Underwater Sensor Arrays To Help Predict Harmful Algal 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 platform 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

Currently there is no accurate data on algal blooms and what conditions in which they occur. These algal blooms release harmful toxins into the water which is harmful to the surrounding environment. Many people from third world countries use lake water as drinking water, which can cause sickness if an algal bloom has occurred. In addition, many organisms in the water suffer due to the decreased oxygen used up by the algae.

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 algal bloom.

The purpose of this project is to be able to predict when an algal bloom will occur. This will allow people to take action to prevent a bloom from happening or neutralize 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 algal bloom from conditions in the environment.

1.3 Operational Environment

Our sensor array 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:

- 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 water
- Device shall be waterproof
- Device shall 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
- The device shall use 3 sensors for any desired measurement
- The sensor array shall be capable of performing readings at a maximum of 3 feet below the water line

1.5 Intended Users and Uses

Biologists: Can use the data to try and neutralize the harmful effects of an algal bloom
Environmentalists: Can use the data to decrease the chances of an algal bloom and protect the plants and animals that are negatively affected
Dependent people: Can use the data to determine when the water is unsafe to drink and to determine when water may be safe to drink to indicate when to begin storing extra water.

1.6 Assumptions and Limitations

Assumptions:

- 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. Some assumptions we made when creating this device is that whether cellular, bluetooth, or other modes of communication our environment will all be able to support the same type of communication. 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 will need to function on its own, manage its power, and be efficient to continue reading data 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 though it, so we will be limited by how we transport data from the sensors back 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 the data for a user. This device must provide a floating surface to communicate above water. Next there will be a flexible array of sensor devices to acquire data about the water at different depths. To ensure the integrity of the data a single platform should be able to support at least three of these arrays to provide statistically accurate data. Next, there should 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 algal blooms. We will use the data collected through this infrastructure and most likely use machine learning to develop a program to analyze this data.

2. Specifications and Analisis

2.1 Proposed Approach

The team began by gaining a better understanding of the end goal: to gather data on algae blooms. With this goal in mind, we worked to find sensors that could be used underwater to gather data. Some of the sensors we will be working with 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 array will communicate with a hub on land. The sensor array would be floating in a lake with potentially miles of water on each side of it. Using a bluetooth module was the first communication idea proposed. Bluetooth has severe limitations on the distance the signal can travel, which doesn't make it feasible for our project. We have transitioned to trying to 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 Arduino platform.

The brain of our sensor array is the Arduino Uno. Arduino provides an easy to use programming interface and also supports lots of useful libraries for things such a 1-wire and I2C. Sensors are wired to the Arduino which is responsible for reading the sensor data and transmitting it back to a hub for processing. A drawback of the Arduino is that we don't have much control over the libraries we use. Another potential limitation is the amount of program memory available on the Arduino Uno.

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 this we plan to cut holes in the tubing for the sensors and seal the holes.

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 amongst 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 kinds: 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

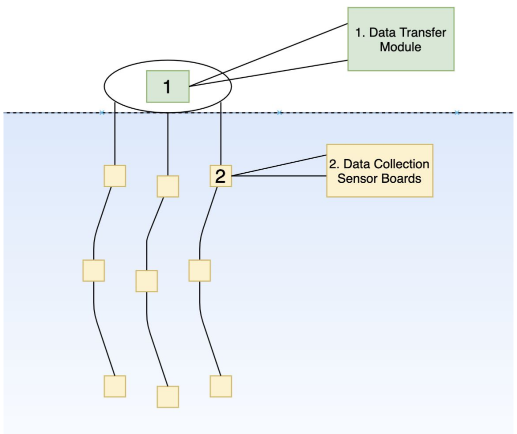

Figure 1: Top level design of sensor arrays.

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 array
2. The sensor boards contains components such as temperature 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

3. Statement of work

3.1 Previous Work and Literature

There is little data relating to the causes of these harmful algal blooms. Today drones have been used to measure the amount of green color in water, however this is not useful information as it means an algal bloom has already occurred and our goal is to predict them.

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 are more susceptible to shorting the circuits and wearing down quicker than other components.

3.3 Task Decomposition

Tasks are decomposed into individual workable units. Each task is labeled with topics approximately decomposed into a tree. An example of such labels is “telemetry - receiving - storage` for the storage of data collected by the platform now on an accessible server set. Another such one may be “platform - sensing - heat” for concerns relating to heat sensors on the sensor platform device.

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 creating a 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 algal 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 are trying a few different types of enclosures/sealants to make sure we find the right one. Additionally we risk losing data due to 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 to create and track individual tasks. It will mark 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 algal 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 design

4.2 Feasibility Assessment

The project will consist of an underwater sensor array 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 a non-urban area. To determine if this project was feasible, we had to determine three main things. First, are there currently sensors for what we want to measure in the water? 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, we needed a way to transfer this data so we could use it. After looking at multiple different methods such as cellular, physical access via a USB, and short range Wi-Fi communication we decided that no matter what we decide we will have a way to get 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 assistant from Christopher Legner for items such as 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 a first iteration of our waterproof housing for our microcontroller and all peripherals.	120
Test housing structure	Test our waterproof housing, confirming it is waterproof, and allows all sensors to collect accurate underwater data.	30
Design prototype housing for internet connected central hub module	Design a first iteration of our waterproof housing for our central hub module	100
Test central hub housing structure	Test our waterproof housing for the central hub. Ensure it is waterproof, and wireless communication is not impeded.	
Design Cellular/Communication framework	Decide on a cellular module that works and setup 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 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 algal 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

Note: Talk about PCB's how sensors were chosen, how we plan to test.

5.1 Interface Specifications

- For hardware, I2C and one wire protocols were chosen as an interface with the sensors as they allowed flexibility and compatible with most of our sensors.
- Board to board communication will occur in a tree topology over the UART Data Link Layer implementation. 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 device and protocol 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

Software

Report Receiver

Report Receiver is an implementation for receiving data to be hosted on a remote server. It contains implementations for server and client side protocols to be used as both references for controller based implementations and in testing.

5.3 Functional Testing

Software (some of these may go in non-functional)
Unit testing
Our unit testing is done through JUnit and is run during and after development. Most of the code has unit tests covering it. We aim for 90% test coverage, but with consideration for edge cases which don't need to be tested. Our current test coverage is 84%, with most unaccounted for lines relating to networking abuse prevention.
Load Testing - Load tests have not yet been written.
Integration Testing - Integration testing has not been able to occur without an operational sensor platform.
Acceptance Testing - Our software capabilities have been demonstrated to the client. They have been supportive of the results.

^^^Look at this in V3

5.4 Non-Functional Testing

5.5 Process

5.6 Results

6. Closing Remarks

6.1 Conclusion

6.2 References

6.3 Appendices