Water Contamination Detection and Alerting System for a Boat

ECE445 Design Document

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1. Introduction

1.1 Objective

We propose to build a system that can remotely monitor water quality and contamination on a boat. This system will be able to automatically log data at distance intervals, determine if water is contaminated, and if it is, send a text message alert with Global Positioning System (GPS) location coordinates, and sensor data. The data will be stored on a SD card and can be transferred loaded onto a computer manually.

Although systems of checking water contamination exist, they are not as accessible for those that live in rural areas compared to those that live in more populated areas, such as cities. The goal of this project is to increase the accessibility of water contamination detection systems by creating such a system that allows for real-time alerts, which effectively reduces the number of people that would have to control the boat and record data.

1.2 Background

Water contamination is a significant issue across society, as it affects the health and well-being of the environment and its inhabitants. In a study carried out by University of California, Irvine, it was found that roughly up to 45 million people are affected each year by water systems that violated certain health-based criterion.[1] In particular, this problem holds significance for those that live in rural areas. Homeowners are faced with the options of installing expensive filtration systems, paying the government more taxes in order to dig deeper wells, or move towards more populated areas such as cities.[2]

Since millions of people are affected yearly, it goes to show that the systems we have in place are not exactly adequate, especially in sparsely populated, rural areas. Many regions, such as lakes or rivers, are more difficult to access and the current methods of monitoring water quality in those spots are not thorough enough. In order to measure and observe water contamination or pollution, a person is required to manually go to the location and record data and take water samples for measurements. This process contains safety risks and inefficient when done alone, since the person in charge would have to both steer the boat and manually collect water quality data.

1.3 High Level Requirements

- System takes water measurements at user-set time intervals and records GPS location data to a local memory unit.
- Temperature readings must reflect actual water temperature to within ±0.5°C accuracy and pH sensor readings must reflect actual pH levels to within ±0.1 pH accuracy in order to accurately determine the quality of the water.
- Detection system sends an alert through text message through a Global System for Mobile communications (GSM) to a user-assigned phone number when collected water data is not within range of pH safety levels - pH 6.5-8.5, which is the normal pH range for surface water systems[3].

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[1] Study conducted by University of California, Irvine: *https://www.pnas.org/content/115/9/2078*

[2] Rural communities and water pollution: *https://www.nytimes.com/2018/11/03/us/water-contaminated-rural-america.html*

[3] Acidic Water and Low pH Water: *https://www.uswatersystems.com/water-problems/acid-water-low-ph*

2. Design

2.0 Physical Design

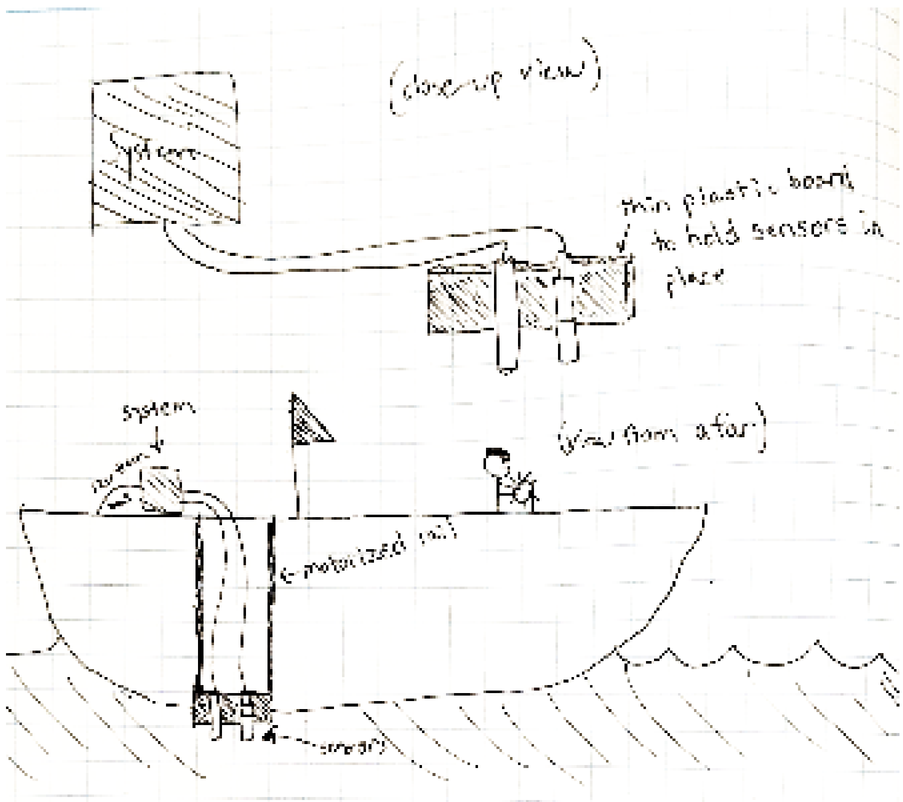

Figure 1: Physical design of system

The system is intended to be placed on a boat and powered by the boat's 12V battery, ideally attached to some kind of mechanical device that communicates with the system and allows the sensors to be submerged underwater apart from the rest of the system, since the system itself (microcontroller, communications unit, IO module, power unit) should not make contact with the water. The sensors should be held in place by some arbitrary thin sheet of material in order to uphold the overall physical integrity of the system. The mechanical components, however, will not be in the scope of this project; our main focus here is the electrical system.

2.1 Block Diagram

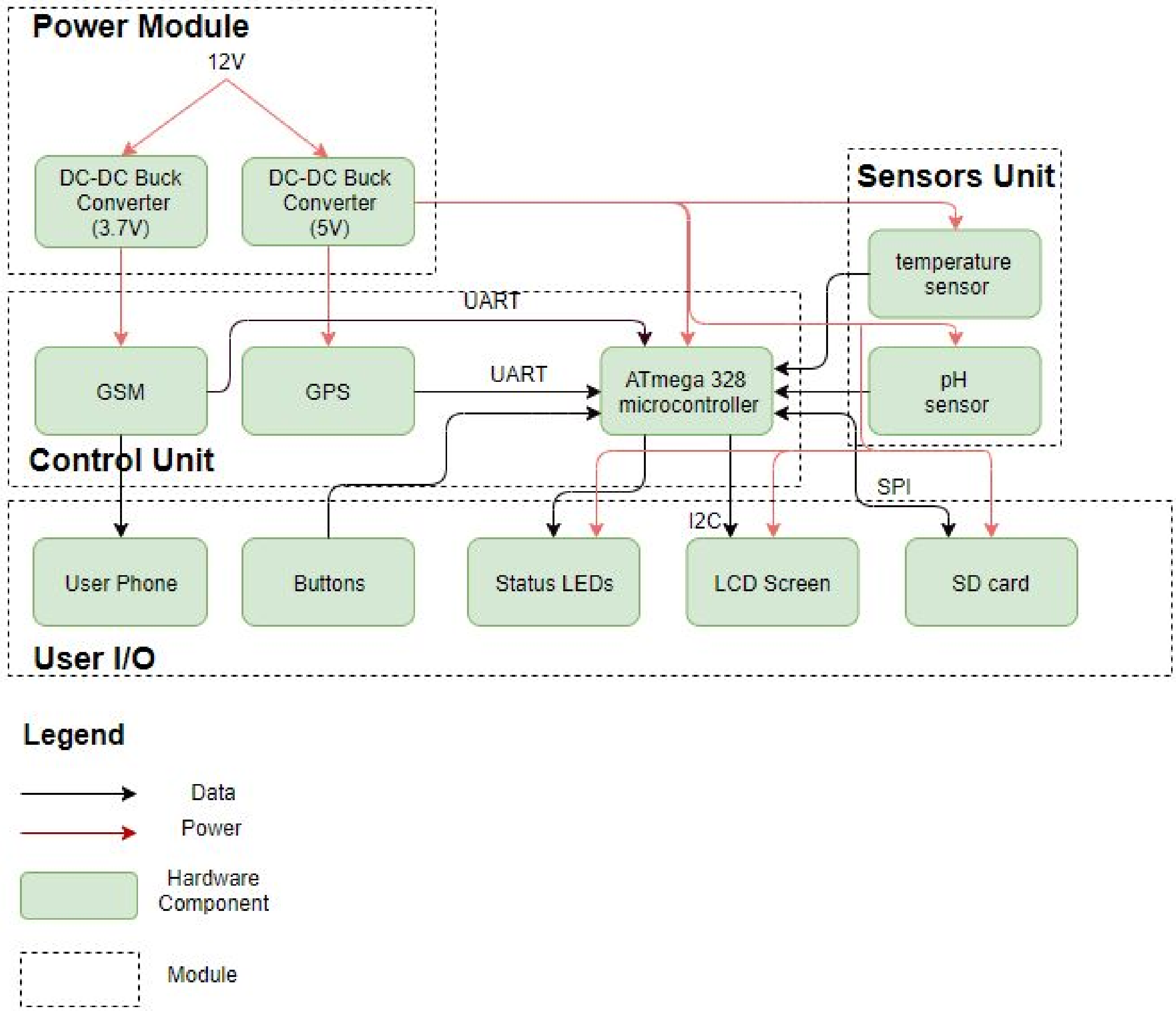

Figure 2: Block Diagram

To satisfy the requirement of taking measurements at a set interval, the MCU continuously monitors the time. The microcontroller performs calculations to get the remaining time left before the interval is met. Based on the user set time interval, the system will collect data at those intervals until the system is shut off. To ensure that the data being collected is accurate, we will use trusted reference devices during the testing process to compare the results from our sensors with those from the reference devices. This helps check whether there are inherent hardware issues or faulty logic. The sensor data is sent to and processed by the MCU and determines whether to alert the user. If the pH of the water falls out of the safety range, the microcontroller will signal to the communications subsystem to send an SMS alert message to the user's mobile device.

2.2 Functional Overview

Power Module

We want the water quality monitoring system to be running all the time to be able to detect and alert water contamination in real-time. To do this, all our modules need to be powered by the battery. This includes the sensors, microcontroller, and communications modules.

1. **DC-DC buck converter**

   The DC-DC buck converter is used to step down the 12V input voltage to 5V in order to power the majority of the modules in our system: pH sensor, temperature sensor, GPS, SD card, microcontroller. However, the GSM requires a voltage of 3.7V with max current of 2A. Due to this requirement, we decided to go with a DC-DC buck converter that utilizes the LM2596 regulator with a current rating of 3A.

Requirement	Verification
1. The DC-DC buck converter must provide 5V ±5% and be able to handle up to 500 mA maximum current draw. 2. The DC-DC buck converter must provide 3.7V ±5% and be able to handle up to 2A surge current.	1. Using a multimeter, measure the regulator output voltage and ensure it is within 5V ±5% when a 10Ω resistor (0.5A load) is applied 2. Using a multimeter, measure the regulator output voltage and ensure it is 3.7V ±5% when a 1.85Ω resistor (2A load) is applied.

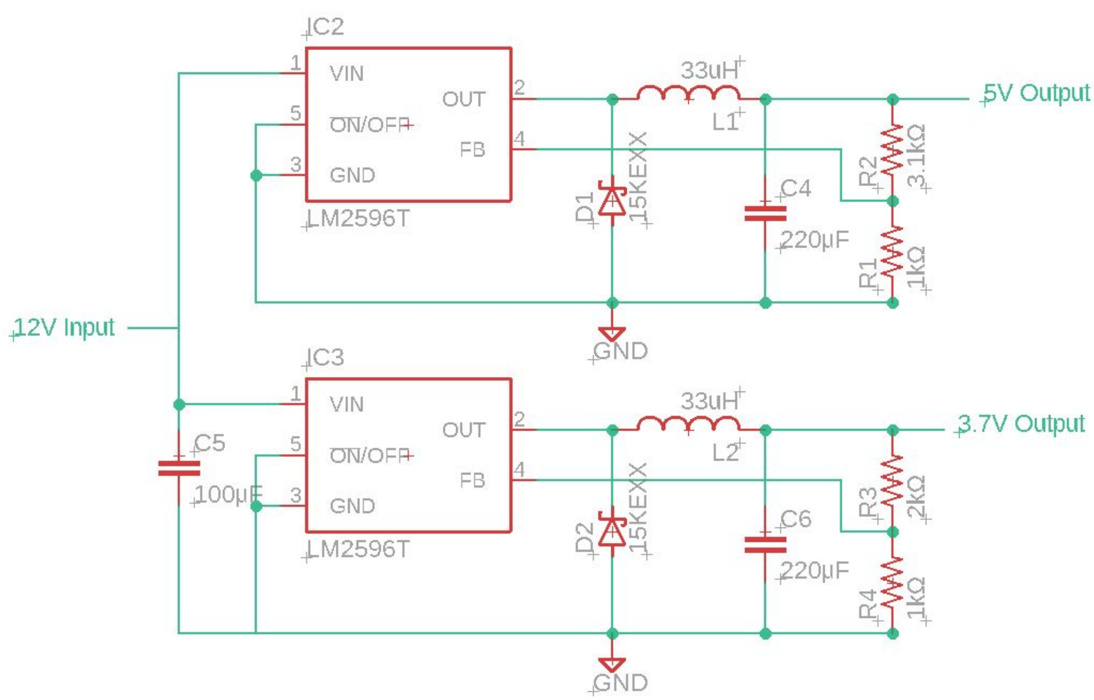

Figure 3: Schematic of Power Module

Sensor Subsystem Unit

We want our system to be able to to record water conditions and to detect contamination. We use sensors to record data for two parameters in the water: pH and temperature.

1. **pH sensor**

   The pH sensor monitors the pH of water with a measuring range of 4 to 10 pH. The analog output of the pH sensor is read by an analog pin on the microcontroller.

Requirement	Verification
1. pH sensor must have measuring range of 4 - 10 pH and to within ±0.5 pH accuracy.	1. Use Ph 4.01 & Ph 7.0 Calibration Solution Kit to calibrate pH sensor. 2. Fill multiple beakers with solutions of known pH level. a. Measure solutions with known pH levels of 4.0, 7.0, 10.0. 3. Compare measurements according to known pH level.

2. **Temperature sensor**

   This temperature sensor can monitor water temperature to within ±0.5°C accuracy. The usable temperature ranges from -55 to 125°C. However, our target measuring range will be from 1.5 to 33°C.

   The digital output of the sensor can be read by a digital pin on the microcontroller.

Requirement	Verification
1. The temperature sensor needs to be waterproof as it will be submerged in water. 2. The sensor needs to measure water temperature to within ±0.5°C accuracy for temperatures ranging from 1.5 to 33°C.	1. Fill a beaker with room temperature water. Submerge the sensor in water for 3 minutes and check for readings. 2. Submerge the sensor in 1.5°C water. Check readings for accuracy. Then submerge the sensor in 33°C water. Check readings for accuracy.

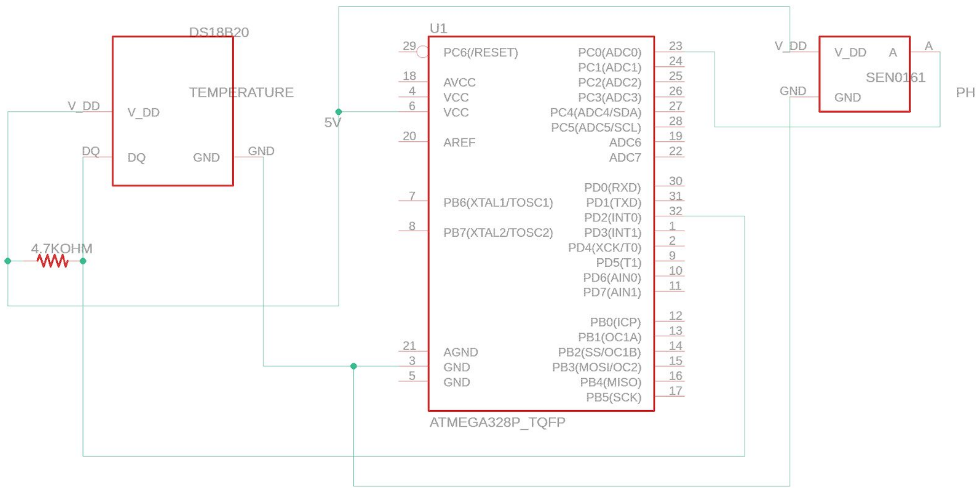

Figure 4: Schematic of Sensors Module

Control Unit

The control unit involves a microcontroller and an SD card module. It is responsible for data logging and interfacing with the sensors and communications modules: GPS, and GSM. It is also responsible for determining if water contamination is present. If water is contaminated, the microcontroller will signal to the GSM module to send a text message alert.

1. **Microcontroller**

   The microcontroller interfaces with the sensors for measurement data and GPS for location data and logs the data on a micro-SD card for later data retrieval. It controls the sensor data collection process at distance intervals. The microcontroller also interfaces the the GPS, and GSM modules. The software on the microcontroller will determine if water is contaminated based on the sensor data. These are the criteria for pH:

   - The optimal pH is 6.5-8.5 for surface water systems, such as lakes, wetlands, rivers, etc.
   - Normal rainwater is slightly acidic, with a pH of 5-5.6. Most fish die if pH is below 4 or above 12. The optimal pH range for aquatic life is 6.5-8.2.
   - Alert will be sent if measured pH is outside the range of 6.5-8.5.

Requirement	Verification
1. The microcontroller must be able to take receive input from the buttons, pH sensor, GPS, and store information to the SD card, send a text message using the GSM module, and light up LEDs.	1. Using the buttons, set a time interval and set a designated phone number. Run the system on a water solution outside the pH range of 6.5-8.5. Check the LED's. All three should light up individually by the end of the procedure.

2. GPS

The GPS is used for getting location information. This GPS has a horizontal position accuracy of 2.5 meters. This allows us to to know the location where sensor measurements were taken.

Requirement	Verification
1. GPS can register changes in location of at least 10 meters.	1. Take GPS coordinates at an outdoor starting point.. Move GPS module 10 meters away in an arbitrary direction and compare the new coordinates to the old coordinates.

3. GSM

The GSM has SMS message data remote transmission and enables our system to send a text message alert to the user of the water quality monitoring system. This GSM module supports quad GSM/GPRS network. This module requires a SIM card in order to operate.

Requirement	Verification
1. GSM must be able to send text messages to a designated recipient's cellular device. 2. Sends a message of up to 96 characters.	1. Insert SIM card into module and use microcontroller to execute a send SMS alert to a selected number. Check designated recipient's device and verify that the message was received on the specified number. 2. Verify that the message is in the following format (which is 96 characters long): BAD Temperature: *XX.X* C pH level: *XX.X* GPS: *XXX.XXXXXX*, *XXX.XXXXXX* Date: *YYYY-MM-DD* Time: *HH*:*MM*:*SS*

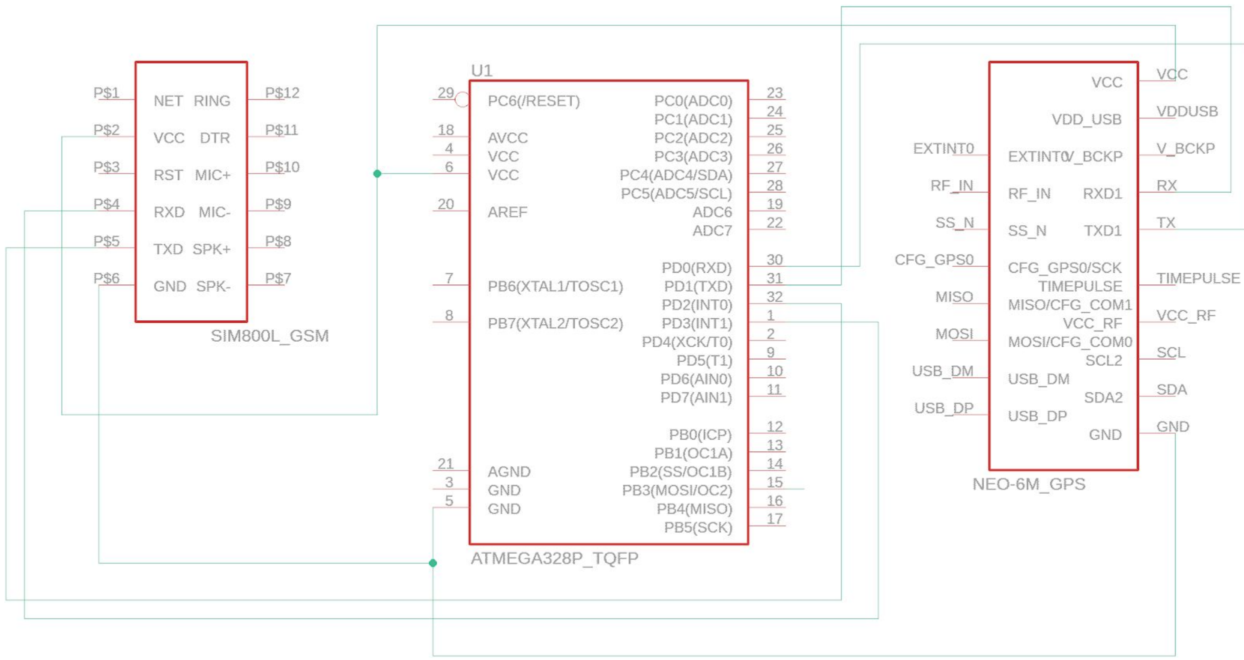

Figure 5: Schematic of Control Unit

User IO Unit

1. **Status LED**
   The purpose of these status LEDs is for state verification, prototyping, and debugging purposes. It gives the user a visual representation of what's going on inside the MCU.
   1. **Data Collection Status**
      This LED indicates the data collection status. Everytime sensor data is read by the microcontroller and successfully logged onto the micro-SD card, this LED turns on.
   2. **Water Quality Status**
      This LED indicates whether poor water conditions or pollution has been detected. If the pH does not fall within the expected range, this LED turns on.
   3. **Alert Status**
      This LED indicates whether an SMS has been sent a notification of poor water conditions. When the microcontroller communicates with the GSM module and an alert has been sent, this LED turns on.

Requirement	Verification
1. LEDs must be visible from 2.5 meters away. 2. The LEDs must turn on to indicate the status of an action, otherwise, it will be off.	1. Verify by looking at LEDs from 2.5 meters away to determine if they are visible. 2. Verify if LEDs are turning on correctly by triggering the following actions or conditions in the microcontroller code for each LED: a. Read sensor and GPS data and save to SD card. b. pH out of desirable range. c. Text message alert successfully sent.

2. Push Buttons

In order to configure the time interval and designated phone number for the GSM to send data to, the user will provide this information via button press. The information will be reflected on the LCD screen. There will be four buttons, each with different functions: *up*, *down*, *set*, *clear/reset*.

1. *Up* - Increase digit
2. *Down* - Decrease digit
3. *Set* - Pressed once a user is done setting a digit
4. *Clear/Reset* - Pressed to reset the entered digits

Requirement	Verification
1. Button input should be registered by the MCU.	1. Press each button 5 times to verify correct functions: a. Up b. Down c. Set d. Clear/Reset 2. Verify by looking for a change in numerical digit on the LCD upon button press.

3. LCD Screen

The LCD screen displays the information the user is sending to the system via keypress. It is a 16x2 LCD which can display 2 lines of characters with 16 characters per line. The microcontroller will send text to display through the I2C protocol.

Upon starting up the system, the LCD menu will ask the user to configure the time interval for data collection and the phone number to send the text message alert to. After configuration, the LCD screen will display the time interval.

Requirement	Verification
1. The LCD screen must be able to handle displaying at least 8 characters on one line for phone number and at least 4 characters on the second line for time interval in units of seconds. 2. The text displayed on the LCD screen must be visible from 2.5 meters away.	1. Enter a phone number (8 characters) and time interval (4 characters). 2. Look at LCD screen and verify if visible 2.5 meters away.

SD card module

The SD card module interfaces with the microcontroller using SPI interface. The sensor data and GPS data can be written to and read from the SD card..

Requirement	Verification
1. The SD card is able to store up to 50MB of data.	1. Create a 50MB file on SD card and verify that the file size is 50Mb.

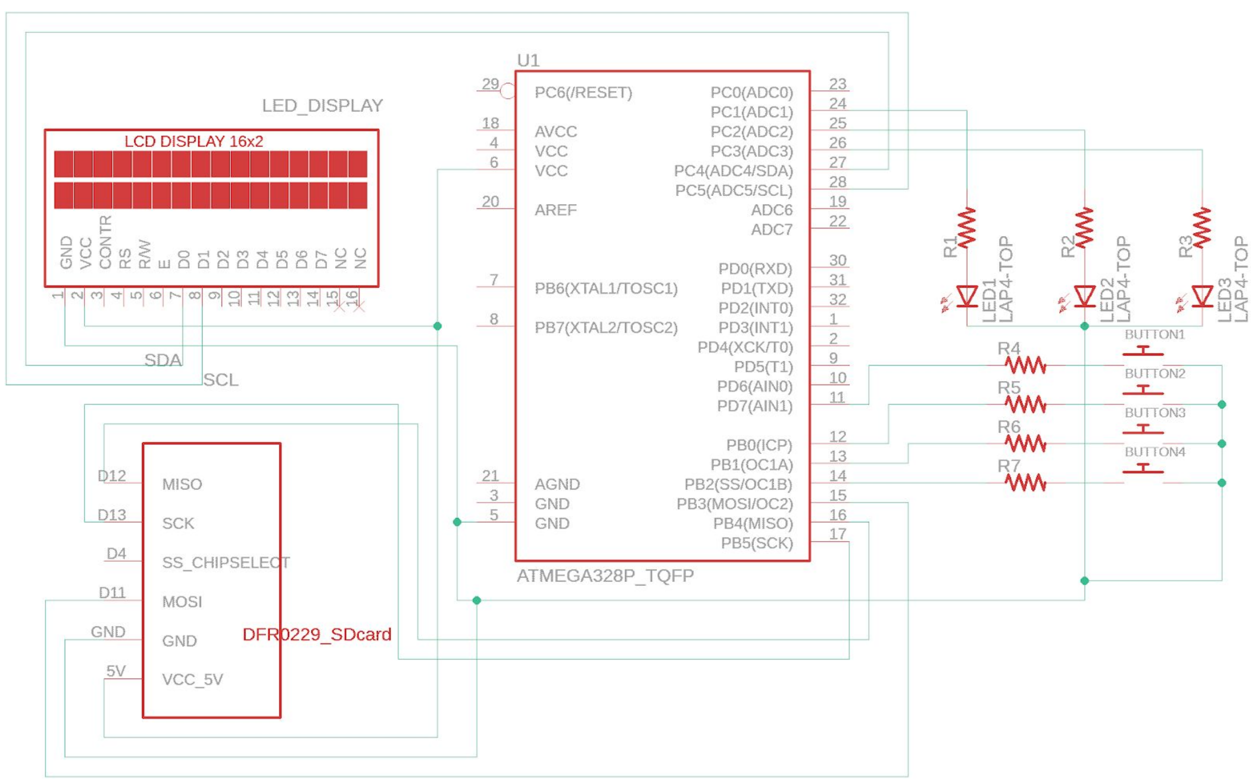

Figure 6: Schematic of User IO Module

2.3 Circuit Calculations

DC-DC Buck Converter

This circuit takes the 12V input and steps it down to 5V to power the microcontroller, sensors, GPS, LCD, and SD card. The 12V input is also stepped down to 3.7V required to power our GSM. We can set the output voltage by selecting appropriate programming resistor values for R1 and R2.

For the buck converters, we choose the LM2596 regulator because it has a current rating of 3A which meets our needs for the GSM module. Also, the output voltage can be programmed. The following calculation can be performed to determine the programming resistors required to get the desired output voltage. According to the datasheet, Resistor R1 can be between 1k and 5kΩ. We choose R1 to be 1kΩ [6].

$$V_{out} = V_{ref}\left(1.0 + \frac{R2}{R1}\right) \quad \text{where } V_{ref} = 1.23\ \text{V}$$

Adjustable Output Calculation

Solving for R2:

$$R2 = R1\left(\frac{V_{out}}{V_{ref}} - 1.0\right)$$

Adjustable Output Calculation

In order to get an output voltage of 5V, Resistor R2 = 3.1kΩ and Resistor R1 = 1kΩ.
In order to get an output voltage of 3.7V, Resistor R3 = 2kΩ and Resistor R4 = 1kΩ.

2.4 Software Flow Chart

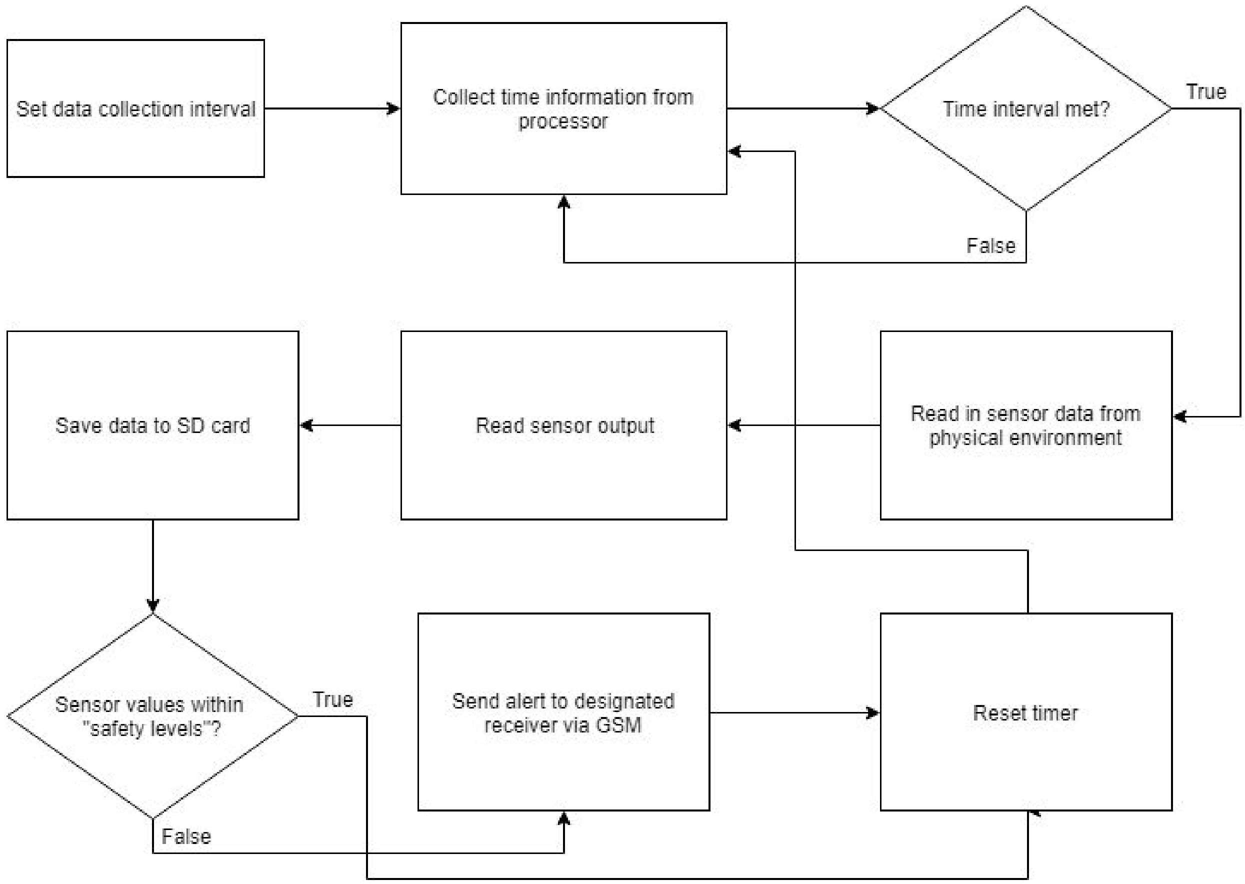

Figure 7: Software Flow Chart

2.5 Tolerance Analysis

The nature of our project involves working with electrical components near water which poses a safety risk. Extra care will need to be taken during testing and development. Also, the bulk of our development and testing will be done in a lab environment. This involves using chemical solutions for testing pH and other water conditions. Due to constraints on time, resources, and geography, we have limited access to real world testing conditions of our system.

Our design is fairly modular, which means that the output of a particular component in a module will be less likely to have an effect on another component in a different module. However, there is one element in particular that could potentially give us skewed data, which is the pH sensor. The goal of our project is to provide accurate data regarding the safety levels of the water, and pH is a significant factor for our method.

Due to the electrochemical characteristics of the sensor, one must first calculate the pH levels at 4 and 7 in order to get accurate readings. Going down or up a pH level corresponds to a rise or drop of roughly 59.16 mV in terms of output.

$$E = E_0 - \frac{RT}{nF} \ln(Q)$$

General Nernst Equation

$$E = E_0' + 0.0591\ pH_{outside}$$

Nernst Equation, pH definition (25 degrees Celsius)

This specific value is derived from the Nernst equation, which describes the reduction potential from a electrochemical reaction. Theoretically, the pH level 7 would correspond to an output of 0 mV.

$$f(x) = 59.16(x - 7),\ x \in [0,\ 14]$$

pH to Millivolt Conversion Formula, derived from the Nernst Equation (25 degrees Celsius)

Acidic readings will provide a positive voltage output and basic readings will provide negative outputs. In addition, the calibration of the pH sensor relies on the temperature of the water. The calibration is most accurate when the water is around 25 degrees Celsius.[4]

ºC	ºF	2	3	4	5	6	pH 7	8	9	10	11	12
5	41	0,30	0,24	0,18	0,12	0,06	0	0,06	0,12	0,18	0,24	0,30
15	59	0,15	0,12	0,09	0,06	0,03	0	0,03	0,06	0,09	0,12	0,15
25	77	0	0	0	0	0	0	0	0	0	0	0
35	95	0,15	0,12	0,09	0,06	0,03	0	0,03	0,06	0,09	0,12	0,15
45	113	0,30	0,24	0,18	0,12	0,06	0	0,06	0,12	0,18	0,24	0,30
55	131	0,45	0,36	0,27	0,18	0,09	0	0,09	0,18	0,27	0,36	0,45
65	149	0,60	0,48	0,36	0,24	0,12	0	0,12	0,24	0,36	0,48	0,60
75	167	0,75	0,60	0,45	0,30	0,15	0	0,15	0,30	0,45	0,60	0,75
85	185	0,90	0,72	0,54	0,36	0,18	0	0,18	0,36	0,54	0,72	0,90

No temperature error

Temperature error < 0.1 pH units

Temperature error > 0.1 but < 0.3 pH units

Temperature error greater than, or equal to 0.3 pH units

pH Temperature Error Table

Figure 8: pH vs. temperature error table

As seen from the chart above, the amount of error increases as the temperature strays from 25 degrees Celsius.

[4] pH Measurement Electrode Basics by Omega: *https://www.omega.com/Green/pdf/pHbasics_REF.pdf*

3. Cost Analysis

3.1 Material Costs

Part	Part Number	Quantity	Unit Price	Subtotal	Manufacturer
Microcontroller	ATmega 328p	1	$2.81	$2.81	Microchip
GPS	NEO-6M	1	$15.99	$15.99	u-blox
Temperature Sensor	DS18B20	1	$9.95	$9.95	Dallas Semiconductor
pH Sensor	SEN0161	1	$29.50	$29.50	DFRobot
GSM	SIM800L	1	$8.99	$8.99	SIMCom
SD Card module	Micro SD storage Board	1	$5.20	$5.20	DFRobot
DC-DC Buck converter	LM2596	2	$6.99	$6.99	On Semiconductor
LCD Screen	1602	1	$9.99	$9.99	LGDehome
Push Buttons	GPTS203211 B	4	$0.74	$2.96	CW Industries
3-pin Screw Terminal Block Connector	10679	2	$0.95	$1.90	4UCON
2-pin Screw Terminal Block Connector	MK3DSN	5	$0.90	$4.50	Phoenix Contact
			Total:	**$98.78**	

3.2 Labor Costs

Worker	Salary (USD/hour)	Weekly Hours	Total Pay
Nelson Lao	$35	15	$525
Sam Hung	$35	15	$525
Junik Kim	$35	15	$525
		Total:	**$2575**

*If we assume the development time is about 8 weeks, the total labor costs is $2575 * 8 = $20,600.*

4. Schedule

Week	Nelson	Sam	Junik
2/18	Research and buy hardware parts	Make detailed pinout schematic of MCU and modules	Write time interval control code
2/25	Prototype and test voltage regulator circuit, and DC-DC buck converter circuit	Build LED circuits and write code	Interface LCD screen and buttons and write code for user input
3/4	Draw schematics for power circuits and layout power board	Interface MCU with temperature sensor, pH sensor	Interface MCU with GSM, GPS
3/11	Finalize Power Circuits Layout **(First Round PCBway Orders due on 14th)** Start schematics and layout for sensor and components board	pH sensor calibration, Interface MCU with SD card, write sensor data to SD card	Verify correct readings on all the sensors, verify interval data collection function debug as necessary
3/18	Spring Break	Spring Break	Spring Break
3/25	Finalize layout for sensors and components board **(Final Round PCBway Orders due on 28th)**	Verify SD Card module is functional and debug as necessary	Verify alert system is functional and debug as necessary
4/1	Mount components on PCB, and test	Mount components on PCB, and test	Mount components on PCB, and test
4/8	Mock demo prep/fix hardware issues	Mock demo prep/fix hardware issues	Mock demo prep/fix hardware issues
4/15	Debug/work on presentation	Debug/work on presentation	Debug/work on presentation
4/22	Debug/finalize presentation/demo	Debug/finalize presentation/demo	Debug/finalize presentation/demo
4/29	Presentation	Presentation	Presentation

5. Ethics and Safety

IEEE Policies, Section 7, Code of Ethics

7.8.1: *To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;*

> To uphold this code of ethics, we are making sure to not use any harmful chemicals or devices that could potentially harm the life in the water. Furthermore, the battery for the sensor system will be quite small, so there is little risk for electrocution of the wildlife in the water.

7.8.9: *To avoid injuring others, their property, reputation, or employment by false or malicious action;*

> There are not too many ways for our device to harm others. As stated above, there is no worry for electrocution of the wildlife in the waters and our sensor system only collects input, so the risk of injuring others or damaging property is highly unlikely. [4]

5.1 Safety

The main safety issue is the use of electricity in the presence of water. To uphold IEEE policy 7.8.1, we must make sure that the equipment we use for our system that will be in contact with water is waterproof and that the parts that are not meant to be around water will be sealed or covered with waterproof materials.

5.2 Ethics

Potential ethical matters involve the inclusion of GPS and GSM in our system. These devices are constantly interacting with sensitive data, such as phone numbers and location data. The phone numbers and location data collected by the system are at risk of falling into third parties, so we have to make sure the data is available only to those working with the system. As for the data that is stored locally on the SD card, it is for the user of the system to handle with discretion.

6. References

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