Underwater Sensor Platform
To Help Predict
Harmful Algae Blooms

DESIGN DOCUMENT

Team: Sddec20-23

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Executive Summary

Development Standards & Practices Used

- Software version control
- Printed circuit board design
- Weekly standup meetings
- I2C Protocol
- 1-Wire Protocol

Summary of Requirements

- Device must observe temperature, movement, and chemical compositions
- Device must be capable of transmitting and storing underwater sensor data
- Device must be waterproof
- Device must have low power usage
- Device must be able to operate for at least 24 hours
- The total cost of one sensor platform should be under $500
- At least 3 sensor arrays per depth to get an accurate set of data

Applicable Courses from Iowa State University Curriculum

- EE 201 - Electric Circuits
- EE 230 - Electronic Circuits and Systems
- EE 333 - Electronic Systems Design
- CPRE 288/388 - Embedded Systems I/II
- COMS 309 - Software Development Practices
- COMS 327 - Advanced Programming Techniques

New Skills/Knowledge acquired that was not taught in courses

- PCB Design
- I2C Communication Protocol
- Soldering

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1. Introduction

1.1 Acknowledgement

We would like to thank the client for immensely generous financial support and the students Christopher Legner and Vishal Patel for continued technical support throughout this project.

1.2 Problem and Project Statement

Algae blooms release harmful toxins into the water which can negatively affect public health, ecosystems, and fisheries. The main concerns are that the toxins released can get into the food we consume, our drinking water, and damage the balance of resources in aquatic ecosystems. For example many organisms suffer due to the decrease of oxygen used up by the algae. By monitoring the factors that cause algae blooms scientists can better prepare and take action to lessen the harmful effects [1].

Our approach to solve this problem is to create a device, called a sensor platform, to collect various types of underwater data. We will use a variety of sensors and eventually analyze and interpret the data to find the conditions that cause an algae bloom.

The purpose of this project is to be able to predict when an algae bloom will occur and use this data to prepare and mitigate or neutralize some of the harmful effects. This data would be beneficial for biologists, environmentalists, and the people who depend on affected bodies of water for basic resources. We aim to create a device that can record all of this data and be able to predict an algae bloom from conditions in the environment.

1.3 Operational Environment

Our sensor platform will operate in a harsh environment. Because the device will be placed outdoors and part of it will be submerged underwater at all times, it will need to be completely waterproof. There are also many outside factors like the weather and organisms in the environment that could disrupt the accuracy of our data or damage the platform.

1.4 Requirements

Functional Requirements:

- The device shall observe environmental factors such as temperature, movement, and chemical composition.
- Device shall be capable of transmitting and storing sensor data
- Device shall be capable of floating on the surface of the water
- Device shall be waterproof

- Device shall have a low power usage
- Device must be able to operate for at least 24 hours
- The total cost of one sensor platform should be under $500
- The device shall use 3 sensor arrays for any desired measurement at a specific depth
- The sensor platform shall be capable of performing readings at a maximum of 3 feet below the waterline

1.5 Intended Users and Uses

Biologists: Can use the data to prepare and mitigate for the harmful effects of an algae bloom

Environmentalists: Can use the data to decrease the chances of an algae bloom and protect the plants and animals that are negatively affected by the toxins

Dependent people: Can use the data to determine when the water is unsafe to drink or aquatic organisms are can be contaminated

1.6 Assumptions and Limitations

Assumptions:

- The device need not be resistant to wildlife interference

Limitations:

- Power consumption of the device must be low
- All sensors must be waterproofed

When designing a waterproof system it comes with many rules and extra necessities. Looking at different means of transmitting data, we found that Bluetooth devices did not have a large range when in contact with water. Because of this, we decided to look into cellular as well as other means of transmitting data. Along with this, we assume that the devices will not need to withstand wildlife trying to break the device. Some limitations of the design include the power consumption of the device. The device needs to function on its own and efficiently manage its power in order to read data for as long as possible. In addition, we must focus on sensors that are capable of being submerged into water or have a way to transmit their data through a medium that touches the water. Water severely weakens wireless communication traveling through it, so we are limited by how we transport data from the sensors to the user.

1.7 Expected End Product and Deliverables

The goal of this project is to create a floatation device that both records and transmits data for a user. This device must provide a floating surface to communicate above the water. Next, there will be a flexible array of sensor devices to collect data about the water at different depths. To ensure the integrity of the data a single platform must support at least three of these sensor arrays in order to provide statistical significance. There should also be a system set up to transfer the data back to the user. Lastly, we will need a software program to analyze the data retrieved to help predict algae blooms. We will use the data collected through this infrastructure and most likely use graphs and a machine-learning algorithm to analyze it.

2. Specifications and Analysis

2.1 Proposed Approach

The team began by developing a better understanding of the end goal: to gather data on algae blooms. With this goal in mind, we researched and found sensors that could be used underwater. Some of the sensors we will be using include a temperature sensor, accelerometer, light and color sensors, and gas sensors. We will begin by getting these sensors to work and send data. After a few sensors are working, we will add more and continue testing. Concurrently, we are working with our data transfer module to find ways to transmit our gathered sensor data.

2.2 Design Analysis

There are a few challenging design considerations we encountered thus far. The most challenging has been figuring out how our sensor platform will communicate with a hub on land. The sensor platform would be floating in a lake with potential miles of water on each side of it. Using a Bluetooth module was the first communication idea proposed. Bluetooth has severe limitations of the distance the signal can travel, which doesn't make it feasible for our project. We have transitioned to try and use cellular modules for communication. Cellular data could potentially provide us with internet access almost anywhere in the world. A challenge we have faced with cellular is the lack of modern cellular modules available for the Raspberry Pi which will be used in our head module.

The brain of our sensor platform is the Raspberry Pi Zero. The Raspberry Pi Zero provides an easy to use interface and also supports many useful libraries for communication protocols such as one wire and I2C. Sensors are wired to the Raspberry Pi, which is responsible for reading the sensor data and transmitting it back to a hub for processing. However, the Raspberry Pi has a significantly larger power draw compared to other platforms such as Arduino.

For the structural design, we plan to use a flotation device at the water line and acrylic like tubing that goes underneath the water. The tubing would contain the various sensors and wiring in a waterproof casing. Some of the sensors need to be in contact with the water. For those sensors, we plan to cut holes in the tubing so the sensors can make contact with the water and then seal the holes around that contact point.

2.3 Development Process

The team has created its own development process that is similar to Agile. Each weekly meeting mirrors a scrum meeting and communication among the team is frequent. Individuals share the progress they've made, as well as upcoming goals and any potential obstacles. Work is done in two different ways: self-guided work which may consist of multiple team members doing development on the project, and guided work where team members walk others through their development processes, such as a demo, in order to keep members up to date. These meetings keep members up to date with information and skills. The team has used this combined with frequent communication to create an effective development process.

2.4 Conceptual Sketch

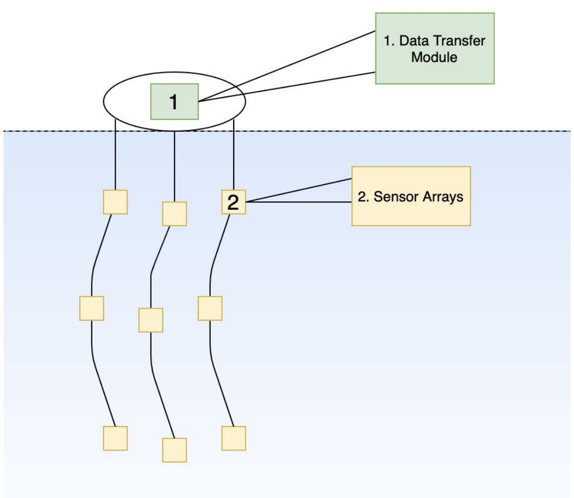

Figure 1: Top-level design of sensor platform.

Description

1. Float to keep the data transfer module outside of the water. This device will be used to store and transfer data from the sensor arrays
2. The sensor array contains components such as temperature sensor and accelerometer to collect data from the water
3. The sensors are placed at different depths to create a more robust and accurate set of data (at least 3 sensors to maintain statistical integrity)

3. Statement of Work

3.1 Previous Work and Literature

Currently, there is not much data on algae blooms, and the cause or environmental conditions in which they occur is unknown. Previously, drones have been used to collect data such as the concentration of green color in the water, however this is not a reliable way to monitor conditions or predict an algae bloom because it usually means one has already occurred.

3.2 Technology Considerations

All of our data is going to be collected underwater. An important consideration would be how to protect our technology and ensure our design is completely waterproof. This is especially important for any exposed wires or sensors which will be in direct contact with the water. They have a higher risk of shorting the circuits and are more susceptible to wear down faster than other components.

3.3 Task Decomposition

Tasks are decomposed into individual units. Each task is labeled with a topic and broken down into smaller more specific subtopics in order to understand the task's hierarchy within our project. An example of this type of label is "platform - sensing - heat" for a task relating to the heat sensors on our sensor array.

The tasks will be divided into two main parts consisting of "Firmware and physical components" and "software and communication". The first piece will deal with all aspects of choosing sensors, getting the sensors hooked up and working, creating PCBs, and designing a waterproof floatation device along with wired connections between the devices. The second piece will focus on taking that data and combining it to be transmitted or received. After the data is back on land it will be analyzed in order to collect data about the algae blooms.

3.4 Possible Risks and Risk Management

Some possible risks are damages to the boards and sensors once we attempt to waterproof the device. To mitigate this we will be researching and testing a few different types of enclosures/sealants to make sure we find the right one. Additionally we risk losing data due to the inability to transmit. We aim to have a high amount of static memory on the sensor platform device.

3.5 Project Proposed Milestones and Evaluation Criteria

- Milestone 1: Determine all sensors needed for the system

- Milestone 2: Create a working sensor board to retrieve data from water in a simple fish tank
- Milestone 3: Create a data analysis tool to make sense of the data
- Milestone 4: Enable communication ability or data storage in a remote environment
- Milestone 5: Create communication between units
- Milestone 6: Full-Scale deployment of multiple units in collaboration

3.6 Project Tracking Procedures

We will use GitLab issues and milestones to create and track individual tasks. It will mark the progress of the tasks so that the overall project process is easy to view. Lastly, we will do regular reviews on current tasks and upcoming tasks.

3.7 Expected Results and Validation

The desired outcome of this project is to create a sensor platform capable of collecting data from multiple depths in the water and use this data to predict aquatic life events, specifically algae blooms. The secondary goal would be to create a network of these devices to communicate across a large lake. To validate the unit we will test it in both lab environments and real-world bodies of water.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

- February: Begin testing sensors
- March: Solder parts to prototype PCBs and begin testing with PCBs
- April: Create new PCBs and continue testing new sensors, work on communication between modules
- August: Have a testable environment and prototype producing data
- September: Final Round of PCBs ordered and assembled, work on waterproofing
- October: Finalize method of communication to home base
- November: Final touches, clean up the design

4.2 Feasibility Assessment

The project will consist of an underwater sensor platform connected to a wireless communication device or onboard storage. This project will undergo many challenges due to both the water-based aspect of the design as well as the communication of data in rural areas. To determine if this project was feasible, we had to determine three main things. First, are there currently sensors available for what we want to measure? With some background from the client, we determined this was realistic. Second, is there a way to safely collect the information without risk to the electronics needed? Through research, we found multiple ways to waterproof the system and make sure we could still acquire the data necessary. Lastly, what type of communication can we use to transfer the data and analyze it? After looking at multiple different methods such as cellular, physical access via a USB, and short-range Wi-Fi communication, we concluded that no matter what we decide, there is a reliable way to transfer the data back making it viable. Since all three parts of the project are feasible the team then decided that the overall project was feasible.

4.3 Personnel Effort Requirements

- This project will require learning assistance from Christopher Legner and Vishal Patel, both students working with Dr. Pandey, for knowledge of pre-existing software, surface mount soldering, and PCB design.
- This project may require help from local wildlife authorities to gain access to a live environment for large scale testing.
- Below is a table breaking down the project into tasks.

Task	Description	Estimated time (Hours)
Selection of sensors	Research and select the sensors necessary to collect the data we need	15
Selection of microcontroller	Research and select the microcontroller(s) needed to fulfill all requirements	15
Designing PCBs	Schematic and board design for prototyping sensors and controllers.	25
Assembling PCBs	Solder parts onto printed circuit boards	15
Testing PCBs	Test printed circuit boards so ensure sensors are working	60
Design prototype housing for data collecting module	Design the first iteration of our waterproof housing for our microcontroller and all peripherals.	120
Test housing structure	Test our housing is waterproof and allows all sensors to collect accurate underwater data.	30
Design Cellular/Communication framework	Decide on a cellular module that works and set up communication between the module and microcontroller.	100
PCB prototype re-design (if necessary)	Redesign a better prototype board following the results from PCB testing	25
Design final housing structure for boards and sensors	Redesign our housing structure from our first prototype to a more permanent solution	20
Build final housing structure based on design	Construct a final housing structure based on the redesign.	40
Documentation	Write up instructions for how to use the device and collect data	15

4.4 Other Resource Requirements

Beyond the financial requirements, we will need a workshop to solder the components together, an environment to test the product in, and help with knowledge of the algae bloom situation, as well as some biological samples to acquire data.

4.5 Financial Requirements

While the total financial requirements to complete the project are unknown at this point due to speculative prototyping costs the goal for the final unit will be no more than $500 in total for a single unit. If the team chooses to use a cellular network for communication of data, there may be a low monthly cost associated with the unit.

5. Testing and Implementation

5.1 Interface Specifications

- For hardware, I2C and one wire protocols were chosen as an interface with the sensors because they allow flexibility and compatibility with most of our sensors.
- Board to board communication will occur in a tree topology over the UART Data Link Layer implementation. When networking is required a binary protocol similar to the go-back-n protocol treats each sensor report as a frame with ordering based on the time the sensor data was read. All boards will be connected in a tree topology.
- It is possible that direct wired communication may not be available. In this case, some Layer 2 or 3 devices and protocols or Bluetooth may be used to deliver the data wirelessly.
- Once a board with internet capabilities is reached that board will use either Ethernet or cellular (GSM aka G2) to communicate with the reporting server(s).

5.2 Hardware and Software

Our reporting system, ReportReceiver, is the system by which data is transmitted to a remote server and is tested using JUnit. JUnit allows unit tests and generates them in a standard XML format.

The hardware to be tested is the main unit and the accompanying legs that include custom sensor arrays

5.3 Functional Testing

Functional testing includes our unit tests, integration tests, and load tests. Our unit testing is done through JUnit and is run during and after development. Most of the code has dedicated unit tests covering it. We aim for 90% test coverage. Taking into consideration the edge cases that do not need to be tested, our current test coverage is 84%, with most of the unaccounted code relating to networking abuse prevention. Currently, without an assembled platform we are unable to run Integration Testing, however the client stubs written with the code will be able to be utilized on our selected controller, so we expect little variance in our integration testing. We will conduct load tests to ensure throughput performance is sufficient, particularly for the cellular system's ability to send data through to the server. The final acceptance testing will be conducted when major changes occur. These features will be demonstrated to the client. One demonstration to the client has already taken place with encouraging results.

5.4 Non-Functional Testing

Non-functional testing will include things such as checking the energy efficiency of the device, passing the 24-hour functional requirement, testing if sensors can be replaced easily, and testing the speed of data transmission. Testing the efficiency will be simple as we can change the sampling rate and see what kind of battery life we have. Testing for replaceability of sensors will require us to look into our design to make sure the device is easily maintainable. Lastly, we will check how fast the cellular network transmits the data to determine the real-time of our information.

5.5 Process

For the data transfer tool, testing occurs through JUnit tests. The hardware we create is run through separate testing that consists of flashing the device with the software and testing the results in a controlled environment. If the results remain consistent with regular sensors (such as a thermometer) that are not attached to the board then we deem the device good.

5.6 Results

For the data transfer tool, all tests are passing with 84% test coverage, which is 6% away from our goal and is within tolerable standards. All important code is written and any code that is not covered is related to network abuse prevention. For the hardware, two PCBs have been soldered with one working and being tested, and the other unfortunately not viable due to applying too much heat during hand soldering resulting in a shorted circuit board. That being said, we have a working sensor array with two components collecting data: the temperature sensor and accelerometer.

6. Closing Remarks

6.1 Conclusion

From the beginning of the semester to now, we have completed a few major steps. The first would be creating a design plan for both the head module to transfer data, and the sensor arrays themselves. We then created working PCB layouts, had them manufactured and printed, soldered and tested a few, and can now receive valid data. While this was happening, we tested different sensors with different communication protocols to see what worked and what didn't. We found multiple sensors that would be good candidates for our project and began connecting them to test their accuracy, eventually choosing the ones that performed the best.

While the hardware design was being implemented, the software was also being developed. A reporting tool as discussed above was created to take data from multiple devices and store it safely for later use. On a lower level the software to obtain data from the sensors and translate it into a usable format was also created. Overall, we got our general design plan created and a great foundation for our implementation of the device.

Our plan for the upcoming months will be to redesign the PCBs to address any issues we encounter connecting the head module to the sensor array units. In addition, we are aiming for the goal of a fully functional sensor device that we can test inside a fish tank and a lake by the end of the next semester.

We chose our solution because it fits all the design choices as best as possible. With the limits on power and communication due to the device's environment, we had constrained options, but made the best design choices we could based on our research. The communication protocol, while more expensive than we would like, is one of the only two viable options between cellular and the satellite internet. The cellular choice was made as it would create a simpler implementation and require the least amount of added hardware.

Lastly, the sensors we chose to use in this design are being iteratively reviewed to make sure that we are collecting the data specifically needed for the analysis of underwater algae blooms. With help from faculty in the area of biological research (Dr. Pandey and Christopher Legner), this combined effort of knowledge and research allows us to find the most optimal sensors to solve our problem. Together these pieces create the best possible solution for the remote analysis of algae blooms surpassing all other possible solutions for real-time data analysis.

6.2 References

[1] Andersen, Enevoldsen, and Anderson (2003). Harmful algae monitoring programme and action plan design. *Manual on Harmful Marine Microalgae*, *33*, 627-645.

6.3 Appendix