Water Quality Measurement at Dana Point

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Abstract—

The goal of this project was to determine water quality using a variety of sensors interfaced with electrical circuits. Experimentation with a pH sensor, a pressure sensor, and a temperature sensor during lab periods eventually allowed data collection at different depths at Dana Point. These sensors, during data collection, were attached to an autonomous underwater vehicle (AUV), within which a Teensy using Arduino IDE controlled the motors attached to its frame. In the experiment, the AUV was given instructions to dive to waypoints where it would shut off its motors, record data, and return to the surface. The AUV stopped at waypoints of 2, 3, and 4 meters, indicating a successful performance of the pressure sensor and the implemented proportional control of the motors. Previous modeling and testing indicated that the temperature and pH sensors were functional and accurate in laboratory environments. The temperature read around 18 ± 2°C when not submerged, matching ground truth values, but the pH sensor was not able to record any accurate data. The malfunction of these sensors during deployment, however, caused there to be no accurate reading of the pH or temperature vs. depth from Dana Point. This provided no data on the overall water quality, meaning no significant conclusions could be drawn from the experiment.

1 Introduction

The goal of this project was to measure the pH and temperature versus depth at Dana Point to reach conclusions about overall water quality. This information is important in keeping people and marine life safe, as toxic water is unhealthy and should be avoided. The project required the use of an AUV to safely record information in the field. In accordance with the goals of the project, it was decided to use a diving robot that could take measurements at different depths to compare results. The robot was designed so that it could measure the depth in order to control its location in the water. The robot was also designed to measure the temperature and pH level of the water.

When seawater increases in temperature, it can cause problems for water quality and negatively impact marine life. According to the Fondriest Environmental Learning Center, increasing water temperature can increase the toxicity of certain compounds, as well as the behavioral choices and metabolic rates of aquatic organisms [1]. Measuring temperature changes could influence human intervention and protect marine species. Changes in ocean pH levels can also have negative impacts on marine life. A report from the National Oceanic and Atmospheric Administration presents many such implications, such as the inability of shelled organisms to maintain and grow shells and the decreased ability of some organisms

to detect predators [2]. Detecting variance in pH levels could provide evidence to support regulations on the pollution and carbon emissions driving these changes.

2 Sensor Design

The goals of the project required the measurement of the pressure, temperature, and pH at each point along the robot's path. Each of the three circuits were designed to receive the raw output from a sensor and shape it into a voltage output legible by the Teensy, which can report voltages from 0 to 3.3V. The general process for this was to model outputs, and then use operational amplifiers to transform the output signal. A 5V input power was used to power each op amp, sensor, and offset.

2.1 Pressure

The first sensor integrated into the robot was the pressure sensor. This sensor allowed for proportional control, allowing the robot to autonomously control its depth, regardless of disturbances from the current of the water. The MPX5700 pressure sensor was used to measure this, as it just needed a simple circuit that had been taught in preceding labs. It had a linear response, which made it easy to calibrate using just a few points.

The range of depths the robot would be subject to was 0 to 5 meters. In sea water, this meant the pressures would range from 101.3kPa to approximately 151.5 kPa, using a common sea water density of 1025 $\frac{kg}{m^3}$. At these pressures, the sensor was expected to produce voltages according to the equation on page 4 of the MPX5700 data sheet [3]. These were found to be 0.85V on the surface and 1.17V at five meters. Using an operational amplifier circuit, these voltages had to shift and scale in the range of 0.3 to 3 V according

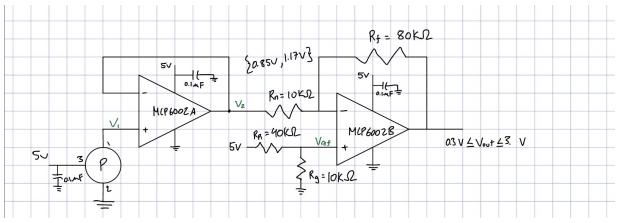


Figure 1: Schematic of Pressure Sensor Circuit

to Equation (1), the governing equation for an inverted offset amplifier, where V_2 represents the expected input voltage range, as shown in Figure 1.

$$V_{\text{out}} = 5V\left(\frac{R_g}{R_g + R_{p1}}\right)\left(1 + \frac{R_f}{R_n}\right) - \left(\frac{R_f}{R_n}\right)V_2 \tag{1}$$

Equation 1 was used with the desired voltage range to determine the necessary resistor values for the circuit. The final circuit included two op-amp stages – a unity gain amplifier to clean noise, and an inverted offset amplifier with a gain of 8 and offset of 1V – which gave the desired range of output voltages.

To calibrate, a pressure tube was held at different depths while connected to the sensor and the output voltage was recorded. The plot of voltage versus depth is shown in Figure 2. The datasheet reports a typical 10% to 90% response time of one millisecond [3], indicating that sampling at 10 Hz was sufficient to capture changes in depth. The pressure sensor has a low output impedance, meaning the unity gain stage of the circuit was not completely necessary, but still helped with noise control.

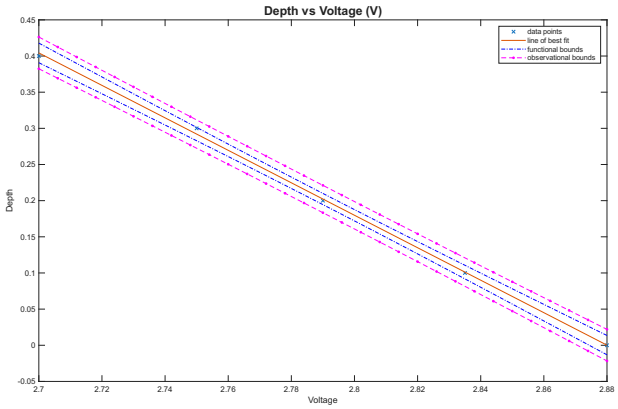


Figure 2: Depth vs. Voltage

2.2 Temperature

The next sensor integrated into the robot was a thermistor, which has different resistances at different temperatures. Finding the resistance at each sample based on the output voltage allowed for the comparison of temperature vs. depth at Dana Point.

According to the Scripps Institute of Oceanography, ocean surface temperatures range from about 17 to 20 °C [4]. To account for this, the center of the range of outputs was set to be 16°C. Intuitively, temperature will decrease as depth increases, so it was good to have more room below the 18°C to account for the vertical drop of the AUV.

Three temperature sensors were viable options for this task, including the thermistor, a linear temperature sensor, and a thermocouple. The thermistor was the best compromise between ease of use, accuracy, and short response time according to the lecture videos from the first half of the semester [5]. In this case a 47 kΩ thermistor was used, which has a resistance of 96.59 kΩ at 10 °C and 53.96 kΩ at 22 °C.

The thermistor circuit was designed with a unity gain buffer followed by an inverted offset amplifier. The first op-amp had a positive input from a voltage divider composed of the thermistor and a 100 kΩ resistor, according to Equation (2). This passed through a unity gain amplifier and then the inverted offset amplifier, which provided a gain of 3.3 and offset of 2.62 V to scale the output into the Teensy's range. The circuit is shown in Figure 3. The gain, offset, and therefore resistance values at this stage were determined using Equation (1) and the resistance values at 10 and 22°C, as this was a reasonable temperature range. Experimentation showed that the circuit railed at 25.5°C, which would never occur in ocean water.

$$V_{out} = 5V \times \frac{100k}{100k + R_{thermistor}} \qquad (2)$$

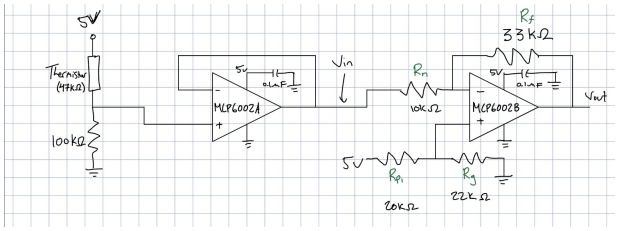


Figure 3: Thermistor Sensor Circuit Schematic

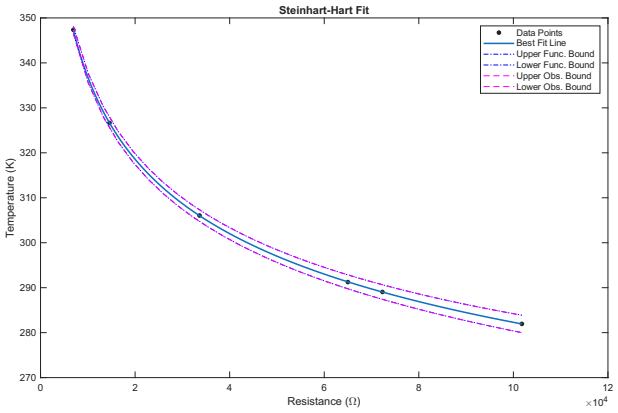


Figure 4: Steinhart-Hart Fit for Thermistor Calibration

Thermistors do not have a linear fit, but rather a Steinhart–Hart fit [6]. To make

the calibration curve, shown in Figure 4, code from a previous module was used to determine the Steinhart–Hart coefficients from data taken of temperature versus resistance of the thermistor using the equation in the E80 lecture video [6]. Using that, temperature could be graphed against resistance, as shown in Figure 4. The thermistor in liquid had a thermal time constant of four seconds [7], which is compatible with the 10 Hz sampling frequency. The thermistor has low output impedance, meaning the unity gain op amp stage was not crucial, but helped with noise control.

2.3 pH

The final sensor used was a pH sensor, which used a probe to create a voltage difference between two electrodes. The pH sensor probe was purchased from Amazon and provided by members of the E80 teaching team.

For this sensor, according to the Texas Instruments pH Electrode data sheet, a pH of 7 corresponds to 0 V and 8 to around -100 mV [8]. It also showed that in the expected temperature range the entire pH scale would fit between -0.5 V and 0.5 V. This information was used to map the inputs to the 0.3 – 3 V Teensy range.

A unity gain and non-inverting offset amplifier were used to map the voltages. The first stage took the 5 V power input and provided around a 1 V output to the reference electrode of the pH sensor. This shifted the range of outputs by +1 V, changing the expected range to 0.5 – 1.5 V. The second op amp stage was used to provide a gain and an offset to scale the outputs. The pH sensor schematic is shown in Figure 5, and the governing equation for the MCP6002B amplifier is shown in Equation (3).

$$V_{out} = \left(1 + \frac{R_f}{R_{g2}}\right) V_{in} - \left(\frac{R_f}{R_{p2}}\right) (5) \qquad (3)$$

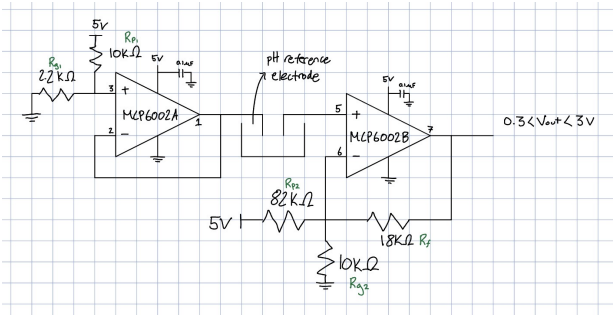


Figure 5: pH Sensor Circuit Schematic

To calibrate the sensor, six buffer solutions were prepared, two each of a pH of 4, 7, and 10. The sensor was dipped in one solution to rinse, and then dipped into the matching solution, where the output voltage of the circuit was measured using an oscilloscope. The resulting calibration curve is shown in Figure 6. The pH sensor had a relatively slow response time, but as the pH was not expected to change with depth, the sample rate did not need to be adjusted. It is also important to note that the pH probe has a very high source impedance, meaning that it should only be measured by a high impedance measuring device. To help, a Faraday cage was created to decrease the noise this would cause to the output signal. Proposed changes to this circuit are discussed further on in the report.

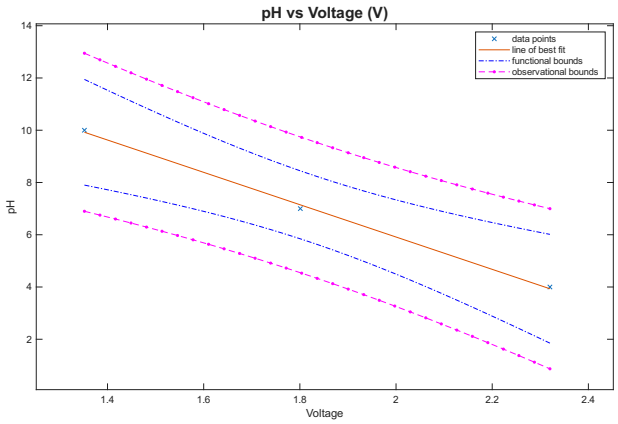


Figure 6: pH Sensor Calibration Curve

3 Robot Design

To implement all of the sensors, changes were made to the waterproof box used to store the core hardware for the robot. This was done to protect the parts of sensors that were not waterproof, while leaving parts that needed to be in the water exposed. To make this possible, holes were drilled into the waterproof box. Wires connecting the sensors to the motherboard were epoxied inside plastic penetrating bolts and screwed into the holes, using rubber washers to seal and complete the waterproofing.

The inside of the box during trials contained every non-waterproof essential part of the robot. First, inside was the motherboard/protoboard stack, containing each of the circuits, each of the inputs, and the SD card reading the outputs. This was powered by the battery source, which provided around 12 V to the board, although regulators were used to provide only 5 V. The pressure sensor was attached to the protoboard and to the pressure tube, which ran outside of the box. This was similar to the temperature circuit, which ran from the thermistor on the robot frame to the input wires connected inside the box to the protoboard. The pH sensor was half inside and half outside the box, and was connected inside to a cut BNC cable which ran inside the pH circuit's Faraday cage and connected to the breadboard. Finally, the motor wires ran from inside the box connected to the motherboard to the motors attached to the robot frame. This can be seen in Figure 7.

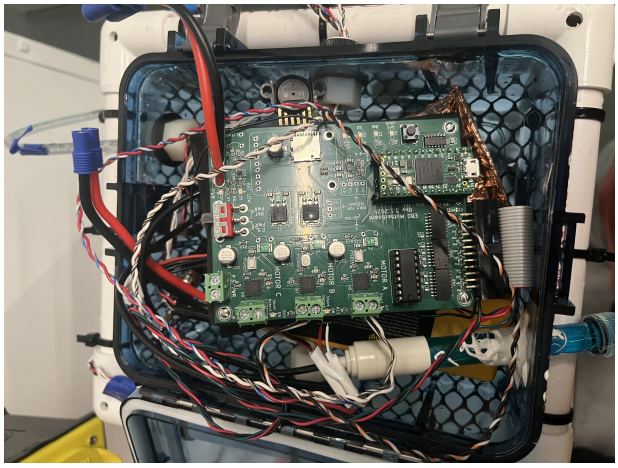


Figure 7: Waterproof Box and Contents

Outside the box, the frame of the robot held the thermistor, pressure tube, both motors, and ballast materials, which can all be seen in Figure 8. Ballast materials were used to offset the buoyancy from the air inside the box and the PVC pipe. To determine the exact ballast weight, materials were added until the robot was neutrally buoyant in the water at Dana Point. Keeping the ballast at the bottom of the AUV, nearly two feet away from the air in the box, kept the center of buoyancy above the center of mass. This allowed the robot to fight against forces that could tip it and stay vertical.

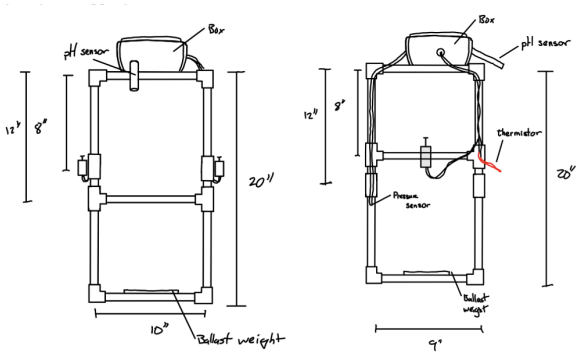


Figure 8: Mechanical Drawings of AUV

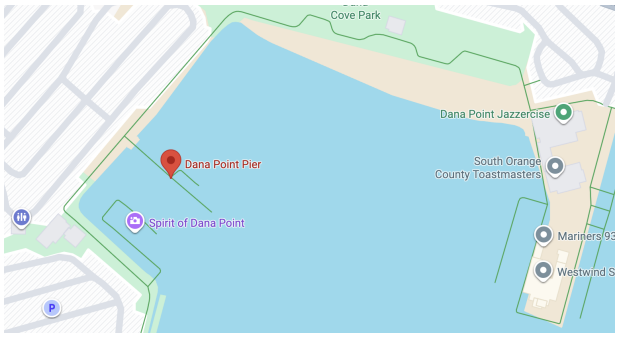


Figure 9: Photo of Deployment Location Map

4 Deployment Details

On Saturday, April 25, 2026, the robot was deployed for multiple trials at Dana Point. In each trial, the way points were set to 2, 3, and 4 meters, where the motors were designed to completely stop in order to minimize noise in the output voltages. To ensure the safety of the hardware, the box was ensured to be completely waterproofed and secured shut. As a precautionary measure to protect against failed motors, a tether was tied to the top of the robot to direct its position or rescue it if it sank. The final safety measure was to secure the new ballast firmly to the robot, ensuring ballast materials did not end up in the water.

Figure 9 shows the location of deployment within Dana Point Pier. As the water density was different than during previous practice deployments in the HMC tank room and pHake Lake, the ballast weight was recalculated and the pressure sensor was re-calibrated on site.

Ground truth measurements from Lynn Kim [9] and from using a thermometer at the surface showed that the actual pH was around 7.5, and the temperature was around 18 °C. These were used alongside the calibration curves of each of the sensors to predict sensor performance. Code had already been implemented within Matlab to calculate the physical quantities from the received voltages, so the final graphical data after a trial was expected to match reasonably with the ground truth measurements.

To begin a trial, the Arduino code to control the motors was uploaded to the Teensy. After this, with the battery plugged into the motherboard and the SD card ready to record data, the box was closed and the robot was placed in the water. It was expected to travel to the way points using PID control, and then return to the surface. To retrieve the data, the robot was removed from the water, dried off, and the SD card was removed. The trial data was then put into Matlab to process. There, the depth, temperature, and pH were graphed against sample number to provide a visual representation of the data.

5 Results

The results from the most successful trial are shown below in Figures 10–12.

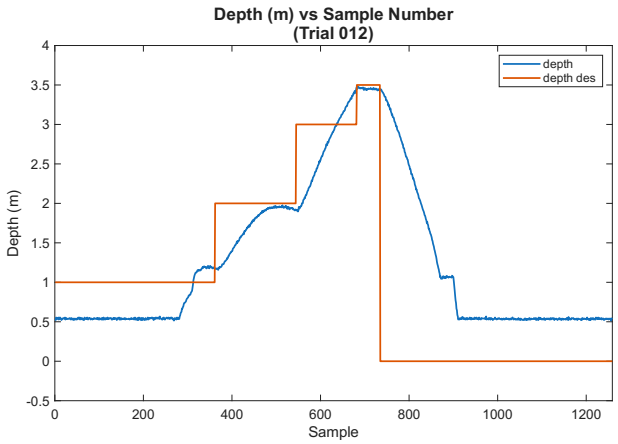


Figure 10: Plot of Depth vs Sample Number

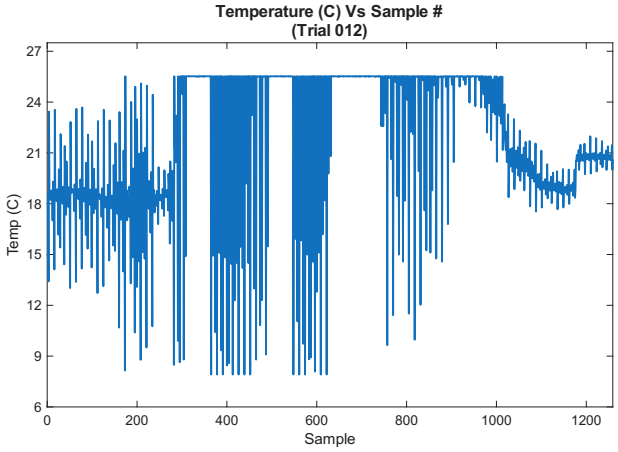


Figure 11: Plot of Temperature vs Sample Number

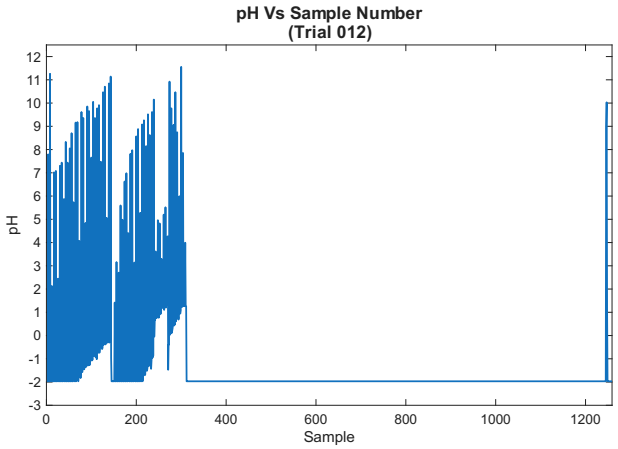


Figure 12: Plot of pH vs Sample Number

Figure 10 shows that the proportional control of the robot's path and depth was extremely successful. At each of the desired depths, the robot exhibited a slightly underdamped second-order response in which it quickly approached each way point and slowed down as it grew closer in order to minimize overshoot. This indicated that the pressure sensor worked, and the proportional control was able to communicate with the pressure output pin to control the motor speed.

In Figure 11, the graph depiction shows that the temperature sensor was extremely noisy while the motors were on, and hit the positive rail when the motors were off to collect data. However, while the robot was not yet in the water the readings were around 18 ± 2°C, which was accurate compared to the ground truth measurement. Through some specific testing between trials, it was determined that the temperature sensor was shorting due to cuts in the wire that could not be sealed given the materials accessible at Dana Point. Specifically, it was determined that the sensor was accurate when the thermistor was in the water before the rest of the wires were submerged. Even with large amounts of tape and heat shrink, water was able to get in, shorting the circuit and causing the rail out seen by the peak measurements around 25.5 °C.

In Figure 12, it is clear that the pH sensor rails out as soon as the robot is fully submerged. With the ground truth pH measurements between 7 and 8, it was concluded that the sensor failed to work completely. This behavior was noticed in the days leading up to deployment. The issue was not directly with the circuit, though, as measuring from the SD card, voltmeter, or oscilloscope, the pH sensor was able to measure in solutions of 4, 7, and 10 pH. It was determined after returning from Dana Point that the reason for the failure

was mainly the calibration of the sensor in low salinity solutions without realizing the impact that the chemical environment could have on the readings [9]. With that being said, this should have led to inaccuracies in the measurement, but not a complete rail out. Another reason for the malfunction could have been the very large measurement impedance of the pH probe, which could be addressed in future studies, as this may have led to the drift and leakage of voltages.

6 Conclusion

This project was completed in order to determine the safety and quality of seawater at Dana Point. The AUV, prior to deployments at Dana Point, was able to successfully integrate sensors with electrical circuits to measure different pressures, pH levels, and temperatures. Although data collection at Dana Point did not match the modeled predictions, there were many positive takeaways and learning opportunities.

The project produced a working AUV that was able to travel along a predetermined path purely based on the readings from the pressure pin on the motherboard. This demonstrated an accurate understanding of circuit integration and proportional control, and showed how each could be used in the field. Each of the other sensors used on the robot was fully working out of the water at one time or another throughout the project, meaning that simple changes to the circuit topography and hardware connections could have provided accurate data from each of the trials.

Much was learned from the unsuccessful sensors as well. First, thinking ahead to waterproofing of sensors before deployment would be a crucial step in future work. Although attempts were made to fix and protect the wires, better practice would have been to replace them right away after finding issues. Additionally, the hours spent on troubleshooting the faulty pH sensor showed the importance of quick preparation. If there had been more time after identifying the issue, arrangements could have been made to change the circuits or replace the sensor. The limited time allowed only for small troubleshooting, hoping to find a quick fix to a larger issue.

If the AUV was able to deploy again next week, the main goal would be to reconnect the temperature sensor using different wires to protect against shorting. Getting the thermistor circuit to work would provide some information about the health of the water. As stated, the pH sensor was functional to the point it could accurately measure pH buffer solutions of 4, 7, and 10, and even small cups of liquid from larger tanks. The impedance issue previously mentioned could be addressed by feeding the output of the sensor through another unity gain buffer with a high impedance of its own to clean the signal after it has been released from the probe. With more time to troubleshoot, finding other causes of the pH sensor railing out in sea water and in large bodies of water in general would make future deployments more successful. Future work should aim to get these two sensors up and running to guarantee accurate quantitative results that could provide insight into water health.

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