ECE 445: Design Document
Automatic Pool Monitor and Regulator

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1. Introduction

1.1 Problem:

Every public or residential pool must be monitored for appropriate water quality to be safe for people to use it. To verify the pool water quality, chemical tests must be taken for several factors such as temperature, pH, and chlorine levels. These checks are very important to maintaining a healthy swimming environment for everyone who uses it. According to the CDC, maintaining the water quality of a pool by using chlorine concentration and pH "will help prevent the spread of germs that cause swimming-related illnesses" [4]. Therefore, having a system to do this efficiently will protect pool users.

Currently, a lot of these tests are done by lifeguards in public pools and they require lifeguard attention away from the pool and even sometimes require the pool to be shut down if the levels of the chemicals are too low or too high. Some products on the market help with this issue already, however, they are expensive or are used to test the water quality of the pool rather than automatically adjust the quality to the necessary standard. This new product will automatically adjust the pool to the appropriate levels for each chemical.

1.2 Solution:

Having consistent water quality throughout the day is very important, especially as people continue to use the pool throughout the day. Most products will alert users when the pool quality is not up to standard, but not dispense the product automatically. This product will automatically dispense the appropriate amount of chlorine to the pool and adjust the pH to maintain the water quality of the pool. The user will also be notified when the temperature is not in the correct temperature range, or the chemical dispensers are empty. The user will only be responsible for refilling the dispensers occasionally; the process of testing and mixing chemicals into the pool will be automated.

The product functions by collecting and analyzing the pool water to determine if it is at the appropriate levels. Then it will dispense the necessary chemicals into the pool to help it meet standards. The microcontroller used is the ESP32 microcontroller, and its task is to calculate data from sensors and transmit data wirelessly to and from each other via Bluetooth. We used this microcontroller for its wireless capabilities which is necessary in our product. There are three different sensors: temperature sensor, pH sensor, and TDS (Total Dissolved Solids) sensor. The product will have a storage of chlorine powder, an acidic compound, and a basic compound that it can dispense into the pool water when necessary. When the pH levels are not up to standards, the product can dispense sodium bisulfate (acidic) or sodium bicarbonate (alkaline basic). When the chemical is notified to be dispensed into the pool, a stepper motor will turn for a specified amount of time to release the calculated amount of the chemical required for the pool; this is determined by the number of rotations x weight in each rotation.

1.3 Visual Aid:

There are two separate entities: the dispenser and the sensors. The sensors (waterproof) will make direct contact with the top of the water and the wires connected to the PCB will be protected by a waterproof case. The case will be located slightly outside the pool. On the other side, the dispensers will be located on the ledge of the pool to add the necessary chemicals to the water, and the same case will be slightly further out for the dispenser's wiring and PCB.

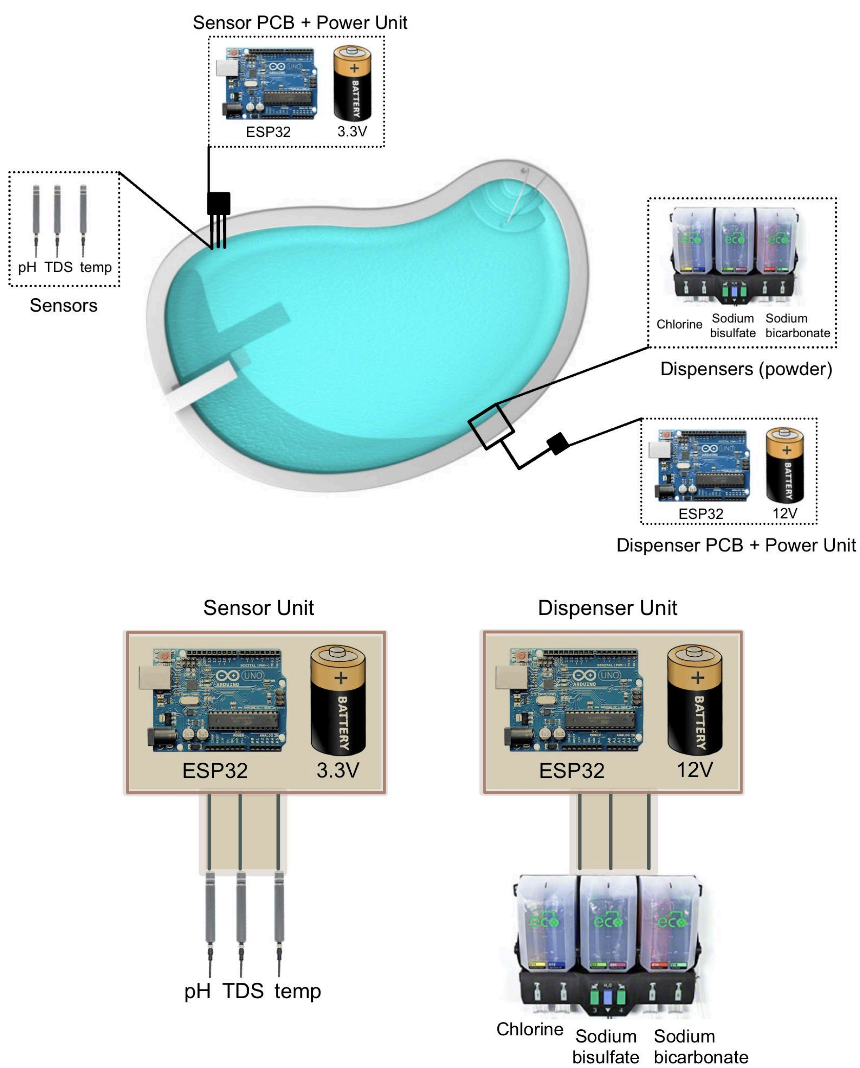

Figure 1: Visual Aid

1.4 High-Level Requirements List:

For successful operations, our project must accomplish the following:

1. The pool sensors must accurately measure and output analog readings for the water quality, with temperature between 78-82 degrees, pH between 7.2 to 7.8, and total dissolved solids level (TDS) levels between 0-1000 ppm. The standard deviation for temperature should be within 1 degree, pH should be within 0.1, and TDS levels should be within 100 ppm.
2. The microcontroller must be able to calculate if readings are in an acceptable range or send a signal to the dispenser unit to release a quantifiable amount of necessary chemicals into the pool otherwise. If the TDS levels do not change from prior measurements, an external alert should be sent to the user. The controller should also display pool temperature, pH, and TDS levels on the LED displays.
3. The dispenser unit will release 0.018 cubic inches of chemicals with a 5% standard deviation ($0.0171 in^3$ to $0.0189 in^3$) using stepper motors according to microcontroller instructions.

2. Design

2.1 Block Diagrams:

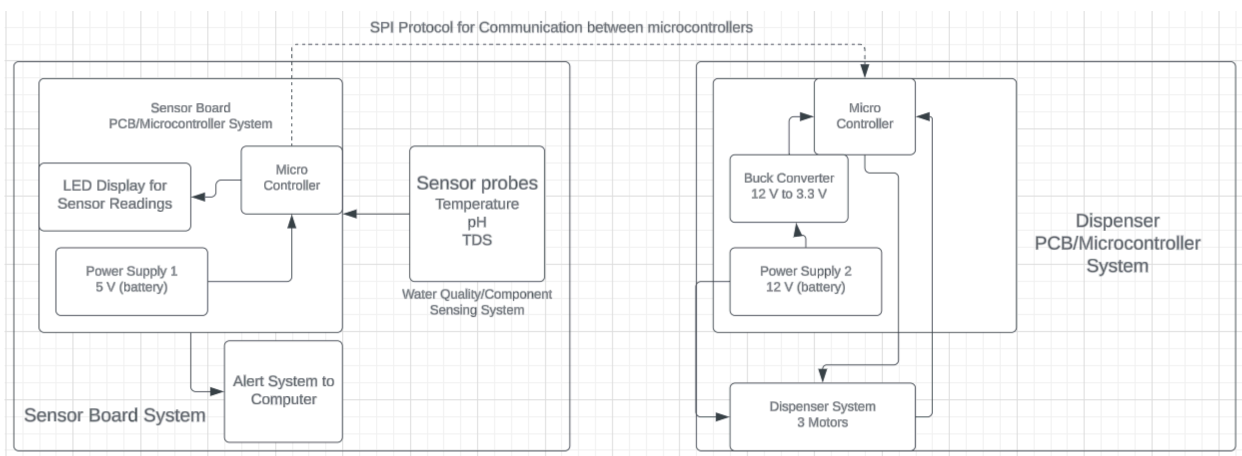

Figure 2: Project Block Diagram

The Sensor PCB system acquires signals from the sensor probes. It calculates if there need to be signals sent to the dispenser PCB system for chemical balancing, or to external alert communication to alert the user of out-of-range measurements. It should also display sensor readings to the LED displays. The Dispenser PCB system should be able to receive signals from the sensor PCB, and control stepper motors to dispense a set amount of chemicals.

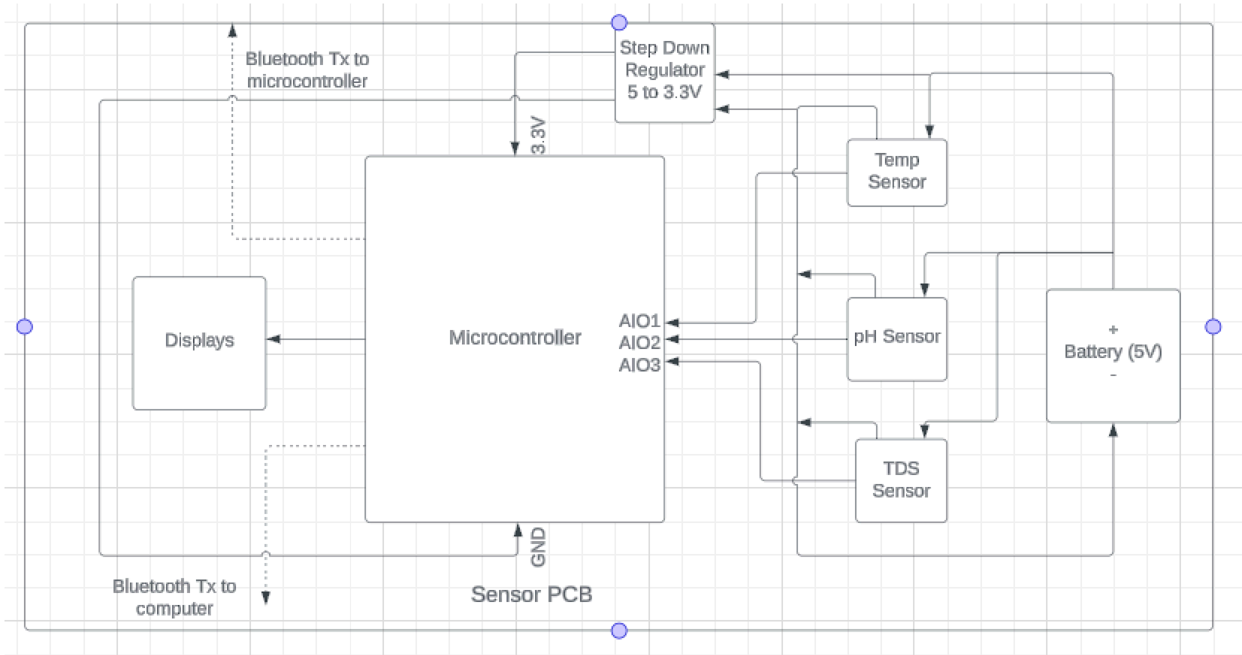

Figure 3: Sensor PCB Block Diagram

The figure above is the Sensor Board PCB. The three sensors all have analog outputs and will each be connected to an analog IO port. The microcontroller will calculate the measurements outlined in high-level requirements and will either display values to the displays, transmit a Bluetooth signal to the dispenser microcontroller via SPI or I2C, or transmit a Bluetooth signal to a computer for an alert. The board will have a 5V battery to power the sensors, and also a step-down regulator to 3.3V to power the microcontroller.

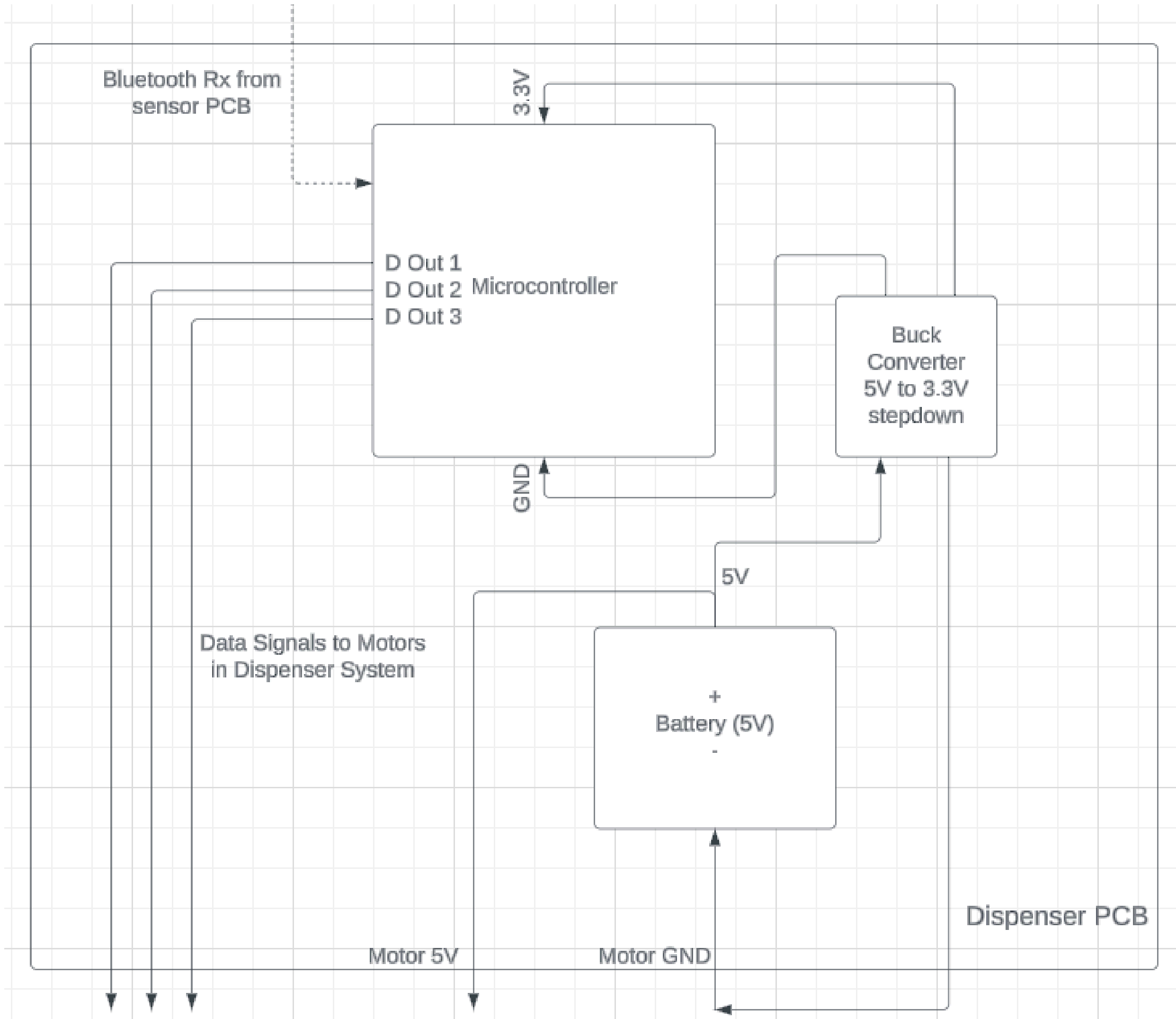

Figure 4: Dispenser PCB Block Diagram

The figure above is the dispenser PCB. The microcontroller receives a Bluetooth signal from the sensor PCB and outputs a signal that controls a motor a certain amount of steps. The PCB also has a separate power system that supplies power to the microcontroller and the motors. The battery is a 5V battery which has the voltage rating to power the motors but exceeds the voltage rating of the microcontroller. The voltage will then need to be stepped down to 3.3V via a step-down voltage regulator to power the microcontroller.

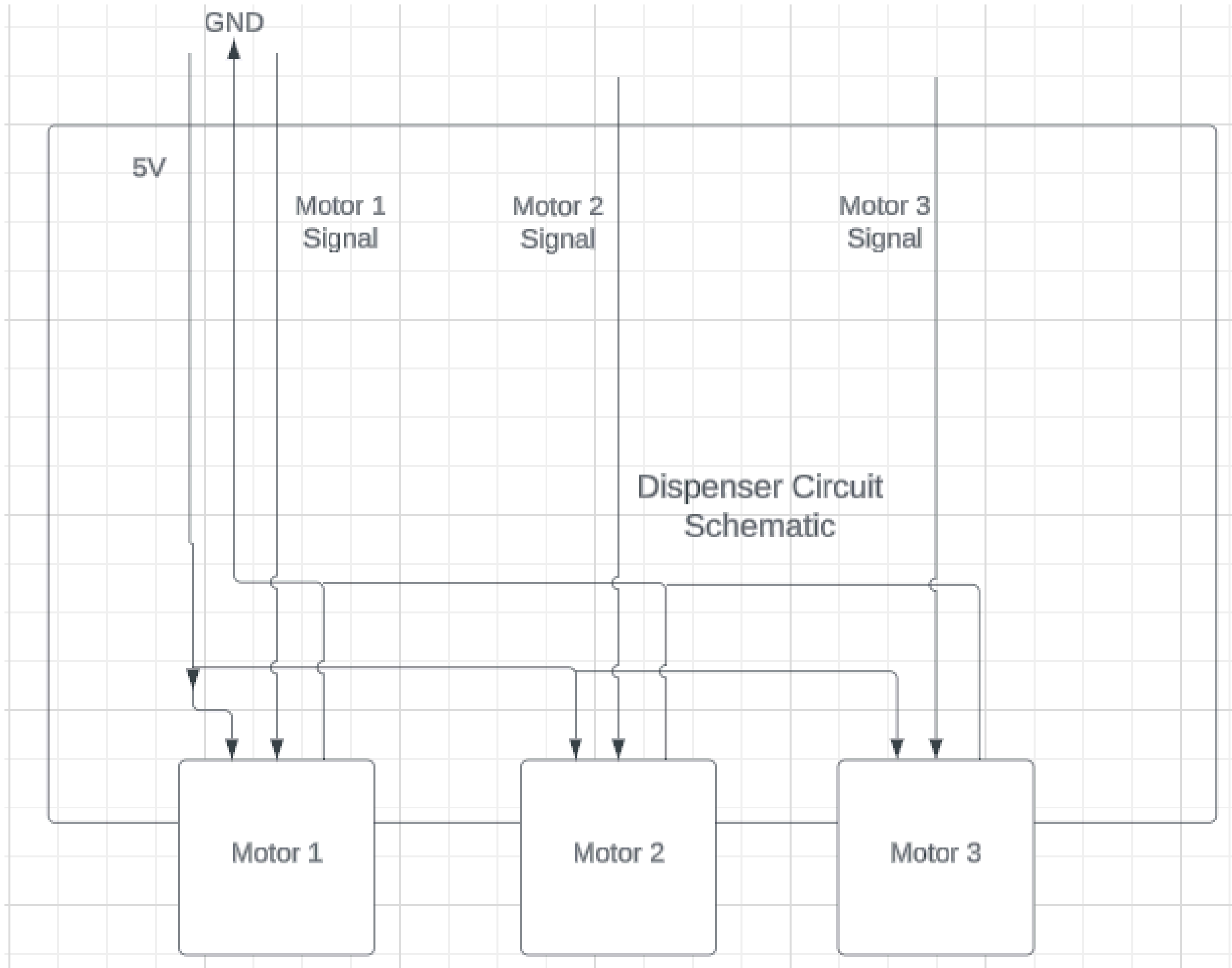

Figure 5: Dispenser Schematic

The figure above is the dispenser circuit schematic. The 5V power is received from the battery in the dispenser PCB, and the motor signal is received from the PCB. Each motor is a stepper motor, which rotates a certain amount of steps per signal. Our design will signal motors to step until one full rotation so that each dispense will be a set amount. We are using this motor because we only need full rotations, so encoding motors are not necessary, and stepper motors are accurate enough to accomplish this task. The dispenser will hold the chemicals in three separate ventilated containers. The containers are stored in a dry, cool environment to keep the chemicals safe for use for up to a year [5].

2.2 Subsystem Overview

Table 1: Water Quality/Component Sensing

Requirements	Verification
The subsystem must be able to acquire sensor data from all sensors and transmit it to the microcontroller.	Verify that different values are being collected when the water environment changes. Accuracy will be determined by the sensor PCB system.

Table 2: Sensor PCB

Requirements	Verification
Must be able to receive and convert analog data from the sensors into the right units for temperature (F), pH (unit), and TDS (ppm) based on the respective datasheets for the sensors.	We can print values to a screen or the display to verify if the data is correct or within range. Also, acquire multiple readings of the same environment to verify that the standard deviation for temperature (±1°F), pH (±0.1), and TDS levels (±100 ppm) are within a valid range.
Must be able to determine if there are any readings out of bounds. Maintain temperature between 78-82 F, pH between 7.2-7.8, and TDS below 1000 ppm.	We can artificially change the environment of the sensors to produce values that are out of range. We can print if values are out of range, or light an LED if any values are out of range.
Must be able to send signals to the dispenser subsystem or computer according to calculations.	Validate with oscilloscope readings, and determine if MOSI data is the one intended.

Table 3: Dispenser PCB/Dispenser Unit

Requirements	Verification
It must be able to receive signals from the microcontroller.	Validate if the data sent from microcontroller Tx is the same as the data received by the dispenser microcontroller. Use an oscilloscope to validate the MISO line

Must be able to move motors to dispense chemicals at the correct amount	Use a weight to determine if the correct grams of powdered chemical are released from the dispenser.
The motor must be able to spin 360 degrees ± 5 degrees to maintain consistent performance for repeated actions. 0.018 cubic inches of chemicals will be dispensed every rotation, with 5% standard deviation $0.018 \pm 0.0009 in^3$.	Spin the motor for multiple rotations and see if motor positioning is significantly off or not. Verify this with a real load from the dispenser with powder on top of the shaft/disk.
Dispenser microcontroller must delay dispensing after a chemical is released to avoid spikes in concentration due to repeated releases before water quality updates.	After a dispense, prevent another dispense for another 5 minutes (~30 minutes in normal pools) or delay sensor reading for the same amount. In normal pools, chemicals will be dispersed uniformly from the built-in pool filter, but for verification/demo, manual dispersion is needed.

Table 4: Power

Requirements	Verification
Must supply 12±0.5V of power to the dispenser unit	Use a multimeter across the ground and power supply to measure the voltage
Must supply 3.3±0.3V of power to the microcontrollers	Use a multimeter across the ground and a power supply to measure the voltage. Include test points on the board to validate trace voltages.

2.3 Tolerance Analysis:

One of the most challenging aspects is making sure that the microcontroller and motors are receiving the rated power and voltage. We could potentially separate the power supply for both aspects, but doing so would increase the external power system complexity. Instead, we opted to step down the 5V voltage for motors to 3.3V for the microcontroller. However, this also poses challenges, since if we use an unregulated or non-isolated power supply, changing the load from the motor might fluctuate power and voltage to the microcontroller which can shut off or overpower it. To combat this, we should use a voltage step-down regulator instead of just a buck converter so that the voltage to the microcontroller is steady. If this does not work, then adding a capacitor between voltage and ground by the microcontroller should be enough to balance voltage ripples.

For the dispenser unit, we have to make sure that the power supply is sufficient for the rest of the circuit. In our design, the microcontroller and 3 motors consume the most power.

However, since the pool will only require a change in pH and chlorine, there will only ever be two motors running at once (sodium bisulfate or sodium bicarbonate and chlorine).

3W + 2(5*1.5) = 18W

Therefore, this is the amount of power necessary for the system to run smoothly.

3. Cost and Schedule

3.1 Cost Analysis:

The total cost for parts can be seen in the table below and will come out to $145.23. With an estimated salary of $45 per hour, and 80 hours worked and with a factor of 2.5, it will cost around $9000 per member of the team. So for three team members, the cost of machine shop labor, and the cost of all parts the total cost of the project comes out to be $27895.30.

Labor
Arnold: $45 avg salary computer engineer x (2.5 overhead factor) x (8 weeks * 10 hrs) = $9,000
Raymond: $45 x 2.5 x 80 = $9,000
Swarna: $45 x 2.5 x 80 = $9,000
Machine shop labor hours: $30 x 25 (hours) = $750

Parts

Part #	Description	Manufacturer	Quantity	Cost	Extra Info
1	Chlorine	HTH	1	$5.55	
2	Sodium Bisulfate	Clorox	1	$9.12	
3	Sodium Bicarbonate	Clorox	1	$10.94	
4	Liquid holders	XINGLIAN	1	$7.99	
5	Temperature Sensor	Honeywell	1	N/A	From 445 Lab
6	TDS Sensor	CQRobot	1	$11.99	

7	pH Sensor	Teyleten Robot	1	$19.88	Or Dr. Qi (UIUC)
9	5V Stepper Motor	ECE Supply Shop	3	$21.66	Link 560131851 290-028
11	Power Supply 5v	Arkare	2	$7.59	
13	Microcontroller	Mouser	6	$23.40	Link Second link
14	Voltage Step down	Digikey	3	3 x 3.87	https://www.digikey.com/en/models/13168317
Total Cost of Parts:				**$145.23**	

Table 5: List of Parts

Sum of Costs
(3 x $9000) + $750 + $145.23 = $27895.30

3.2 Schedule:

	Arnold	Swarna	Raymond
2/18	Buy Sensors/Motors by the end of the week Complete parts list for all components		
2/25	Start Dispenser PCB design, submit for audit this week or next week	Machine Shop Request for Dispenser Assembly Help with dispenser PCB	Start Sensor PCB Design and submit for audit
3/3 (first round audit)	Begin coding for dispenser board microcontroller based on documentation	Begin coding for Sensor board microcontroller based on documentation	Begin soldering onto whichever board comes first
	List errors in boards to improve for next round of audit		
3/10 (spring break)			
3/17	Test Sensor board PCB, try to get sensor readings If it does not work, debug and figure out errors for next round audits		
3/24	Test, Order, Debug, Leeway week		
3/31	Fully finish functionality of Sensor Board PCB		

4/7	Ensure all subsystems are working correctly and can communicate
4/14	Mock Demo Week

Table 6: Schedule

4. Discussion of Ethics and Safety:

While our project provides several advantages to the maintenance of a pool it is important to address some of the ethical and safety questions.

4.1 Safety

The main safety concerns center around improper chemical handling, potential excess chemicals, accessibility of chemicals, and cybersecurity vulnerabilities. Leaks, spills, malfunctions, or calibration errors could expose users, pets, and the environment to harmful chemicals or create dangerous pH imbalances. Easy access to these chemicals poses additional risks. While handling chemicals, gloves or some form of skin protection should be used as skin contact can be mildly harmful [2]. There can be a discussion about safety issues with dispensing chemicals into the pool where people are swimming. If there is a technical malfunction and too many chemicals are put into the pool, it could be harmful [2]. Usage of the product while people are in the pool may have some security risk. Usage of expired chemicals is also something that may need to be considered. For this product, chemicals should be replaced every year [6]. Some safety measures to counteract this are to dispense chemicals evenly across multiple locations in the pool and have the dispenser directly inaccessible to other people.

There are also safety concerns about using electricity around water, especially around pools where water is dynamic and can splash around. To combat this concern, we should protect all circuitry with water-resistant casing and make sure there are no exposed wires or circuits to the environment. We can also practice IEEE's powering and grounding electronics [1]. Any moving parts associated with the motors should also be encased to prevent injury.

4.2 Ethics

Ethically, transparency about chemicals used, potential risks, and safety measures is crucial. The environmental impact of the chemicals and their potential discharge raises sustainability concerns. Additionally, the cost of such devices might create an access barrier, furthering existing inequalities. Data privacy becomes an issue if the device collects usage or chemical-level data. However, our product is not storing private information, so it is not a major concern.

Beyond these concerns, the device's reliability, maintenance needs, and user training are vital. Fail-safe mechanisms and regular maintenance are essential for safe operation. Pool owners need proper training on chemical handling, potential risks, and emergency procedures. Finally, adherence to relevant safety and environmental regulations is critical.

5. Citations:

[1] "IEEE code of Ethics," IEEE Code of Ethics, https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Feb. 20, 2024).

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[3] "Sodium bisulfate," Safety Data Sheet, https://beta-static.fishersci.com/content/dam/fishersci/en_US/documents/programs/education/regulatory-documents/sds/chemicals/chemicals-s/S25535A.pdf (accessed Feb. 20, 2024).

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[5] "Swimming after Adding Pool Chemicals." *In The Swim Pool Supplies & Equipment*, In The Swim, intheswim.com/eguides/swimming-after-adding-pool-chemicals.html#:~:text=You%20may%20have%20asked%20at,wait%20between%20adding%20pool%20chemicals%3F%22&text=It%20is%20recommended%20to%20wait,after%20adding%20water%20balancing%20chemicals. Accessed 20 Mar. 2024.

[6] Toedter, Alicia. "How to Store Pool Chemicals the Right Way." *Pool Supplies, Service & Repair*, Leslie's, Inc., 20 July 2022, lesliespool.com/blog/how-to-store-pool-chemicals-the-right-way.html.