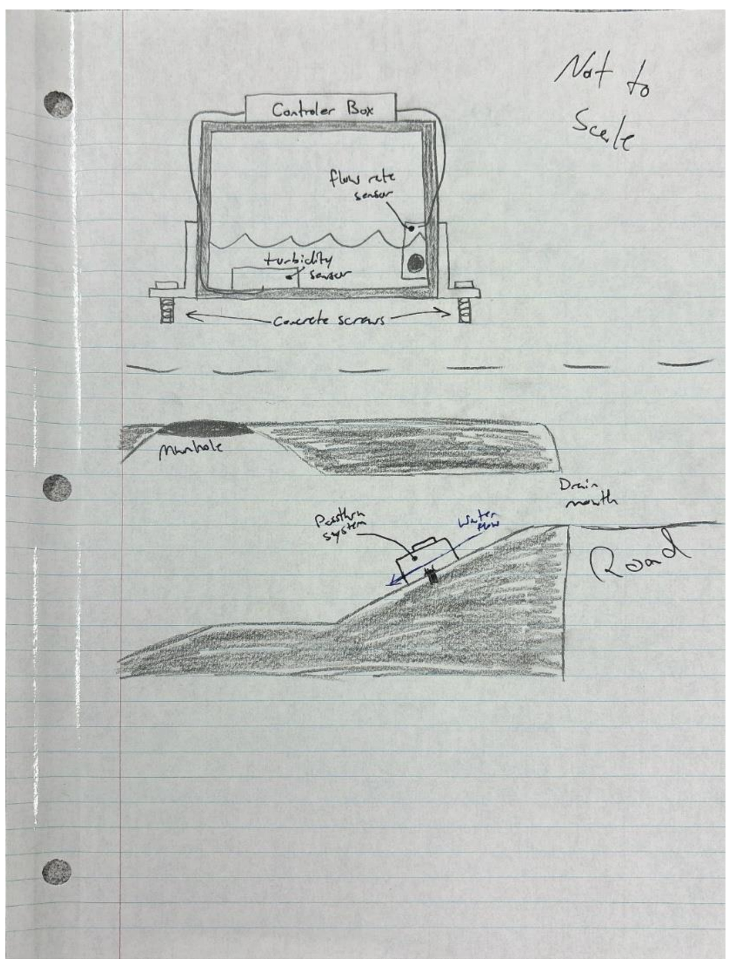


Figure 1 “The Pass Through”

THE PROBE

The second possible solution, “The Probe,” consists of a primary unit magnetically attached to the top of a storm drain, and small probes hanging from the primary unit into the water below. All processing and data transmitting parts within the primary unit. Sensors, including flow and turbidity, are located on the probes, and transmit gathered data back to the primary unit. This design is easy to install and allows for placement away from water. The dangling probes allow for “The Probe” to be installed in storm drains of any size, with adjustments to the probe length. Some flaws in this design include a voltage drop across the wire from the probe to primary unit, which will alter the analogue signals gathered from the sensors, as well as potential failure to withstand extreme forces applied from heavily running water.

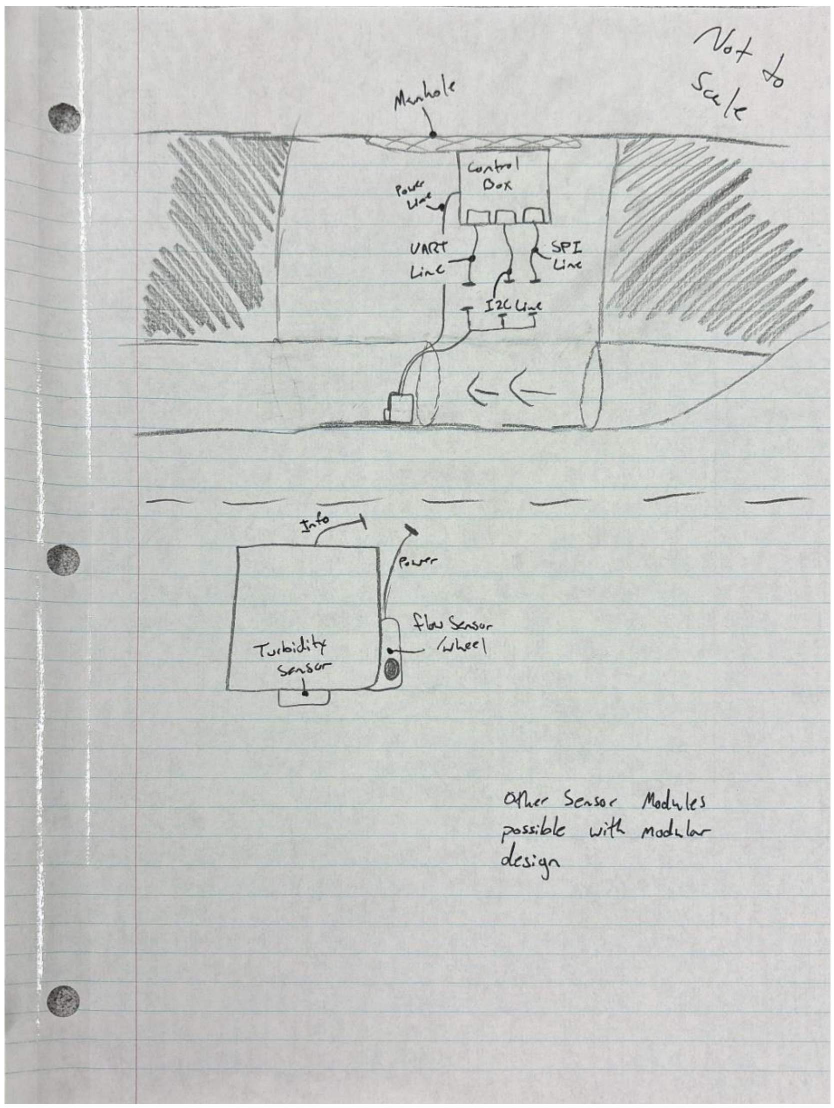


Figure 2: “The Probe”

THE BALL

The third possible solution, "The Ball," consists of a sensor array inside of a spherical structure. This unit is placed in a storm drain and flows with the water while collecting data. It utilizes GPS so that it can be found after data is gathered. The design is the simplest to install, and it collects data for the entire drain system. Challenges of creating "The Ball" include requirements for complete submergibility and small size. Additionally, the unit could easily be lost or stolen, as data will likely not be transmitted through the drain system. The unit also would need to be retrieved after use.

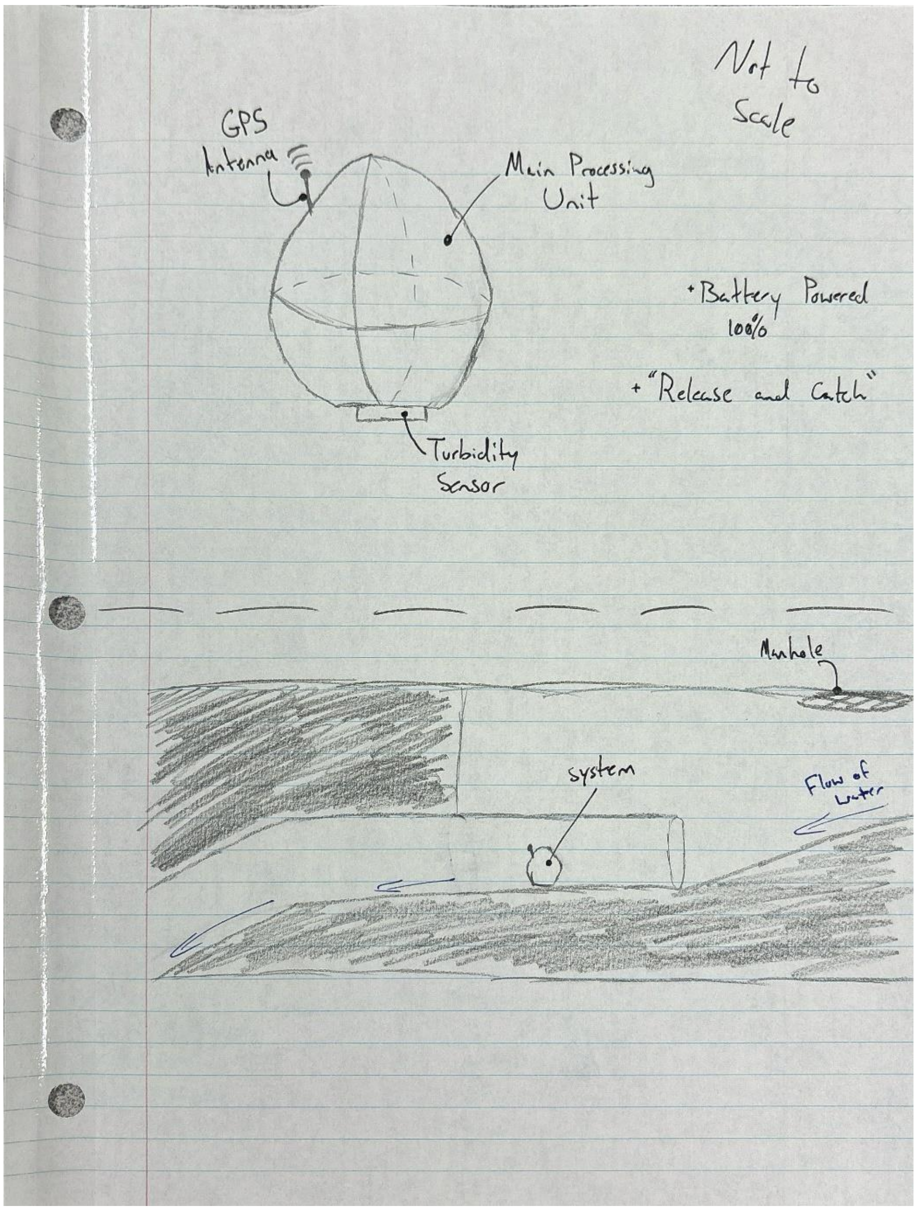


Figure 3: "The Ball"

THE CURB DESIGN

After reviewing our solutions and considering feedback, a fourth solution was created to fix identified issues – “The curb design.” Issues that were identified with the probe in the probe design would be things like the cable being too long and the difficulty of having to enter the storm drain to install the unit. This new solution is very similar to “The Pass-Through.” There is a single unit installed with concrete screws close to the intake of a storm drain. To prevent strong forces on the device during intense rainfall, it is structured to be hydrodynamic to allow water to flow over it while still being able to allow water to flow through it. The advantages of this design over the other designs are that there is not a long probe line to have to deal with voltage drops (drops due to a long probe wire when taking data samples). The unit would also be easy to install due to not having to enter the storm drain. With the unit being on the surface, it is easier to do wireless communications and have the option of solar power. However, some downsides of this solution are that it is exposed to outside elements, and the unit has the potential of being run over by a vehicle.

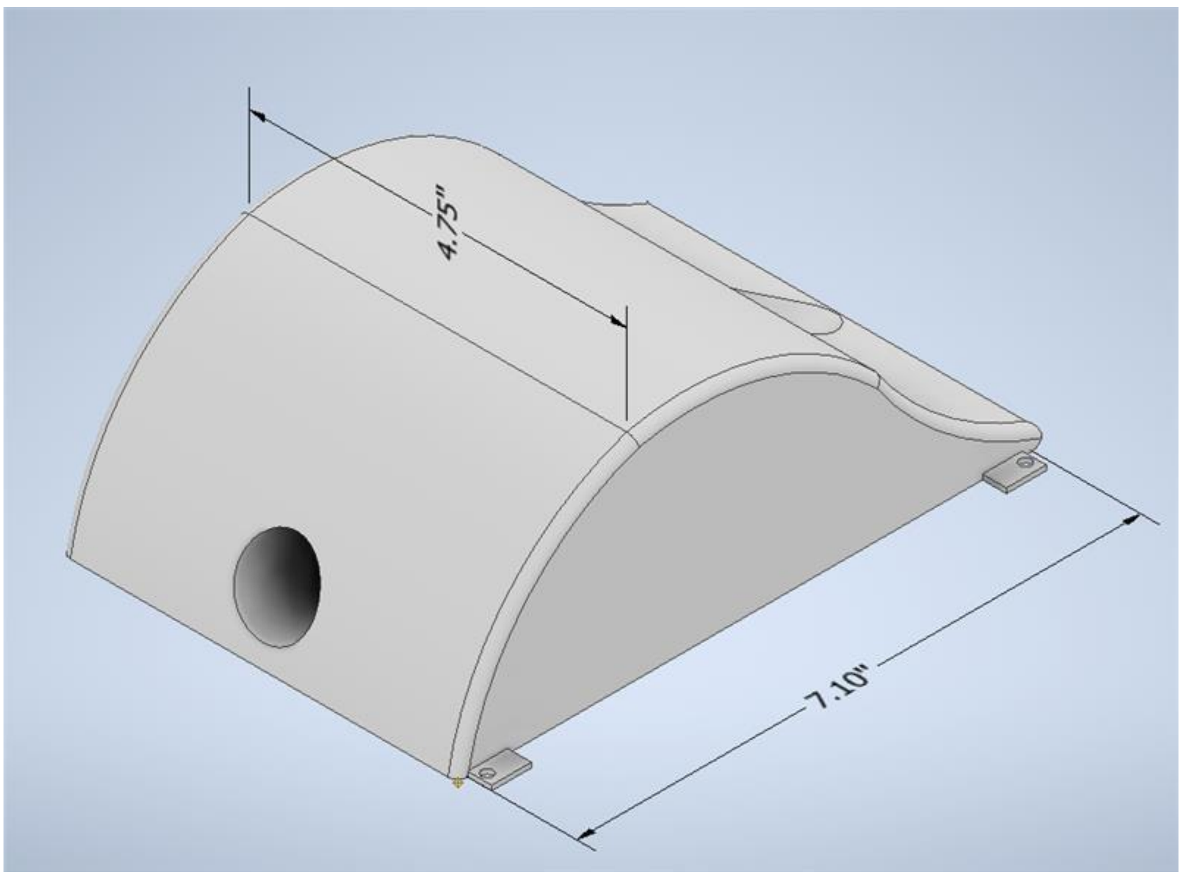


Figure 4: "Curb Design"

Selection Process for Preliminary Design Solution

Initially, using the Pugh matrix, we had a tie between “The Passthrough” and “The Probe.” We decided to compare the strengths of each design to see which better met customer and system requirements. Initially, the final design was chosen to be “The Probe" because, among other things, it could be easily installed while also transmitting data from the drain to our central data hub (while “The Passthrough” did not meet these requirements). As mentioned previously, this design had many unaddressed design flaws, and we were encouraged to return to the drawing board. After some research and discussion, the “curb design” was created. This new design satisfies customer needs (ease of install, ability to test turbidity, etc.) while also being more easily serviceable and a more robust design than “The Probe.”

Data Pre-Processing and Exploratory Analysis

For our design to meet its requirements: research into sensors, communications, and power was required, and we have decided to use a turbidity sensor. The turbidity sensor measures the clarity of the water, which is directly correlated to soil content. For our communication needs, we have selected an Arduino Teensy 4.1 microcontroller connected to the SIM7000A cellular modem. The ADC on the microcontroller has a maximum voltage input of 3.3 volts. This meets the voltage range of the turbidity sensor output. To meet our power requirements, we conducted research into the power use of our microcontroller, antenna, and sensors. Most of the power will be consumed by the microcontroller and the cellular antenna. For the system to have the lifespan required we will either need a large battery (>2500 Milliamp Hours) or the ability to recharge a smaller battery with a solar cell. We have decided to add a solar charging option to the unit to meet a longer battery life.

Preliminary Design/Solution Description

Global Issues

Engineering projects often have impacts that span farther than just the immediate area. Our initial design is being developed for use in Manhattan Kansas; however, our product has potential to be deployed globally. This global deployment brings on different challenges as well as local issues.

1. There are different environmental standards in different countries.
    a. Summary: Other countries have different standards for water turbidity.
    b. Resolution: Have region specific software packages that detect appropriate levels of water turbidity.
2. Battery leakage into the water.
    a. Summary: Our device contains a battery that has the potential to leak hazardous material into the system and the drain.
    b. Resolution: The battery will be housed in a waterproof casing to reduce the likelihood of moisture interacting with the battery.
3. 3D printed materials - waterproofing.
    a. Summary: Not all 3D printed materials are waterproof.
    b. Resolution: Carefully select the material that our prototype will be made from so that it will not degrade when exposed to water. In final production, outside of this class, the enclosure can be made from other materials such as concrete to avoid plastics dissolving into the water.
4. 3D printed materials – durability.
    a. Summary: Depending on where the product is deployed, vehicles have the potential to drive over the system and destroy it.
    b. Resolution: In future models, use stronger materials as the chassis for the system. NOTE: This brings on potential issues with cellular communications depending on which material is used.

System-Level Overview

After testing the different systems, we have found a better solution to meet our requirements. The old system consists of seven primary subsystems, comprised of both electrical and software elements. The electrical subsystems included power, sensors, and communications, while the software subsystems included embedded, MQTT, webserver, and user interface. An overview of the old electrical and software systems is pictured below.

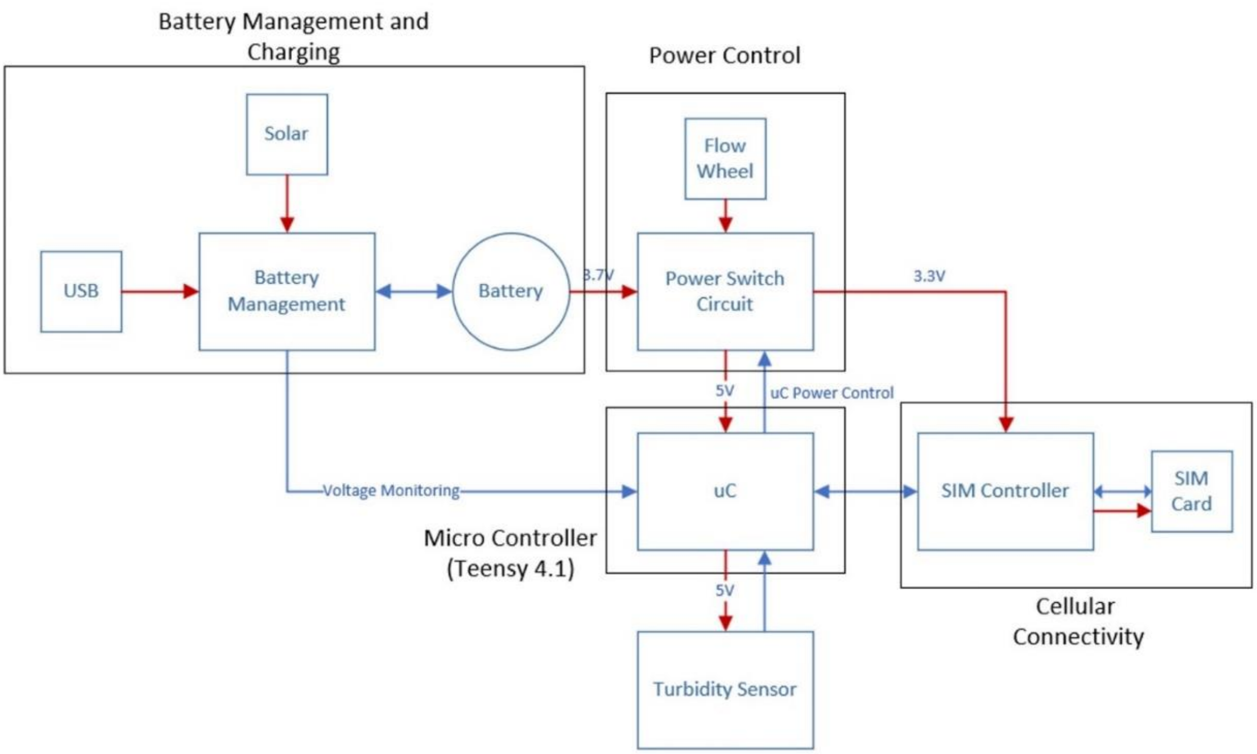


Figure 5 Old Top-Level Design

The new subsystem chart is presented below. After testing the flow wheel, we realized that the amount of pressure and flow we would need to get a significant voltage to drive a MOSFET is not feasible. To maintain our battery lifespan requirement, we did significant testing on the amount of battery life the new system requires. The results of the tests showed that even in the worst-case scenario of sending packets every 30 seconds, the battery life could meet the requirements. We also replaced the self-made SIM board with a proprietary sim test board that will allow for cheap access to a cellular network. The only component the boost converter is supplying is the turbidity sensor which requires a 5V input to get the full range of values.

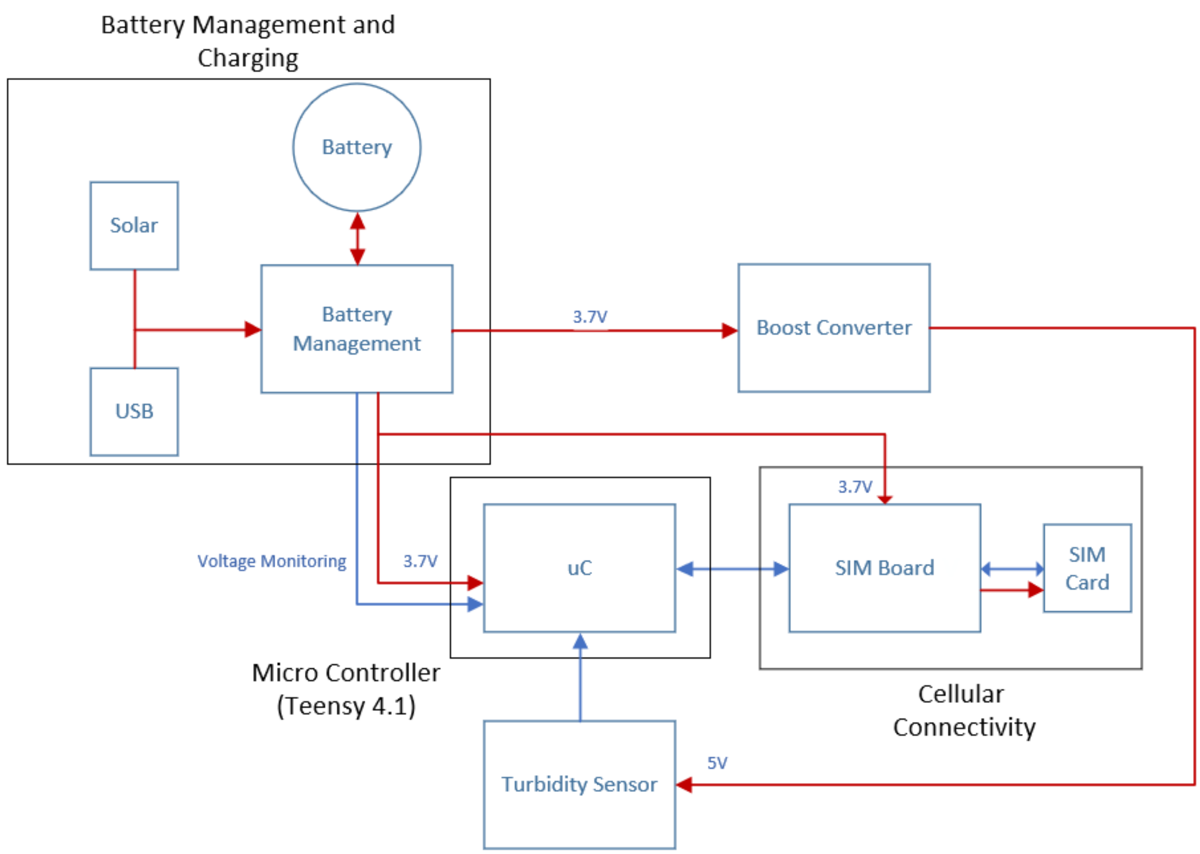


Figure 6 New Top-Level Design

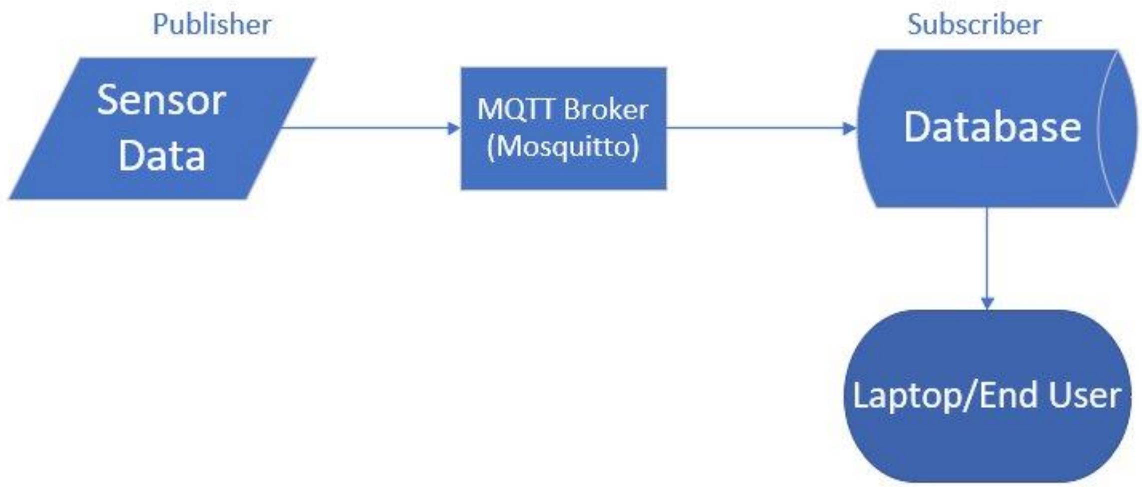
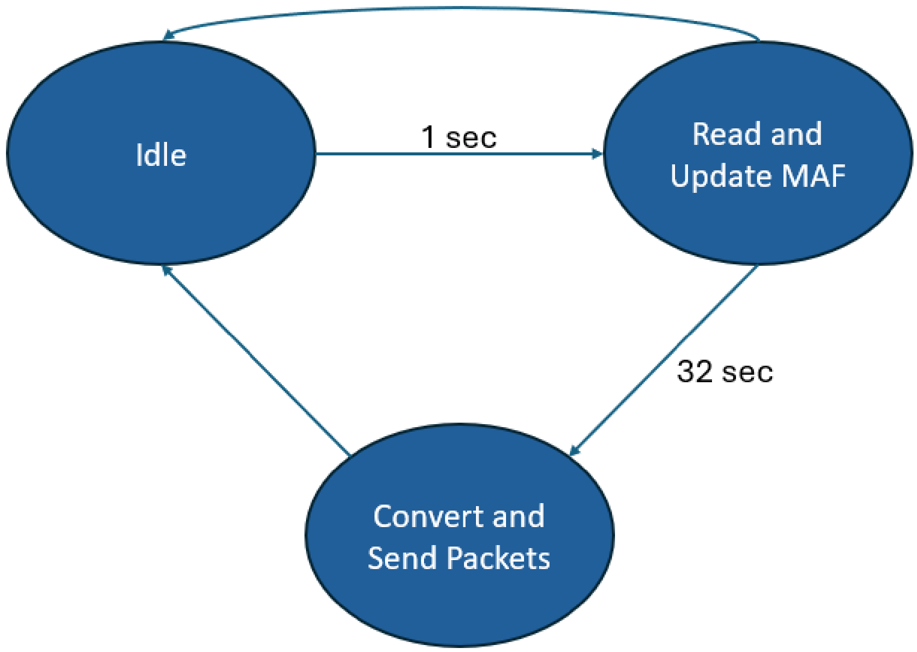


Figure 7 Top-Level Software

Embedded Software

The software state machine is divided into 3 main states: idle, update, and send. The idle state was supposed to be a sleep state, but since the teensy 4.1 microcontroller does not support sleep functionality, the microcontroller idles for 1 second until it can enter the next state. Once the microcontroller enters the update state, the teensy will read the voltage and turbidity and then update their respective moving average filters. The moving average filter acts as a finite impulse response, allowing us to transmit more reliable data. Finally, after 32 seconds, we transmit our readings. This state is responsible for converting our readings to usable data and then sending it using MQTT. The embedded software system is not super complicated and is split into relatively simple functions. The main loop is only about 10 lines long, allowing the code to be extremely readable and adaptable. A diagram of the state machine can be found below.



Listed below is a more detailed explanation of the different electrical subsystems. Each subsystem has its own flowchart to show data connections/flow and power connections.

Module-Level Descriptions

Power Management and Charging

The system is powered by a 3.7V lithium-polymer battery, and its power distribution is managed through a charging board. Specifically, the chosen charging board, the Adafruit Universal Solar Lithium Ion/Polymer Charger, ensures efficient power delivery from the battery. This board is equipped with features such as optimized solar charging and overcharging protection. The charging board accommodates power input from both the solar panel and an external USB source, enabling versatile charging options for the battery. A visual representation of this subsystem is depicted in Figure 8.

To ensure a reliable power supply for the various components of the system, the charging board is equipped with an internal regulation of 3.7V. Most of the items used are operated with this 3.7V supply. The exception to this is the turbidity sensor, which requires 5V to operate. To meet this need, an

LT1072HV switching regulator is used as a boost converter. More detail on this converter can be found in the detailed design/solution section of this document.

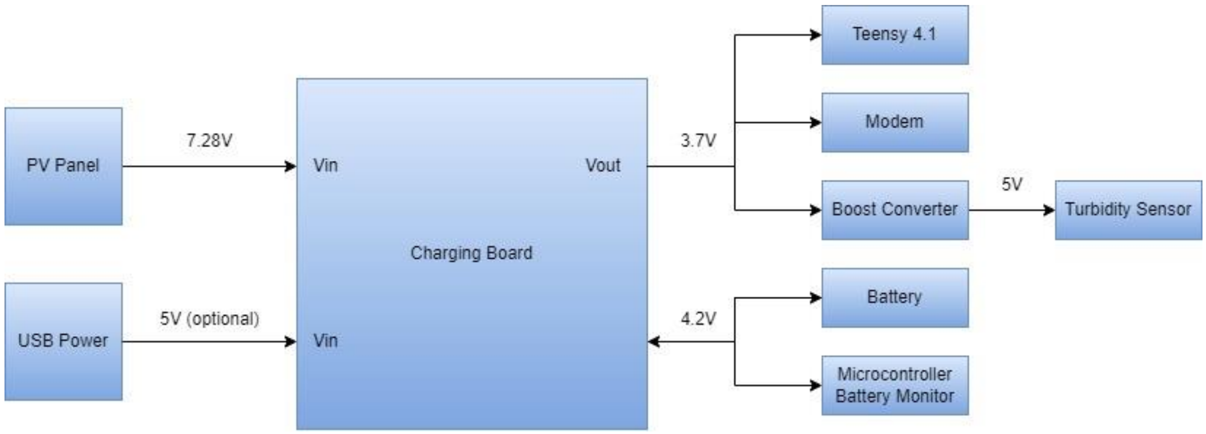


Figure 8 Battery Management and Charging Flow Chart

Micro-Controller and Sensors

The micro controller (uC) we have selected is the Teensyduino 4.1. The reason we selected the Teensy 4.1 is because we can control the clock speed of the uC to achieve a lower power draw. With a 5V supply required to power the teensy, it will be powered with a 5V boosted supply due to the battery being only a nominal 3.7V. In the future, we would select a different more supported microcontroller. Due to the Teensy not having any sleep library support, a good alternative to would be the ESP32. The ESP32 is known to have an immense amount of community library support.

The sensor we picked to measure turbidity was the Thermometrics TSW-10. This sensor measures turbidity of water based on how much light is detected on one side of the sensor when light is shined through water on the other side.

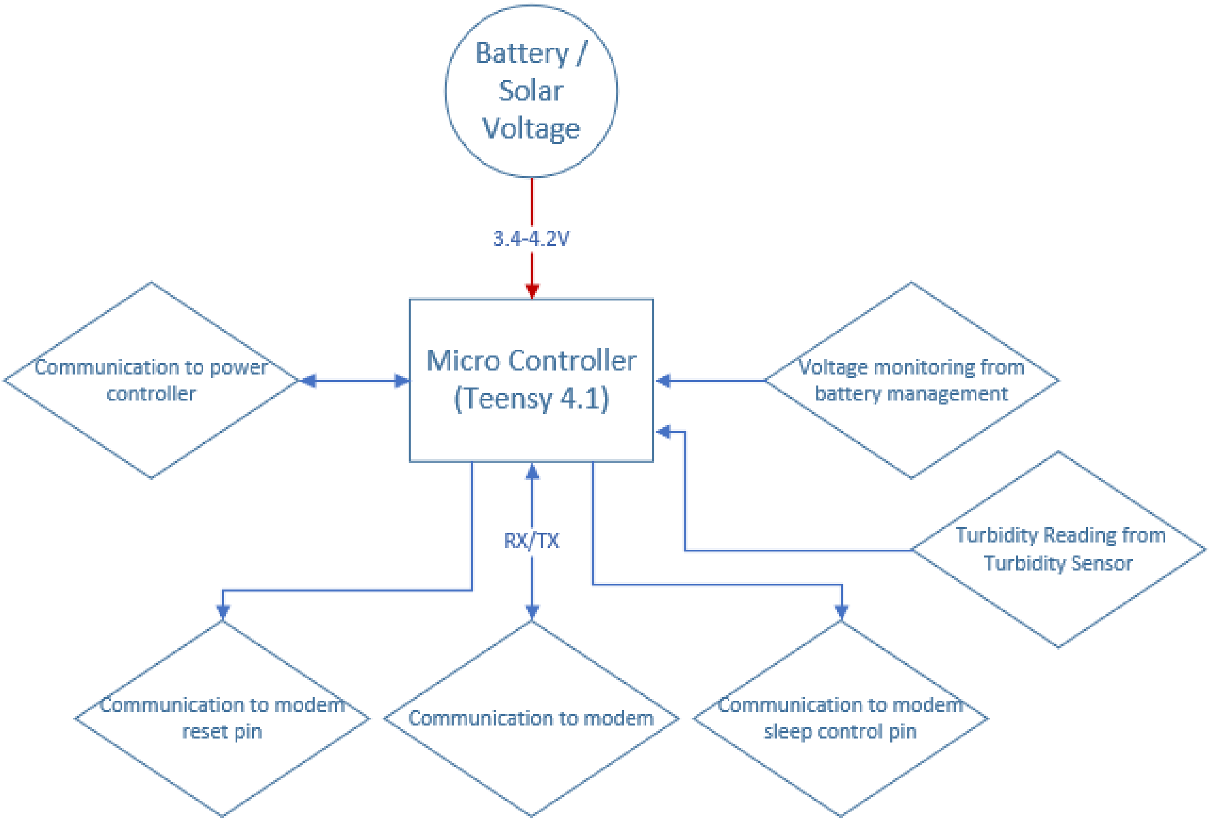


Figure 9 Microcontroller Flow Chart

Cellular Connectivity

To connect to the IOT cellular network, we decided to use a breakout board called the SIM7000A by Botletics. The board runs off 5V; however, it can safely operate off 3.3V power with special wiring. It can handle all the SIM card data reading and writing for us with basic commands on our microcontroller. The modem board also has a low power mode which will come in handy for minimizing power consumption, and it does not consume much power when idle anyway.

Communications

Our system will have a communications system containing a modem and SIM card that will communicate to a storage server using MQTT. Users of the system will be able to access the data stored on the webserver to monitor turbidity readings, battery level, and potentially other useful information. Below are brief descriptions of each subsystem of the communications system.

MQTT

MQTT is designed for connections with remote locations that have devices with resource constraints or limited network bandwidth. This makes it perfect for Internet of Things applications like our use case. MQTT has a publisher, broker, and subscriber model. Our microcontroller will act as the publisher, MQTT Mosquitto will act as our broker, and our web database will act as our subscriber. The Mosquitto broker will be hosted remotely along with our webserver and database.

Database

The database that we have selected is the Azure SQL Database. We have selected this database because we wanted something that was familiar and practical. Using this azure database allows us to use a C# based coding language while still getting all the advantages of SQL. The Azure database will be one of the subscribers of MQTT. Once the data is transferred, the database will allow the UI to query for relevant information.

User Interface

We have selected a website as our primary user interface. Using a website as our primary interface allows us to display our results to regulatory officials and the public. We believe that this will ensure accountability on a social and governmental level.

The user interface (UI) functions as a calendar-based dashboard showcasing dates throughout the month. Dates when our device was active with readings within tolerance are presented in green, while dates with the device active but readings outside tolerance are shown in red. All other dates are represented in gray. Users will then be able to click on the active dates and see the devices readings and battery level. The turbidity will be displayed as a line graph and users shall see the device's readings over the day.

Applicable Standards

The battery and power management systems are subject to some non-mandatory industry standards under Underwriter Laboratories (UL), namely UL 60950-1, which dictates specific safety requirements that battery powered equipment must meet to ensure protection against electrical shock, fire, and other hazards. While the design detailed in this paper is not certified by UL, these requirements were kept in mind during the design process. The prototype device is still, however, prone to mechanical hazards with the current 3D printed enclosure.

Legal limits for water turbidity in natural environments exhibit variability across states, with specified limits ranging from 15 NTU (Nephelometric Turbidity Units) in surface water to instances where no numerical limit is defined. In the case of Kansas Surface Water Quality Standards, while there is no explicit quantitative limit for water turbidity, guidelines emphasize that it must not impede wildlife behavior, reproduction, physical habitat, or other factors crucial for the survival and propagation of wildlife. The Environmental Protection Agency (EPA) notes that fish and similar wildlife begin exhibiting noticeable behavioral changes at turbidities as low as 15 NTU, while prolonged exposure to turbidities of 50 NTU or higher can result in observable harm to fish and wildlife. Note that these numbers are relevant to full bodies of water, and that the very high turbidity seen in water runoff is not what the final turbidity will be when the water reaches a larger body of water.

Additionally, The Federal Communications Commission (FCC) has standards in place for telecommunications and radio space. This project is designed to leverage the T-Mobile IoT network, a company which adheres to and complies with FCC standards. This ensures that our project aligns seamlessly with regulatory guidelines and industry benchmarks. Primarily, we must ensure that we are operating in an appropriate and safe band of frequencies. These guidelines are detailed in Parts 1 and 2 of the FCC's Rules and Regulations (47 C.F.R. 1.1307(b), 1.1310, 2.1091, and 2.1093) along with the ANSI/IEEE C95.1-1992 guidelines.

Detailed Design/Solution Descriptions

In this section the subsystems, given in the top-level design flow chart below, will be further explained.

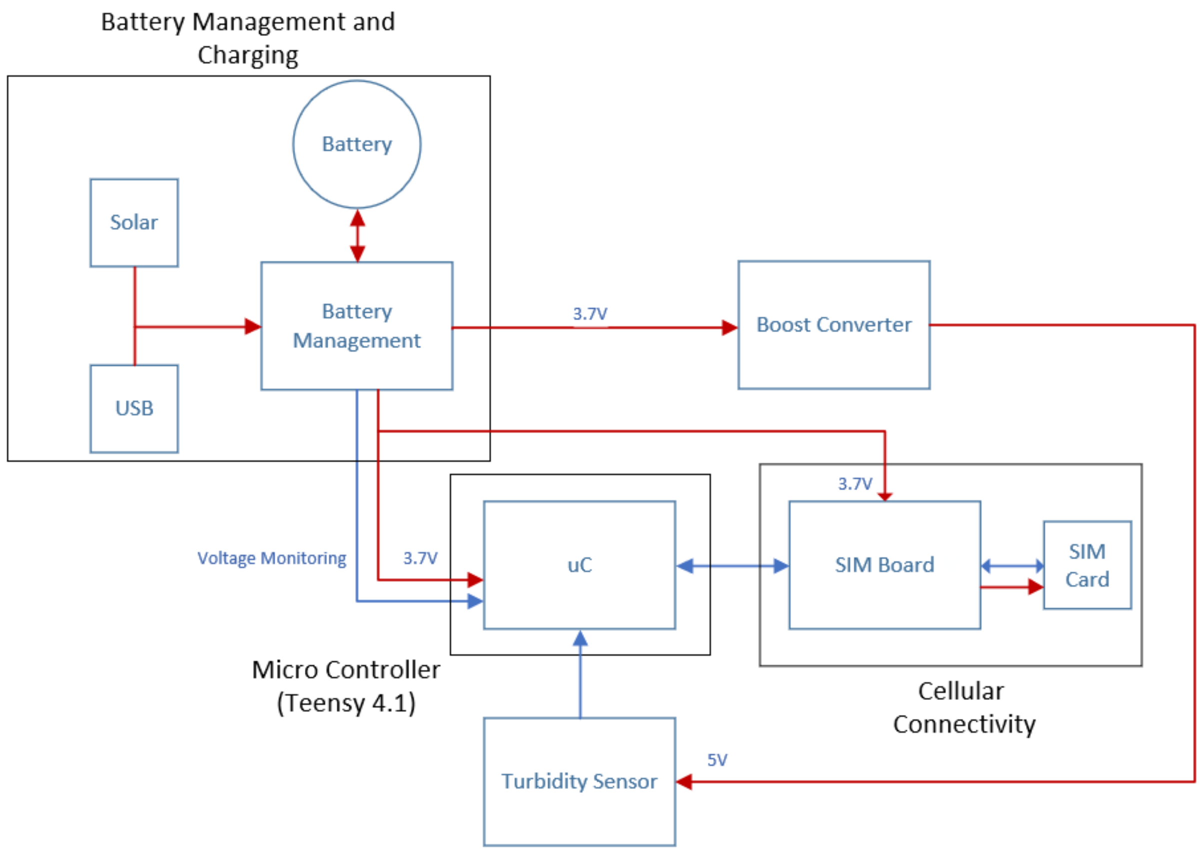


Figure 10 New Top-Level Design

<u>Battery Management and Charging</u>

Battery: LP675365JU

LP675365JU is a 3.7V, 2.8Ah lithium-ion battery created by Jauch Battery Solutions. Ideal charging voltage and current for this battery occurs at 4.2Z and 600mA, and the battery is rated to operate in temperatures ranging from –20 to 60 degrees Celsius. This battery, coupled with our design for solar charging, allows our device to operate with no external power supply over the length of the device's life.

Solar Panel: P126

P126 is a 2W monocrystalline solar cell from Voltaic Systems, with an open circuit voltage rating of 8.51V. Voltage at max power point is rated 7.28V at 330mA. This solar cell enables power to be harvested and used in our device during sunlight hours and charges the battery in approximately 4 hours. When solar power is unavailable, the stored power in the battery is used.

Battery Charging Board: Adafruit Universal USB/DC/Solar Lithium Ion/Polymer Charger

This board acts to regulate the interaction between the solar panel and the battery, equipped with MPPT (max power point tracking) to ensure optimal charging happens within the available conditions. The board steps the solar voltage down to 4.2V when charging and regulates output battery voltage to a maximum of 3.7V. Additionally, it provides access to a USB C port for charging and power delivery if that method is desired. A picture of the board is seen below.

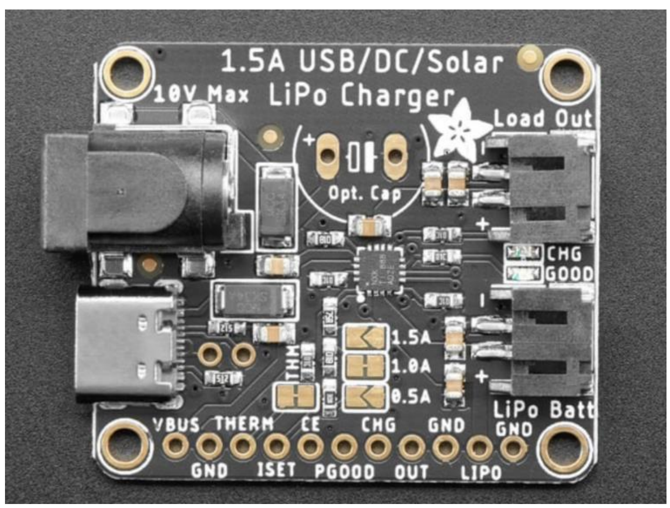


Figure 11 Charging Board

Voltage Regulator: LT1072HV

The LT1072HV is a high power and high efficiency switching regulator that can operate at logic levels. For our purposes it is set in a boost configuration, as seen in the schematic below. Given that the turbidity sensor needs 5V to operate, this boost converter allows for proper power delivery without compromising the other items using the 3.7V system voltage.

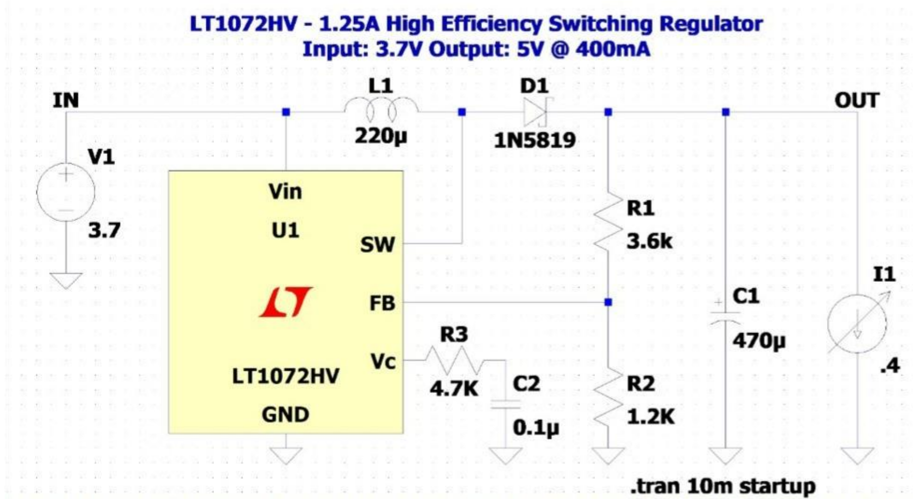


Figure 12 Boost Regulator Circuit

Turbidity Sensor

TSW-10

The TSW-10 is a light turbidity sensor that allows you to relate the voltage of an output pin to the turbidity of the water that is in front of the LED. To connect this to the system there is an issue where the sensor requires 5V to function properly but the ADC on the microcontroller only goes up 3.3V. The output voltage of the sensor is divided to meet the 3.3V maximum. Specific resistors were chosen to maintain a certain impedance to the output of the sensor. The sensor is connected to the board via a 3-pin female header that will allow us to remove it from the board for testing.

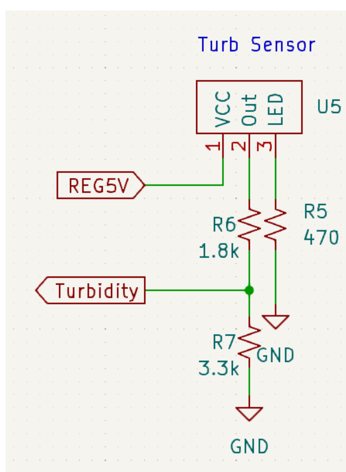


Figure 13 Turbidity Sensor Circuit

Cellular Connectivity

SIM Board: SIM7000A

The SIM7000A is a cellular shield designed for Arduino microcontrollers, but it supports many other microcontrollers too. It supports LTE CAT-M and NB-IoT technologies and has ultra-low power consumption. Below is a diagram of the product highlighting some of its primary features:

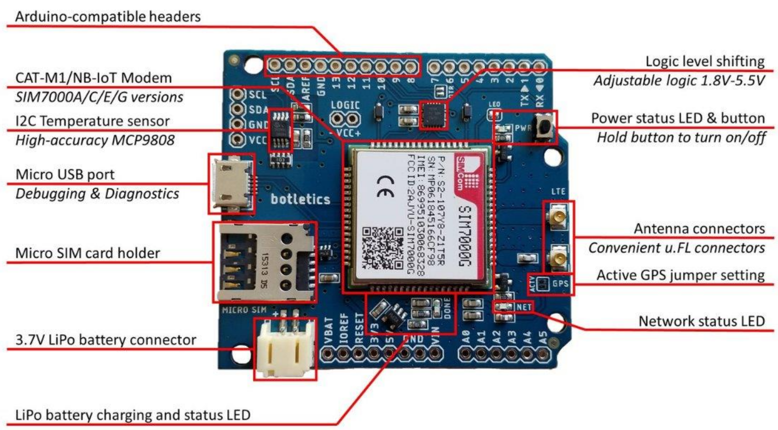


Figure 14 Diagram of SIM7000A Board

SIM Card: Global Hyper eUICC IoT SIM Card

The Hologram Global Hyper eUICC IoT SIM Card is an inexpensive and reliable SIM card. It can switch between networks automatically so that the product is guaranteed to be on the strongest available network. It functions in over 200 countries and is currently the recommended SIM card for use with the SIM7000A cellular shield.

Microcontroller

Teensy 4.1

The teensy 4.1 will be connected to the PCB through female pin headers, so we are able to easily connect and disconnect the microcontroller. Electrically connected to those pin headers will be another set of female pin headers that we can use to tap signals from the microcontroller. The microcontroller is powered with full battery voltage (3.4V-4.2V).

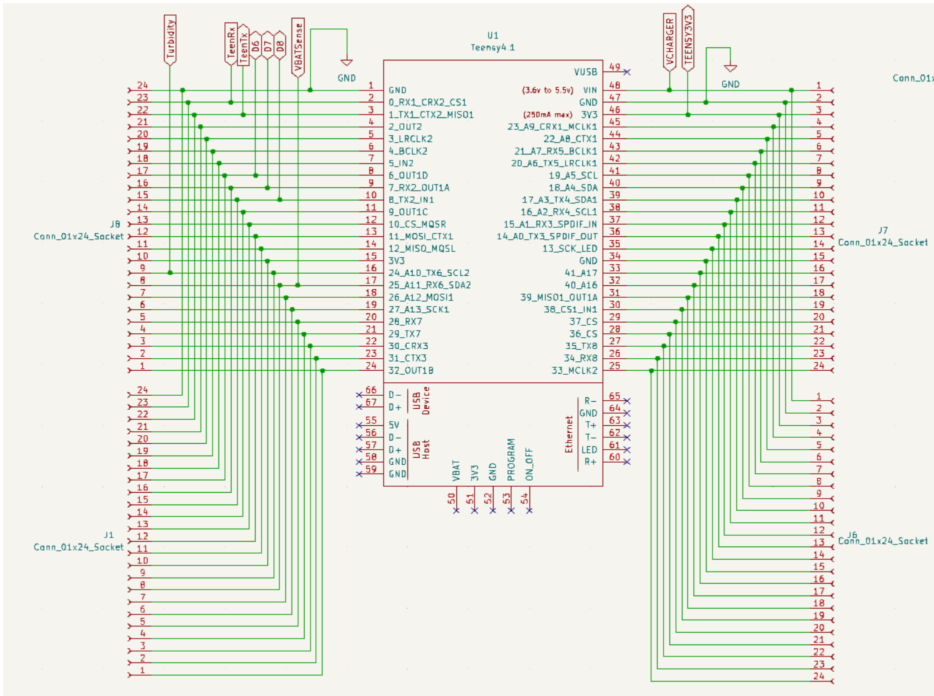


Figure 115 Turbidity Sensor Circuit

The pins we selected for the microcontroller are as follows:

Turbidity Sensor: Pin A10/24

VBAT Voltage Sense: Pin A11/25

Teensy Rx: Pin 0 -> Shield Pin 10

Teensy Tx: Pin 1 -> Shield Pin 11

Teensy 3V3 -> Shield 5V Pin

PCB

The power traces coming from the charging board were made thicker to allow for more current flow. Through hole components were chosen to have the ability to easily replace the resistors with different values in case we need different voltage divider ratios. The regulator is in an 8pin through hole IC socket to allow for easy replacement. The SIM Board is connected to the PCB through female pin headers to allow for easy debugging and testing.

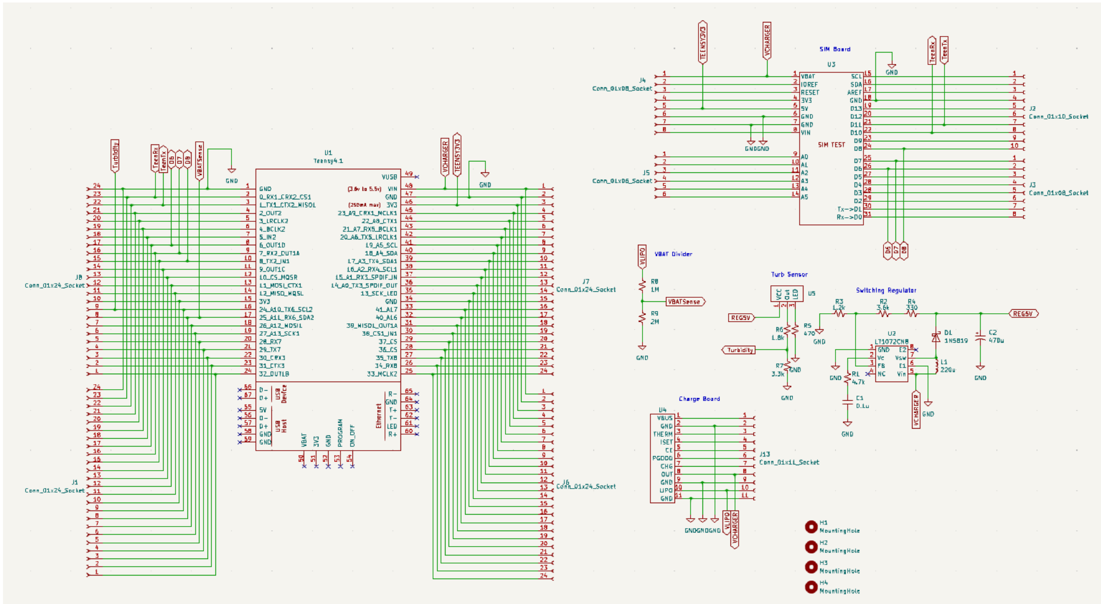


Figure 16 Final PCB Schematic

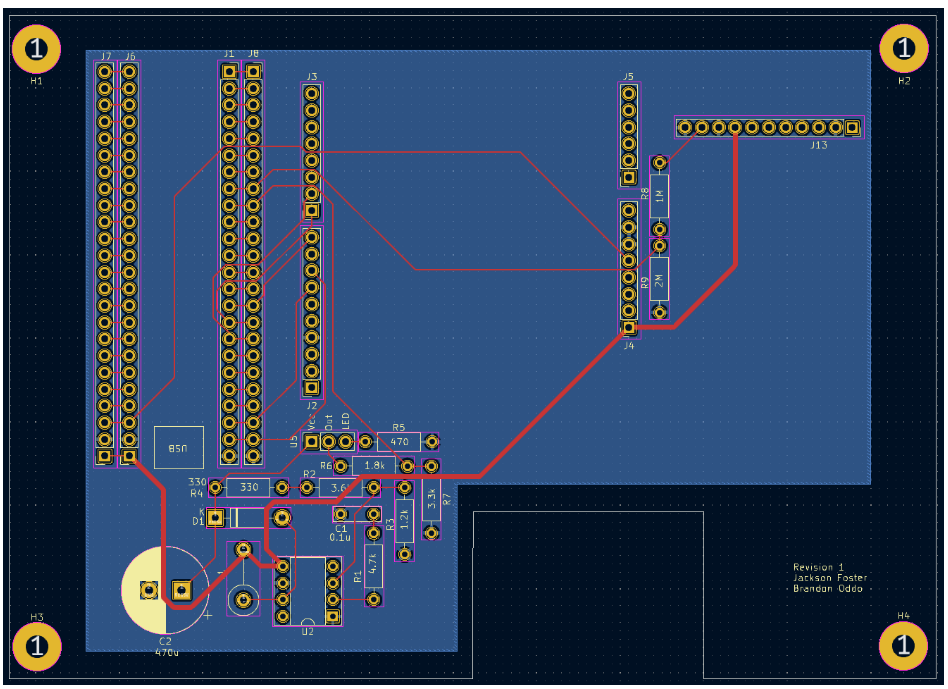


Figure 17 Final PCB Layout

<u>*Ubuntu Server*</u>

Our software is being hosted remotely online using a service called Digital Ocean. They provide a Linux Ubuntu server environment that can be modified as needed. This will serve as our MQTT broker, our database, and our webserver. This allows us to focus on building the software and removing networking issues that could arise using a locally hosted solution. Our embedded software has been able to communicate with our MQTT broker to send packets across a cellular connection. Our website for viewing and interacting with the data is still a work in progress.

Mechanical Assembly

Our mechanical design has two main features. The core of the design is a small waterproof box that we researched and tested to make sure it would meet our size and durability requirements. This box houses the electronics and will keep them dry while they are exposed to the outside. It is made of polycarbonate plastic and is very durable. The second part of the design is a 3d printed shell that attaches to the outside of the waterproof box to funnel water towards the turbidity sensor and to reduce the horizontal forces that flowing water will apply to the side of the box.

Figure 17 Mechanical Assembly Version 1

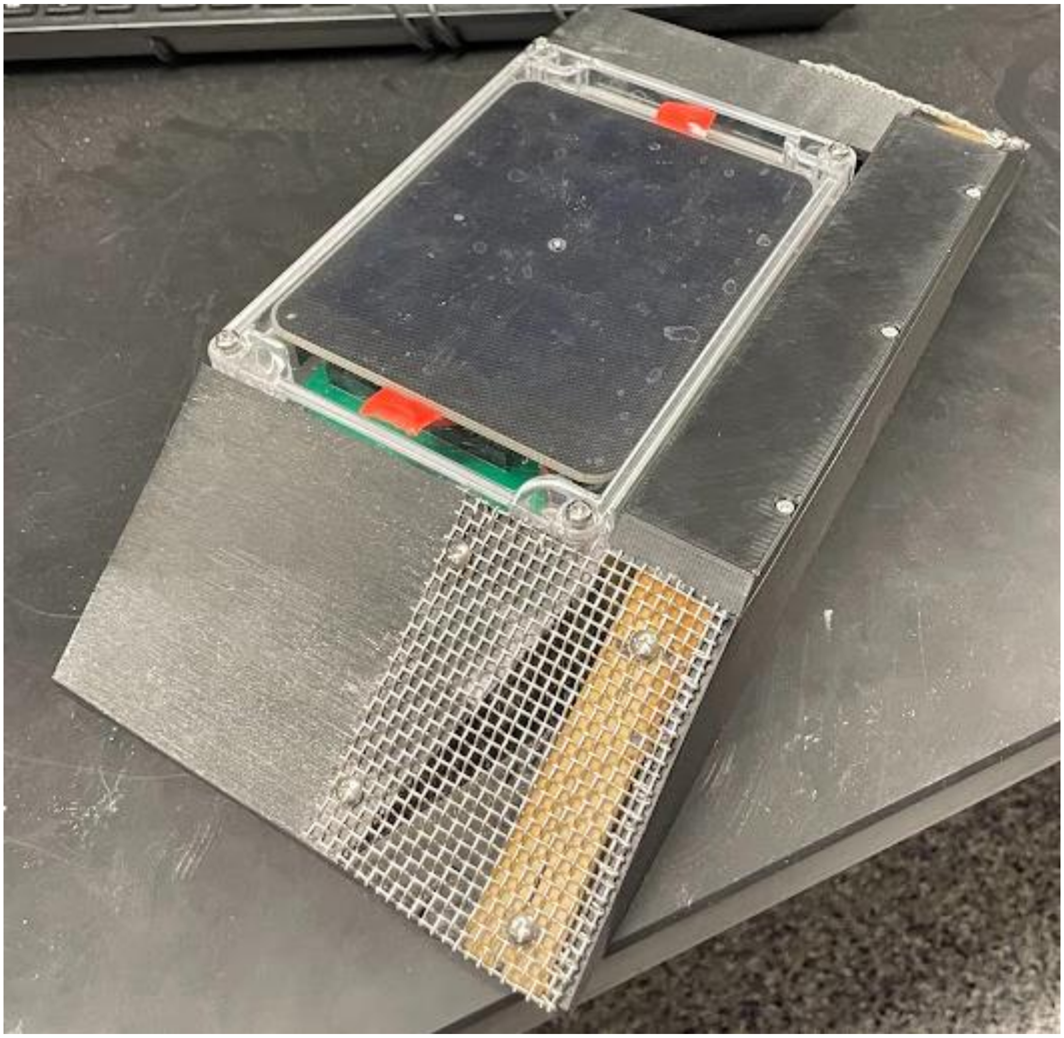


Figure 18 Final Mechanical Design

Validation and Acceptance Test Results

Beginning with requirement 1.1, by analysis of our budget, we spent ~$252.5 of our allotted $250 budget. Next, requirement 1.2, was tested by verifying that the turbidity sensor provided accurate readings. Requirements 1.3 to 1.5 are optional sensors, and they were not implemented in this version of our design. As for requirement 1.6, analysis on the turbidity sensor from requirement 1.2 was able to verify a rough estimate as to how much of a tolerance was in the reading. Our main concerns come from the battery life requirements in requirement 1.7. With the current design, the system was able to survive for ~36 hours (about 1 and a half days) without charging during operation and without a fully charged battery while sending data out every 30 seconds to the MQTT server. Moving on to our physical requirements, requirements 1.8 and 1.9 were verified by taking measurements of our prototype(s), and it was found that the system fits within our size and weight specifications. Requirement 1.10 was then verified by confirming that the system functions properly when supplied with a 3.7V battery that is further boosted to 5V for the turbidity sensor. Finally, requirement 1.11 has been verified by successfully sending data packets from our system to our MQTT server via IoT connectivity.

Assessment of Test Results

Overall, most of the requirements for our product have been met, and the project does, indeed, solve the problem statement. The only two requirements that were not met were the product life of the system and the budget. The budget was only slightly missed due to the need to purchase a backup battery. As for the product life, this would be as easy a fix as switching our microcontroller and creating an updated version of our PCB to accommodate it; however, due to the remaining time in the semester, we were unable to do this. We originally selected the Teensy 4.1 for its expansive I/O and a sleep library granting us the ability to have multiple sensors on our system as well as a low-power mode. Unfortunately, the sleep library appears to have been abandoned in an incomplete version back a few years ago. If our waterwheel was still part of the project, sleep for the microcontroller possibly could have been implemented with an interrupt service routine; however, we cannot verify this at this time. Some alternative microcontrollers include the ESP32, Arduino Uno R3, Arduino Mega 2560 Rev3, Arduino Leonardo, and the Arduino Nano Classic. These boards all have documentation for functional sleep modes/sleep libraries and/or documented use with the SIM7000A modem breakout board.

WORK PLAN

Work Breakdown Structure & RACI Chart

Our current concept can be broken down into three disciplines of designs. We will have mechanical, hardware, and software designers all working together to make the complete prototype. Our team is composed of two electrical engineers and three computer engineers. We have divided the work accordingly to each member's skillset and desires. See the RACI chart below:

Task	Responsible	Accountable	Consulted	Informed
Develop preliminary mechanical design	Jackson	Oddo	Andy	Team
Embedded software design	Andy	Micah	Phil	Team
Network and Communication software design	Micah	Phil	Andy	Team
Client dashboard Data visualization software	Phil	Micah	Andy	Team
Sensor Selection	Oddo	Jackson	Andy	Team
Schematic Design	Oddo	Jackson	Andy	Team
PCB Design	Jackson	Oddo	Andy	Team

Figure 19 RACI Chart

Schedule / Gantt Chart

Task	Date(s)
Team Meetings	Over Break & Throughout Spring 2024 Semester
Sensor Tests	Beginning Feb. 2024
Schematic	Mid/End Feb. 2024
PCB	Week after Spring Break 2024
SIM to Server	Middle March 2024
1st Prototype	April 1, 2024
Turbidity Sensor Calibration Test	End March 2024
1st Software Version	Over Break-April 2024

Prototype Testing/Refining (Physical+Software)	April 2024
DDR	Mid-March 2024
Expo	Beginning of May 2024
Final Report	End of Spring 2024 Semester

Figure 20 Schedule / GANTT Chart

Prototyping and Testing Protocol

To ensure we adequately meet the goals detailed by our requirements, two primary tests were conducted. One aimed to determine the feasibility of the solar charging design, while the other aimed to ensure accurate sensing of turbidity in water.

The first test involved taking our charging system and battery outside to assess their performance in real-world conditions. Conducted on two separate days with partially cloudy conditions, we placed the solar panel flat on a table and connected it to the charging board and battery. Voltage measurements were taken across the open terminals of the battery every five minutes and recorded. Battery capacity was interpolated based on measured voltage, utilizing data from Benzo Energy, a professional manufacturer of lithium batteries.

The second test focused on the collection of turbidity data and the transmission of collected information over the network. We created a turbid solution using corn starch and water, which we measured with both a Secchi stick (a tool used to measure water clarity) and our turbidity sensor. Utah State University provided data that we used to convert our measured Secchi depth to NTUs (Nephelometric Turbidity Units). By having both an NTU value and a corresponding voltage from our sensor, we could calibrate our device. Additionally, during this experiment, we transmitted the turbidity sensor's measurements over the network to a computer to test our ability to wirelessly communicate and to assess packet loss.

FINANCIAL PLAN

We initially proposed a budget of $250. For most of the project, we were well below budget, but we ended up over our budget since we purchased the SIM7000A modem board and an extra battery. Overall, we are expecting to stay within the budget for this project. Below is a list of parts purchased for this project. The list is split in the middle by an empty blue row to indicate spending above being from the first semester and spending below being from the second semester.

Item	Technical Name	Total Price
Micro-Controller	Teensy 4.1	$30

Turbidity Sensor	TSW 10	$8
Water Wheel	SEN0229	$8.50
Battery	LP675365JU	$18
Solar Cell	P126	$21
USB/Solar Charger	4755	$15
Current Total Spent		~$100.50
PCB	PCB	$25
Cell Modem Board	SIM7000A	$69
SIM Card	Hologram Global Hyper	$6
NEMA PolyCase	WC24 F outdoor	$30
Battery (new)	1471-MIKROE-4475-ND	$22
Total		~$252.5

Figure 21 Budget

Comparison of Final Expenditures to Budget

While not as inexpensive as initially intended, we managed to only just go over the allotted $250 budget. The largest hit to the budget was switching from a surface mount modem on our PCB to the SIM7000A modem breakout board; however, this saved us many hours of labor. It was unfortunate that we were unable to implement the water wheel in our design, but it is not too much of a hit to the budget since it was only an $8 part. What sent us over the budget was having to purchase a second battery after we had destroyed the first one.

FEASABILITY ASSESSMENT

Objectively, this project is very feasible. Much of the required technology needed for the project already exists; the important part is selecting proper components. With the current design, there is room for expansion with additional sensors without having to completely revamp the entire system. The major concerns with our product are battery life and robustness of the chassis. While having the solar panel to charge the system is nice, not having a low power/sleep mode for our microcontroller is a bit jarring. As mentioned earlier, there are simple fixes to this power problem; however, due to time constraints, they will not be implemented in our version of the design. As for the chassis, there are two major concerns. Firstly, there is the risk of getting run over by vehicles. Here, to mitigate potential damage, the chassis/shell of later versions can be made of stronger material like concrete. On the other hand, there is the debris issue. There is a very real chance of the mouth of the system becoming clogged with mud, sticks, leaves, and stones. A grate could be installed in front of the system to keep the debris from getting stuck in the waterway, but this still does not fix the problem. As of now, one of the best solutions would be to add this grate and encourage customers to go out and clear blockages after rainy days.

Individual Work Chart

Task:	Responsibility:	Status:
Generated processes and functions that allow the teensy to use the SIM7000A's cellular connection to transmit and receive packets	Phillip Disidore	Complete
Added MQTT functionality to Teensy 4.1	Phillip Disidore	Complete
Enabled turbidity data sensing, filtering, and transmitting	Phillip Disidore	Complete
Researched and tested sleep functionality for Teensy 4.1	Micah Hoover	Complete
Researched and selected devices for the cellular connectivity of the project (Hologram SIM & SIM7000A modem board after receiving feedback from Dane Thompson on our initial plans for cellular connectivity)	Micah Hoover	Complete
Generic secretarial work (organization of presentations, reports, and budget)	Micah Hoover	Complete
Researching software libraries and utilities that could be used for our server and website	Andy Freshnock	Complete
Created Ubuntu server environment and set up MQTT broker and python script for testing	Andy Freshnock	Complete
Designed mechanical system model with cardboard and worked with Ben to get a 3d print made	Andy Freshnock	Complete
Designed power circuitry for battery solar charging and system power delivery/management	Brandon Oddo	Complete
Created and conducted a system test for solar chargeability	Brandon Oddo	Complete
Created and conducted a system test for turbidity sensing and calibration of the sensor	Brandon Oddo	Complete

Designed electrical schematic for the top-level electrical design	Jackson Foster	Complete
Designed and submitted board layout for the PCB	Jackson Foster	Complete
Assisted with mechanical design	Jackson Foster	Complete

LESSONS LEARNED

While working on this project there are two lessons that we have learned. Both lessons have been from feedback that the team has received. Our first lesson came from our conceptual design review. We presented three distinctive designs that had similar core functionality but different approaches to mechanical designs and how the sensors would be placed. After we presented these designs, it was clear that our chosen design was not going to be successful. This caused us to re-evaluate our design decisions and create a new design that will be more successful. Being able to learn from feedback is very important.

The next takeaway from class was the importance of creating good tests. While we have tested the basic functionality of our sensors, we have yet to create a test setup that will mimic the real-world conditions that our system will be in. Creating a test setup that can accurately simulate real-world conditions is important as it is how we will test and verify the requirements.

Recently, we have also had another important takeaway. During our initial research, we selected a newer version of the teensy Arduino microcontroller, the Teensy 4.1. During our research, we deduced that using this microcontroller would lower our necessary power budget since the microcontroller was much more energy efficient. We determined that by coupling the newer version's optimizations and a sleep mode, we could significantly expand the lifetime of our project, this was not the case. The processor on the new version does not yet support sleep functionality, so while we did gain lifetime from the increased efficiency of the newer Teensy, the overall lifetime is probably lower since we cannot implement a sleep. While we did preliminary research to see if there was sleep functionality, it only supported the Teensy 4.0 and not the 4.1. Our takeaway from this situation was that newer is not always better, some features that you might expect to be there may not be.

CONCLUSION

With many hours of research, general advising, design planning, and integration, we were able to create a functional product that met our initial list of requirements. Using the Teensyduino 4.1 and SIM7000A, we were able to read turbidity levels from runoff water and send it to our webserver to be interpreted and displayed in an easily readable graph.

Video of project: https://www.youtube.com/shorts/aczA7vNO7iI

Figure 22 Full System Test

Overall, we conclude that our product is a good proof of concept for a curb-mounted turbidity sensor and water analyzer. Additional sensors can easily be added for extra data collection, if desired. Further work can be done to improve the system's cost and the mechanical design. Price reduction could be done by creating in-house RF circuitry for the cellular portion of the project. As for the mechanical design, utilizing more robust materials for the chassis and design layout modifications can be considered.

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