Examining Effects of Temperature and Depth on Green Matter in the Ocean

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Abstract— **As global warming increases ocean temperatures, the changes in survivable habitat for small organisms at the bottom of the food chain like phytoplankton can mean drastic changes for whole ecosystems. Understanding where these organisms congregate and how that is changing is essential to predicting the distribution patterns of those that depend on these organisms for food. Thus, this paper aims to explore the relationship between concentration of algae, ocean temperature, and ocean depth. The experiment deployed an autonomous underwater vehicle (AUV) up to 2.5 meters deep at Dana Point with sensors to measure temperature, depth, and green LED turbidity. The initial hypothesis was that the concentration of algae would decrease as depth increases and temperature decreases. However, the results of the experimental data depict an increasing amount of green matter as depth increases, likely due to green sediment other than algae from the bay floor. It was tentatively concluded that the concentration of green matter (mostly algae) increases with increasing depths with a positive linear relationship between depth and voltage of slope 0.912 for depths in the range of 0 meters to 2 meters from the surface. The temperature stayed roughly constant across 0 meters to 2.5 meters in depth at an average temperature of 15.75ºC in this range. Solidifying this conclusion would require further data collection at a larger range of depths and data noise reduction due to the interference in the temperature data, the malfunction of the turbidity transmittance reading, and the inability to produce repeated results.**

I. Introduction

Climate change is turning the deep-blue sea a touch greener which reflects changes in the communities of phytoplankton that reside in the ocean. These changes impact all the marine life that feed on plankton and the uptake in ocean carbon sequestration [1]. Studying the dispersion of phytoplankton in the ocean gives insight to potential behavioral changes for the organisms who rely on algae as a food source. Thus, this project intends to investigate the change in concentration of green matter (assumed to be majority algae) at different depths and temperatures.

In order to measure the amount of algae in a water sample, the AUV was fitted with a turbidity sensor. Turbidity is the measure of relative clarity of a liquid or in other words how cloudy a liquid is [2]. The more turbid a solution, the less light can be transmitted through the liquid and the more light is scattered by the liquid. To focus on green algae in the ocean, the study measured green light scatter with a green LED turbidity meter rather than the standard IR LED turbidity meter. Comparing ocean depth and temperature to the ratio of 90º scattered green light to 180º transmitted green light will determine whether the concentration of green matter increases or decreases below the surface. Ocean depth was measured with a pressure sensor and was used as a waypoint indicator for the AUV to move autonomously.

The remainder of this report will present the methods and analysis used to design the sensors and the mechanical build of the AUV and to deploy the AUV for data collection. The methods section will describe each circuit's calibration and schematic design alongside the physical AUV construction. Then, the results section will explain the filtering and excluding of turbidity transmission data then present graphs demonstrating the ocean depth, temperature, and 90º scattered green light measurements. The report will conclude by addressing potential improvements for future iterations and the limits of the existing experiments.

II. Sensor Design

A. Theory of Input Quantity

With an interest in exploring the transmittance of light underwater, Dana Point expected temperature and turbidity levels were used. The temperature range expected at Dana Point was from 10°C to 20°C [3]. With this range in mind, turbidity also has a relationship to depth. As light transmittance occurs closer to the ocean surface, turbidity of the water is expected to be greater as well [4]. Therefore, the farther in depth, the less turbid the water will be. Although a green LED was used for turbidity, this relationship would still apply.

B. Sensor Selection

In order to carry out investigations of algae distribution in seawater, three sensors were chosen. These sensors were temperature, pressure sensor, and turbidity.

The Murata NXFT15WB473FA2B150 thermistor was chosen to measure temperature because of its relatively quick response time and simple design. From the datasheet, it was determined to have an accuracy of ±0.1°C [5]. Aside from accuracy, the thermistor also provided a large range in which temperatures can be measured from (-100 to 450°C)- where temperatures of Dana point were likely to be within this range [3].

To create a relationship directly between depth and temperature, the MPX5700 sensor served two purposes. One was to give the AUV the ability to autonomously travel to various depths using water pressure over time to record depth. The output range of the MPX5700 is 0.2 to 4.7V [6]. This encompasses the Teensy range so it will be convenient to implement this active component as the pressure sensor With the measured values, the team could better understand the concentration of algae at different ranges of depth.

Turbidity was the most effective way of determining green matter concentration in ocean bay water because it measures the amount of dispelled particles in the water. It can achieve this by finding the ratio of 90 degree reflected light to transmitted light. This ratio would increase as more particles entered the tested solution. In order to create a turbidity sensor, one Green LED and two BPW46 photodiodes that were sensitive to green light. The assumption was that green matter would absorb all wavelengths of visible light except green and non green matter would absorb green light. Using a green LED allowed us to filter the green particles out from other suspended particles in the solution. With these measurements, further conclusions about temperature changes and algae growth can be examined.

C. Pressure Sensor Circuit Design

The most important sensor for this sensor network is the pressure sensor. This is because the depth is the independent variable of each of the other two sensors and in order for the AUV to navigate to desired depths underwater it needs to know its own current depth.

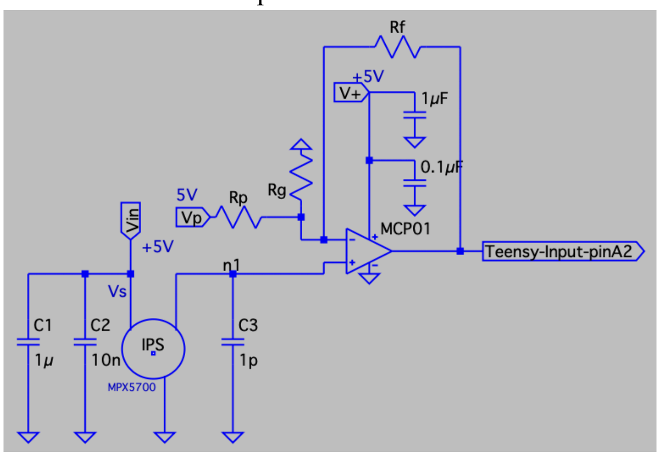

Figure 1: Pressure Sensor Schematic

The pressure sensor reacted to changes in pressure by increasing the output voltage (Vn1) as pressure increased. The pressure sensor was attached by a long tube and snaked outside of a water sealed container the AUV to get real time pressure readings. Using the MPX5700 datasheet [6] the relationship between depth and voltage is described by Equation 1.

$$V_{out} = V_S(0.00128858P + 0.04) \qquad (1)$$

where;

V_{out} = Output Voltage of the MPX5700 [V]

V_S = Input Voltage to the MPX5700 [V]

P = Pressure [kPa]

Using Equation 1, it was possible to estimate the expected output voltage of the MPX5700 at different depths.

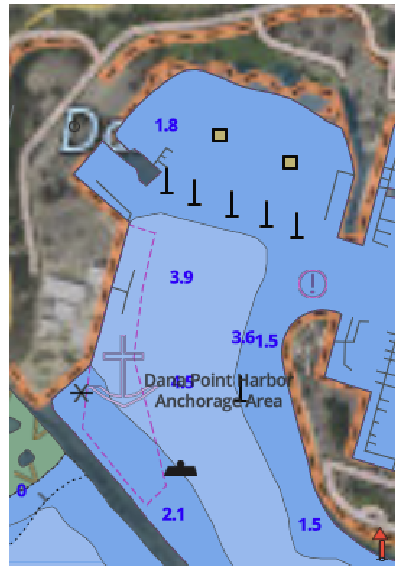

Figure 2: Dana Point Depth Map [7]

In order to use the pressure sensor properly it was necessary to scale the output of the sensor to the input range of the Teensy. Before this could be done the expected output voltage range had to be determined so that it could then be mapped to the Teensy input range. From Figure 2, it was found that the estimated maximum depth was approximately 4 meters which corresponds to a pressure of 39.2 kPa [8]. Assuming that the pressure on the surface of the water was 1 atm or 101.325 kPa, the relevant range of pressures was 101.325 kPA to 150.525 kPA. The expected output voltage of the MPX5700 was determined using Equation 2. Before any scaling was done, the output range of the MPX5700 at the expected depths was a narrow 0.852V to 1.167V. A biased non-inverting Op-amp was used to scale the voltages to the Teesny input range due to its ability to have a gain factor greater than 1. With the circuit seen in Figure 1, the op amp had three resistors; R_f, R_g, and R_p. Along with bypass capacitors to help filter specific frequencies to the power rail.

$$V_{out} = \left(\frac{Rf}{Rg} + \frac{Rf}{Rp} + 1\right)V_{n1} - V_p\left(\frac{Rf}{Rp}\right) \qquad (2)$$

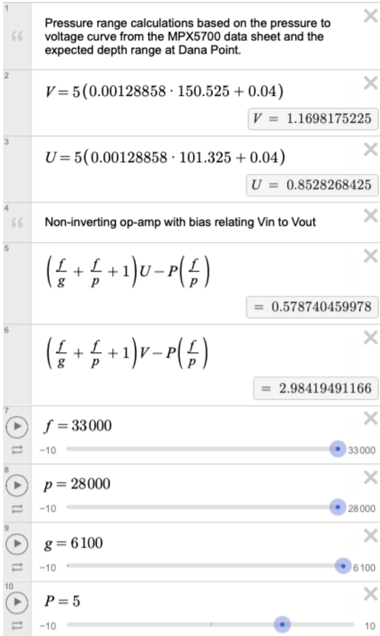

Figure 3: Calculations done to map MPX5700 output to Teensy input. V and U correspond to the limits of the range of output voltages from the MPX5700. *f, g, and p correspond to R_f, R_g, and R_p*

The objective was to map the output voltage of the MPX5700 to the Teensy range of 0.3V to 3.0V using the non inverting op amp. Using Equation 2 and Desmos seen in Figure 3 it was found that the optimal values for the circuit configuration were R_f = 33kΩ, R_g = 6.1kΩ and R_p = 28kΩ.

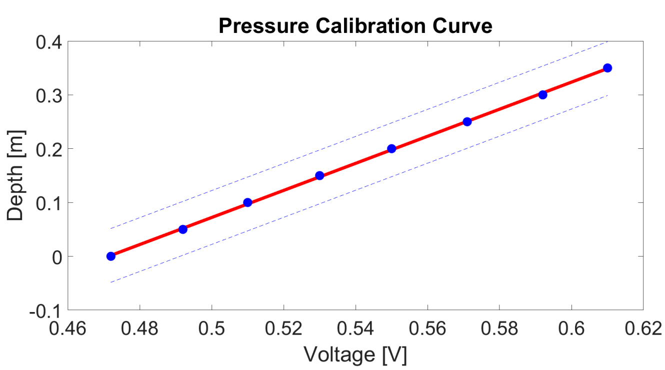

Figure 4: Calibration curve of voltage [V] to depth [m] with linear regression line D = 2.516V - 1.186.

Using a 35cm deep graduated cylinder and a yardstick with an uncertainty of ±0.05 m, the pressure sensor calibration curve seen in Figure 4 was found. This slope and intercept is crucial for navigating to desired depths as mentioned earlier. The Teensy will be able to read the output voltage from the A0 pin and relate that to a depth.

D. Temperature Sensor Circuit Design

An important factor for algae growth is the temperature of the water. Harmful strains of algae can multiply rapidly in warm water [9]. A thermistor interface circuit using the muRata NXFT15WB473FA2B150 measured the temperature of the water as the AUV descended to each depth waypoint [3]. The muRata thermistor has a resistance of 47kΩ at 25ºC. The expected temperature range of Dana Point's water in April is 13.9ºC to 16.8ºC [6] which results in an expected thermistor resistance range of approximately 69.0kΩ to 79.5kΩ calculated. To allow for leeway in the temperature range, the thermistor interface circuit was designed to produce readable results for a temperature range from 10^{0}C to 20^{0}C, which results in a thermistor resistance range of approximately 60kΩ to 100kΩ (a higher temperature translates to a lower resistance). Resistance ranges were calculated using Equation 3.

$$R = R_0 exp(B(\frac{1}{T} - \frac{1}{T_0})) \quad (3)$$

where R is the thermistor resistance, R_0 is the resistance at the reference temperature T_0, T is the input temperature, and B is a constant found in the datasheet [3].

To regulate the voltage entering the thermistor interface circuit op-amp, the circuit implements a voltage divider between the thermistor and a fixed resistor. The schematic for the thermistor interface circuit is shown below.

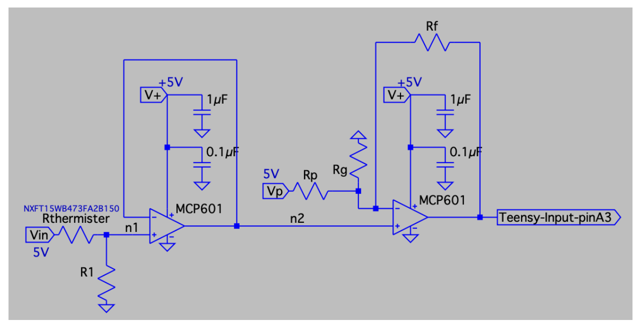

Figure 5: Thermistor interface circuit connected to an inverting amplifier circuit with a voltage bias.

where;

$V_{in} = V_p$ = 5V
R_1 = 82kΩ
R_p = 6 kΩ
R_g = 8.2kΩ
R_f = 10kΩ.

As seen in Figure 5, the voltage divider for the thermistor circuit is between the thermistor and R_1, where the resistance of R_1 = 82kΩ was chosen to be in the middle of the expected resistance range of 60kΩ to 100kΩ. Because $R_{thermistor}$ is in the denominator of the voltage divider equation (see Equation 4), a higher temperature reading means a smaller $R_{thermistor}$ and a larger output voltage from the voltage divider This means that the thermistor circuit has a voltage output that increases with increasing temperatures. However, with the expected temperature range, the thermistor circuit outputs a voltage range calculated using Equation 4 of 2.25V to 2.88V. This calculated voltage range is within the Teensy input range of 0.3V to 3.0V, but does not provide a wide enough range to visualize small changes in temperature.

$$V_{out,\, thermistor\ circuit} = \frac{R_1}{R_1 + R_{thermistor}} \cdot V_{in} \quad (4)$$

Thus, the thermistor interface circuit voltage output was connected to an inverting amplifier circuit to broaden and drop the output voltage range. The resistor values for the inverting amplifier circuit were calculated using Equation 5

$$V_{out} = \left(\frac{R_1}{R_1+R_{therm}}\right)\left(\frac{R_f}{R_g} + \frac{R_f}{R_p} + 1\right) \cdot V_{in} - \left(\frac{R_f}{R_p}\right) \cdot V_p \quad (5)$$

such that the theoretical final output voltage range to the Teensy was 0.42V to 2.88V as simulated in Desmos (see Figures 6 and 7).

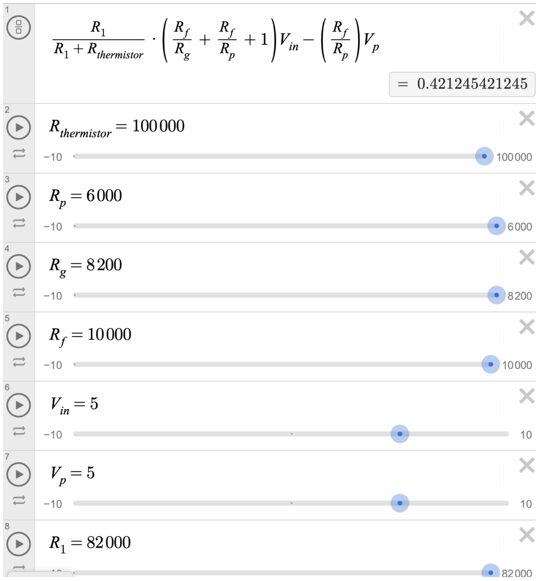

Figure 6: Desmos simulation depicting the output voltage at the lowest expected temperature of 10ºC (thermistor resistance of 100kΩ).

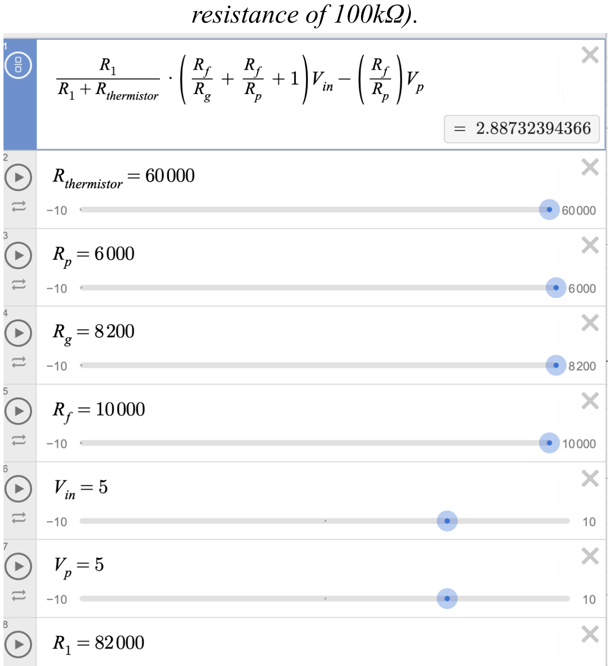

Figure 7: Desmos simulation depicting the output voltage at the highest expected temperature of 20ºC (thermistor resistance of 60kΩ).

The Desmos simulation supports the calculations for the inverting amplifier resistor values. To cross check the Desmos calculations, the circuit was also tested in the lab by dipping the thermistor into baths of different temperatures between the expected range of 10ºC to 20ºC to produce a temperature calibration curve (see Figure 8). The temperature of the bath was measured with a digital thermometer that had an uncertainty of ±1ºC.

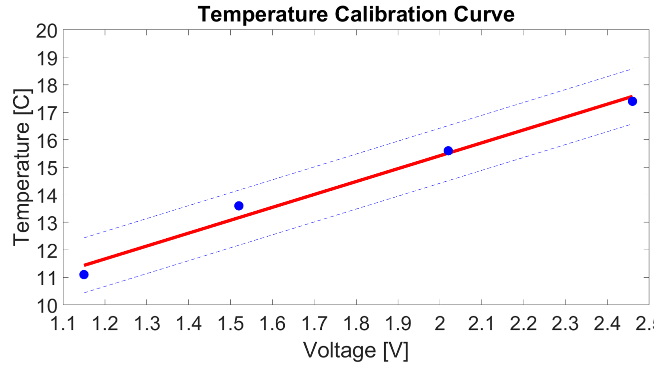

Figure 8: Calibration curve of voltage [V] to temperature [ºC] with linear regression line $T = 4.688V + 6.045$.

The voltage range was smaller than the calculated range but still within the Teensy input range, thus no further changes were made to the temperature sensor circuit.

E. *Green Matter Turbidity Sensor*

The primary function of the AUV is to detect green matter as a function of depth in Dana Point Bay. To do so a turbidity meter was assembled using a pair of transimpedance amplifiers that could convert the current output by a BPW06 photodiode to a voltage that could be measured by the Teensy. A photodiode and green LED were used to detect suspended particles in the water. This design was based on the notion that the amount of particles in the chamber is proportional to the amount of light the photodiode would see.

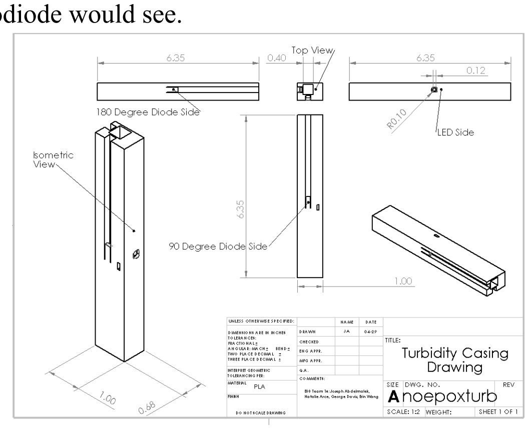

Figure 9: Casing used to shield sensors from ambient light.

One of the complicating factors of detecting light is the presence of ambient light in the medium under test. In order to combat this, a 555 timer was constructed along with a light absorbent housing for the LED and photodiode (see Figure 9). This casing was designed with a long chamber that would minimize the amount of ambient light leaking into the photodiode while still letting in water and particles at varying depth. Additionally, the color of the 3D print material used was specifically chosen to be a dark color to be as light absorbent as possible. Ideally the part would only be printed in black, however due to supply limitations this was not possible for all iterations of the part, including the final product. As such, a dark brown PLA filament was used instead, as shown in Figure 10 below.

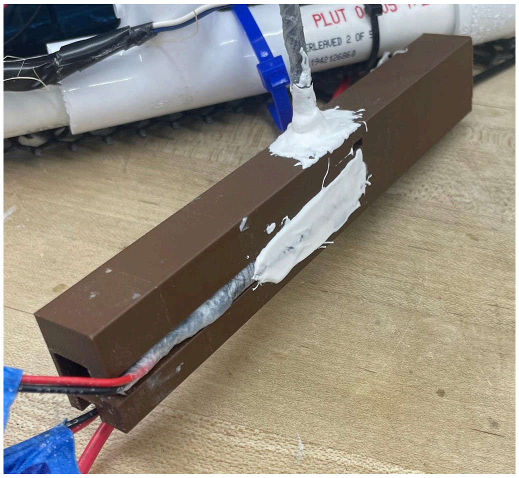

Figure 10: 3D-printed turbidity casing with LED and photodiodes secured with epoxy

The 555 timer allowed for a square wave with a dictated PWM and frequency to drive the LED. Having a periodic signal like this would allow for future data analysis to have a reference point to calculate the magnitude of voltage increase by the photodiode when illuminated by the LED. Additionally, the valley of the periodic signal would indicate how much ambient light had leaked into the sensing chamber

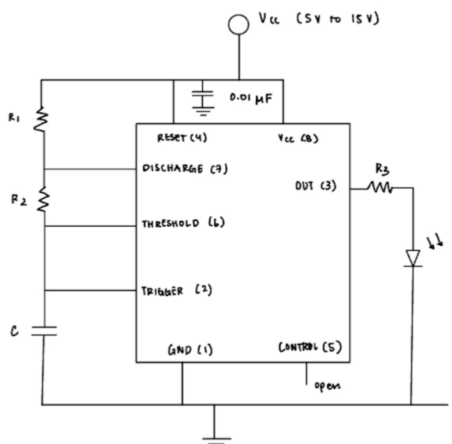

Figure 11: 555 timer circuit schematic

As seen in Equation 6 and 7, the output frequency and duty cycle of the 555 timer square wave were dictated by choosing R_1, R_2, and C notated in Figure 11.

$$frequency \approx \frac{1.44}{C(R_1+2R_2)} \tag{6}$$

$$Duty\ Cycle = 1 - \frac{R_1}{R_1-2R_2} \tag{7}$$

where;

f = 1kHz

$Duty\ Cycle$ = 60%

R_1 = 3kΩ

R_2 = 6kΩ

C = 0.1µF

There was little need for a specific frequency and duty cycle of the LED because the relevant feature was the blinking light. The team relatively arbitrarily decided on a frequency of 1kHz and a PWM of 60%. A 60 percent duty cycle allows more time for the capacitor to charge to the maximum value in the RC filter that was implemented later. A 1kHz signal is a non-extreme signal that safely avoids potential disturbances like parasitic inductance and 60Hz noise from wall power for troubleshooting purposes. The component values were chosen to achieve these characteristics of the 555 timer using Equations # and #. The 1.44 value was a constant value indicated in the data sheet for the 555 timer [10].

$$V = IR \tag{8}$$

$$V_{out} = \frac{R_2}{R_1+R_2} V_{in} \tag{9}$$

Finally, R_3 was chosen to control the voltage across the LED so that it would be preserved and be illuminated. From the data sheet it was determined that in order for the diode to turn on the forward current and voltage must be 20mA and 2.2V. The output voltage of the 555 timer when it was on would be 5V so a resistor that would drop the voltage down to 2.2V was needed. Using Ohm's law (Equation 8) and the voltage divider equation (Equation 9) R_3 was chosen to be 200Ω. This value saw changes throughout the project due to the team's attempt to limit the light emitted by the LED.

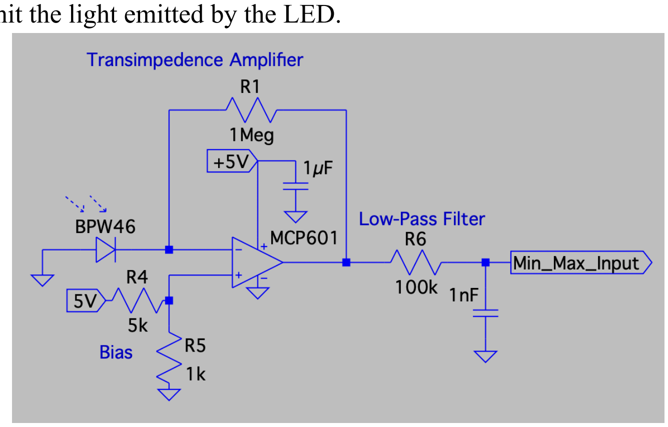

Figure 12: Transimpedance Amplifier Schematic

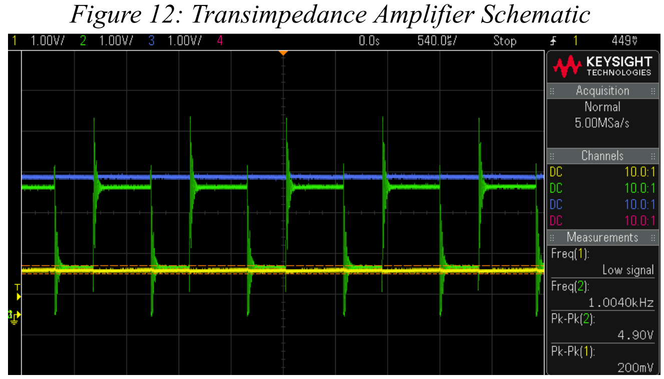

Figure 13: Transimpedance Amplifier Output Trace with No Filtering

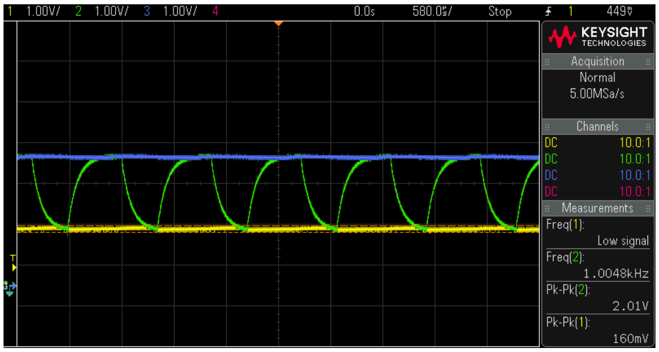

Figure 14: Transimpedance amplifier Output Trace with Filtering.

The transimpedance amplifier circuit allows for the output of a current source like the BPW46 photodiode to a measurable voltage. R_1 was selected to be 1MΩ to convert the current at a large enough scale to be legible by the Teensy [11]. During preliminary saltwater testing it was found that there was a considerable amount of high frequency ringing in the output of the transimpedance amplifier as seen in Figure 13. This ringing contributed to approximately 10% error of the measure maximum (blue) to the actual maximum (green) of the signal seen on Figure 13. The time constant of such a filter was decreased based on the observed response until all ringing was eliminated. The values of R_6 and the capacitor were the results of the testing. The new filtered signal can be seen on Figure 14, notice the accuracy of the min/max DC readings.

$$f_{sample} \geq 2f_{max} \tag{10}$$

where;

f_{sample} = 10 Hz Sampling Frequency [Hz]

f_{max} = 1kHz Max Output Frequency of Measured Signal [Hz]

The sample rate (f_{sample}) of the Teensy was 10 Hz and the output frequency (f_{max}) The transimpedance amplifier was 1kHz. According to equation 10, in this case f_{sample} would be much less than twice f_{max} so some intervention was necessary to effectively sample the signal [12].

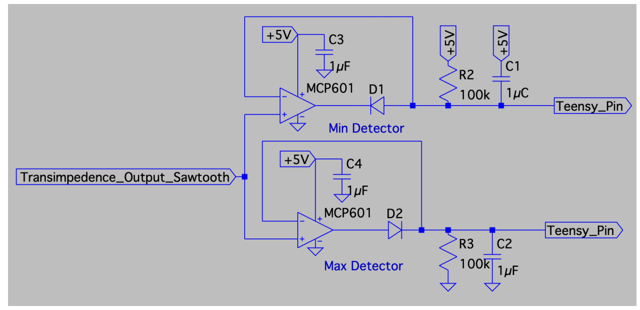

Figure 15: Min/Max detector circuit schematic

$$\tau = \frac{1}{2\pi RC} \tag{11}$$

where;

τ = 5/π Hz

R = 100kΩ

C = 1μF

To avoid aliasing the Min/Max detector seen in Figure 15 was constructed to convert the photodiode signal from a periodic sawtooth to a pair of min and max DC values. The time constant of the RC components of the Min/Max detector connected to each output were determined by acknowledging that the time constant needed to be much greater than the input frequency but smaller than the change in amplitude. Within lab testing, it was determined that the component values selected rectified the signal most effectively as seen in Figure 14.

Calibration of this sensor was complicated because it was difficult to predict the turbidity of the water the sensor would be testing. The output measured was dependent on the number of dispelled particles in the water, so accurate scaling to Teensy range was only possible with a water sample. Without such a sample of ocean water the team could only guess with an imitation salt water solution synthesized in the lab. This lab solution was a 35 g/L solution of salt water to mimic the average salinity of ocean water [13].

The team reasoned that since voltage increases with more light entering the photodiode, if the maximum value of the transimpedance amplifier when there is green matter in the water was less than the maximum of the Teensy input range, every other solution with more suspended particles would also stay within the Teensy range. This was based on the assumption that the ocean water would never be clearer than the lab solution and the transimpedance amplifier never output a negative voltage. The first assumption was validated by the team after considering the clarity of tap water compared to the cloudiness of ocean water let alone ocean bay water. The second assumption was true because the transimpedance amplifier was built on a single rail MCP601 op amp. This means that the output voltage could never be negative. In the laboratory test, the maximum value recorded with 5 g/L of blended green matter was 2.025 V.

F. Software Considerations

Default software used to control the AUV and collect data was provided through the E80 GitHub repository. This AUV was run on a version of the E80_Lab_07_dive.ino code file that was modified to include new depth waypoints that the AUV would navigate to, longer waypoint delays for collecting more accurate data, and the addition of a second motor to the z-axis driver because of the second motor acting in that direction. Further explanation of this motor choice will be discussed in the following section.

Arduino IDE was used to upload code to the Teensy 4.0 and signaled the Teensy to collect data from each of the three sensors mentioned above (thermistor, green matter turbidity, and pressure sensor). The Teensy 4.0 sampled each of these sensors at the default frequency of 10 Hz.

Along with the default code provided, changes were made for AUV-operated depth control to incorporate the measured calibration of the pressure sensor from the calibration curve to the Teensy's z-state estimator function. This estimator signaled to the Teensy whether or not the desired depth had been reached, and controlled the z-axis motors accordingly.

The output of each sensor during tests was routed to their own individual pins on the protoboard, which was then routed to the corresponding pins on the Teensy. The pressure sensor was routed to the A00 pin, thermistor output to the A01 pin, the minimum voltage of the right angle oriented photodiode to the A02 pin, the maximum voltage of the right angle oriented photodiode to the A03 pin, the minimum voltage of the 180 degree photodiode to the A11 pin, and the maximum voltage of the 180 degree photodiode to the A12 pin.

It is important to note that the motherboard was designed for use with a Teensy 3.2, not the Teensy 4.0. As such, the back analog pins (A10-A13) are not properly connected to the motherboard when the Teensy is plugged in directly. To circumvent this, an adapter board was used to reestablish the connections between the Teensy's back pins and their corresponding motherboard pins.

III. AUV Design

To accomplish the goals of this study, the AUV was designed to be as agile as possible and symmetrical while also maintaining underwater stability. Two motors were attached to the PVC frame in the same direction using zip ties and were utilized in sync during operation. The choice of using two motors was made after testing prior to the Dana Point launch revealed that a single motor was not strong enough to return the AUV back to the surface after the completion of data collection.

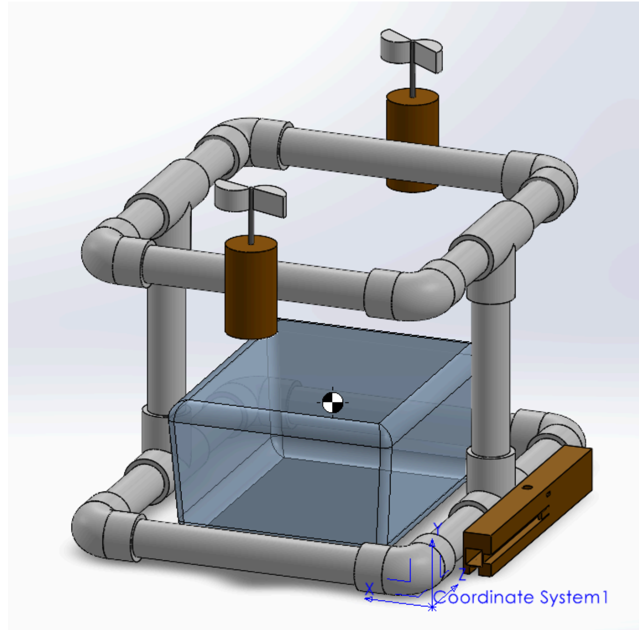

Figure 16: 3D model of PVC frame with motors, turbidity casing, and waterproof box

In the center of the frame as seen in Figure 16, a waterproof box holding the Teensy 4.0, motherboard, and two protoboards which housed each sensor circuit was placed and strapped to the AUV using velcro. With the provided waterproof box, holes were drilled to house penetrators that helped extend wires outside of the box. The penetrators were marine epoxied with the wires already through them to make certain no water went inside the box where all the electrical components were housed. A second layer of epoxy was applied for extra security.

Through a similar process, all connections outside of the box had layers of waterproofing to avoid shorts of the electrical components. The thermistor, photodiodes, and LED were first all attached to stranded wire and exposed wire had heat shrink placed around them. To provide extra security, parafilm, a stretchy wax material was used for extra seal.

The fully assembled AUV, shown in Figure 17 below, weighed a total of 3200.8 grams and was neutrally buoyant in saltwater. The waterproof box, including the motherboard, protoboards, Teensy, battery, and two ballasts weighed a total of about 1710 grams. The frame with the motors, turbidity casing, bottom mesh, and extra ballast weights that were added to create neutral buoyancy weighed a total of 1439 grams and the remaining weight came from zip ties and wiring.The center of mass–and consequently center of buoyancy because the AUV was fully submerged–calculated through SolidWorks was located at (4.53 in, 2.52 in, 5.60 in) according to Coordinate System 1.

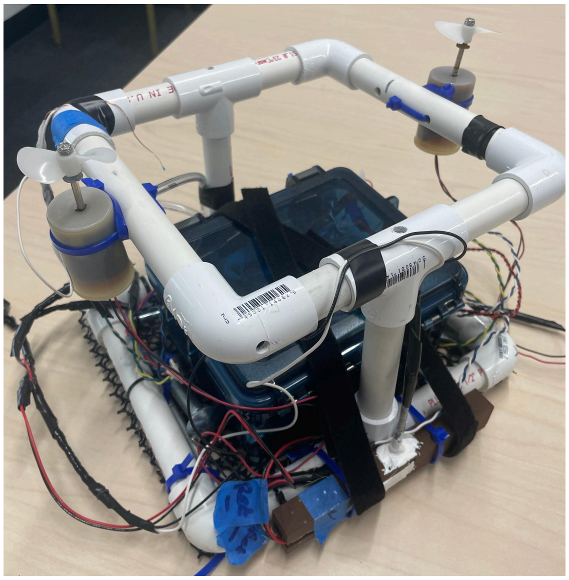

Figure 17: Fully assembled and waterproofed AUV

IV. Deployment Details

To collect data, the AUV was tested in two locations. For deployment, robot retrieval and as mentioned in the previous section, waterproofing was prepared. A tent rope attached to a carabiner was used as a tether to ensure the safety of the bot.

The first location was "pHake Lake" at the Bernard Field Station in Claremont, California. While preparing to take data, one diode of the turbidity sensor could be read without an adapter board for the Teensy, something that was not made before pHake Lake. As a result, the goal was to take data using temperature and depth. To double-check waterproofing, the box was placed under water for a few seconds, uncovering a leak in the waterproof box. The wires secured in the penetrator had gaps that led to water seeping into the waterproof box. Once the box was waterproofed and the team began testing, the motors continued to travel downward after taking data. With a singular motor carrying the weight of the AUV, the robot had to be pulled up manually. Temperature and depth at various unknown levels were recorded despite the problems that were encountered.

The final deployment was at Dana Point in California. To set up deployment in regards to ocean water, an extra ballast was added as salt water is more buoyant. From the previous waterproofing at pHake Lake, all outside wire connects were covered by flex seal on top of other waterproofing measures mentioned earlier in this section. Various occurrences led to onsight changes. Due to the difference of salt water to fresh water, the thermistor stopped working and had to be replaced. Pressure sensor calibration was changed on site due to being at sea level, a higher pressure than the robot experienced at pHake Lake. With these elements updated, the area chosen for deployment was the dock. The dock was listed as a depth of four meters, allowing for taking more depth waypoints as a result. With the dock height shifted tidal movements, one consideration not taken was the change of tide throughout the day. As a result, with final testing, not all programmed depths could be reached because of the tide low, the AUV reached the surface of the ocean floor. Originally with a turbidity sensor, the ratio of transmittance and the 90º diodes were to have multiple detection angles of turbidity. But, at Dana Point, a voltage divider was first applied because the diode directly measuring transmittance was railing out. With the voltage divider causing more problems, eventually a unity gain buffer was put in place. This worked, but due to low tide not all depths could be reached. Therefore, the data before the tide lowered, the 90º reflection of transmittance from the IR LED, temperature, and depth measurements were taken.

Figure 18: E80 Team 14 at Dana Point Launch Day

V. Results and Analysis

To explore the question of algae concentration, Temperature and turbidity were measured in relation to depth. Two tests were taken at different times of the day where light varied, but were recorded in the same location. The depth of the AUV during these two tests can be matched up relatively well and thus they are overlaid on the same graph. The resulting data is shown below:

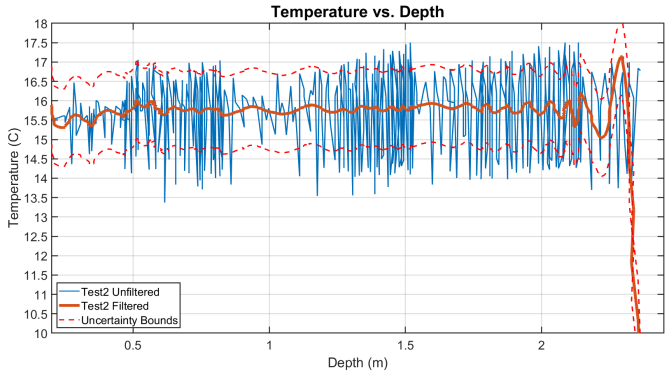

Figure 19: Temperature and depth data for two tests run at 10:26 AM and 12:50 PM

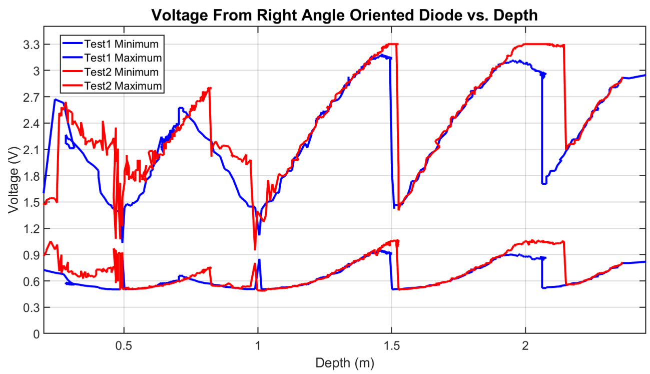

Figure 20: 90 degree diode voltage and depth data for two tests run at 10:26 AM and 12:50 PM

Figure 19 (temperature) shows the thermistor Test 1 reading a voltage that cannot be interpreted by the Teensy, thus resulting in a rail out. After switching out the thermistor in between the tests, Test2 shows readable, yet noisy data as shown by the blue line. To resolve this, a Fourier Transform was used to filter the data for noise that was introduced to the system by the motor movement and the saltwater, resulting in the readable red line. This filtered data shows that the temperature of the ocean water between 0.2 to 2.4 meters deep was relatively the same, suggesting that the temperature does not change much in this range of depths.

Figure 20 (90º diode voltage) shows the minimum and maximum voltages captured by the Teensy which can be correlated to the amount of green matter in the water. As green matter increases, more green light from the LED is reflected towards the right angle oriented diode, resulting in an increased current that is picked up by the transimpedance amplifier and sent to the Teensy as an increased voltage. As can be seen in the figure, the voltage sent to the Teensy seems to increase with depth– a consequence of the current generated by the photodiode increasing with depth. By calculating the linear regression of the increase in voltage before the rail out between 1.6 and 1.9 meters, an estimate of the maximum voltage possible was found. The estimated maximum generated by this phantom plot was 3.937 volts at 2.1 meters. The linear fit then created by the peak voltages at depths 0.5, 1, 1.5 and 2.1 meters, shown in Figure 21, indicates an increase with depth by the positive sloping equation.

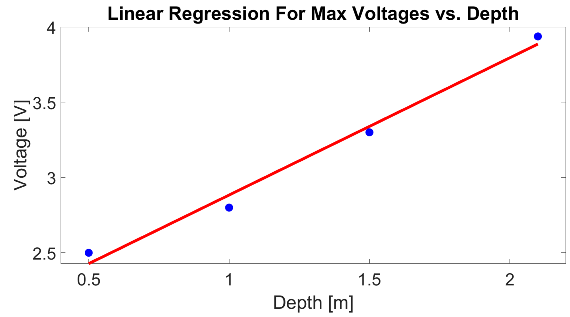

*Figure 21: Linear regression line of max voltage as depth increases, having an equation of volts=0.912*depth+1.972*

VI. Conclusion

The hypothesis originally predicted that the concentration of algae would decrease the further in depth the AUV would travel. However, the data taken at Dana Point suggested otherwise. When comparing reflected transmittance and depth, the greater the depth, more green algae was detected, as can be seen by the increasing voltage from the max 90 degree diode sensor until it railed out as depth increases.

Simply, the results from this study indicate that the initial hypothesis is inaccurate for the range of depths the AUV traveled. Further research into this topic suggested that the results, instead, could be explained by environmental factors such as ocean currents, surface craft movement, and more (find a source indicating increased depth and green matter and reference). Given this information, the results were shown to be correlated with this understanding and show that the increasing depth is properly correlated with the increased depth.

As mentioned in the deployment section, there were instances in which waterproofing was a problem. The stem of this was resulting from the mechanical design of the turbidity casting. With the use of marine epoxy, when dried it acts as a brittle material. As a result there were instances when the IR LED snapped from the casing from shifting around through the tests and when epoxying the photodiodes to the casing, sometimes epoxy would get on the receiving side of the diode. Therefore, making new ways to easily take out these components would prevent new wires needing to be soldered and risks the exposure of more water. To avoid further risks of soldering more than needed.

A limitation of deploying the robot from the dock at Dana Point was the range of depths the AUV could travel to. Most light emittance occurs up to ten meters deep [14]. Because most light drop occurs at this depth, there would be a greater range of data measuring reflected transmittance at different depths.

As a final implementation that would strengthen data for light transmittance in water would be to keep the transmittance diode from railing out. In order to do so a greater resistor value for the transimpedance circuit would need to be added.

VII. Acknowledgements

The team would like to acknowledge the help of the E80 professors and proctors for supporting us throughout the semester. Special thanks to the help of Xavier and Lynn for debugging help for the circuits.

VIII. References

[1] Whitt Kelly Kizer, "Oceans turn greener due to global warming" earthsky.org, July 16, 2023. [Online]. Available: https://earths ky.org/earth/oceans-turning - greener-climate-change-phytoplankton//. [Accessed April 23, 2024].

[2] United States Geological Survey, "Turbidity and Water." *United States Geological Survey,* 2018. [Online]. Available:https://www.usgs.gov/special-topics/water-science-school/science/turbidity-and-water. [Accessed: April 24, 2024]

[3] "Dana Point Water Temperature," *seatemperature.org,* 2024. [Online]. Available: https://www.seatemperature. org/north-america/united-states/dana-point.htm. [Accessed March 2024].

[4] United States Geological Survey, "Estimation of Secchi Depth from Turbidity Data in the Willamette River at Portland, OR (14211720)" *United States Geological Survey,* 2016. [Online]. Available: https://or.water.usgs.gov/will_morrison/secchi_depth_model.html. [Accessed April 25, 2024].

[5] Data Sheet muRata, "NXFT15WB473FA2B150", NXFT15WB473FA2B150 datasheet, [Revised Feb. 2024].

[6] Data Sheet NXP, "Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated", MPX5700 Series datasheet, 2009 [Revised 2012].

[7] GPS Nautical Charts, "DANA POINT HARBOR (Marine Chart: US18746_P1898)",2024. [Online]. Available at: https://www.gpsnauticalcharts.com/main/us18746_p1898 -dana-point-harbor-nautical-chart.html. [Accessed March 5, 2024].

[8] The Engineering ToolBox, "Hydrostatic Pressure vs. Depth", 2010. [Online]. Available at:https://www.engineeringtoolbox.com/hydrostatic-pressure-water-d_1632.html [Accessed March 4, 2024].

[9] S. P. Singh and P. Singh, "Effect of temperature and light on the growth of algae species: A review," *Renewable and Sustainable Energy Reviews*, vol. 50, no. 50, pp. 431–444, Oct. 2015, doi: https://doi.org/10.1016/j.rser.2015.05.024.

[10] Data Sheet Texas Instruments, "xx555 Precision Timers", xx555 datasheet, 1973 [Revised Sept 2014]

[11] Data Sheet VISHAY, "Silicon PIN Photodiode", BPW46 datasheet, 2014 [Revised Jan. 2024].

[12] T. Zawistowski and P. Shah, "An Introduction to Sampling Theory," An introduction to sampling theory, http://www2.egr.uh.edu/~glover/applets/Sampling/Sampling.html#:~:text=The%20Sampling%20Theorem%20states%20that,maximum%20frequency%20in%20the%20signal. (accessed Apr. 30, 2024).

[13] "Why is the ocean salty?," Why is the ocean salty? | U.S. Geological Survey, https://www.usgs.gov/faqs/why-ocean-salty#:~:text=The%20concentration%20of%20salt%20in,be%20about%20120%20%20million%20%20ton. (accessed Apr. 30, 2024).

[14] University of Hawai'i at Mānoa,"Light in the Ocean," *University of Hawai'i* at Mānoa*,* 2024. [Online]. Available: https://manoa.hawaii.edu/exploringourfluidearth/physical/ocean-depths/light-ocean#:~:text=Within%20the%20first%2010%20m,as%20it%20travels%20through%20matter. [Accessed April 28, 2024].

IX. Code Appendix

A. *estimator.m*

```
clf
depth1 = alldepth(:, 2);
depth1 = depth1(2327:2407);
max90 = allmax90(:, 2);
max90 = max90(2327:2407);
error = 0.05;
figure(1)
p = polyfit(depth1,max90,1);
px = [min(depth1), max(depth1)];
py = polyval(p,px);
plot(px,py,'red','LineWidth',5)
hold on
scatter(depth1,max90,200,'blue','o','filled')
ylabel('Voltage [V]','FontSize',50)
xlabel('Depth [m]','FontSize',50)
title('Pressure Calibration Curve','FontSize',75)
ax = gca;
ax.FontSize = 30;
eqn = sprintf('%f*depth+%f\n',p)
```

B. *tempCalibrationC.m*

```
clf
clear
temp = [11.1 13.6 15.6 17.4];
volts = [1.15 1.52 2.02 2.46];
error = 1;
figure(1)
p = polyfit(volts,temp,1);
px = [min(volts), max(volts)];
py = polyval(p,px);
plot(px,py,'red','LineWidth',5)
hold on
plot(px, py+error, 'LineStyle','--', 'Color', 'b')
plot(px, py-error, 'LineStyle','--', 'Color', 'b')
scatter(volts,temp,200,'blue','o','filled')
ylabel('Temperature [C]','FontSize',50)
xlabel('Voltage [V]','FontSize',50)
title('Temperature Calibration Curve','FontSize',75)
ax = gca;
ax.FontSize = 30;
ax.XTick = 0:0.1:3;
ax.YTick = 10:1:20;
ax.XLim = [1.1 2.5];
eqn = sprintf('%f*volts+%f\n',p)
```

C. *psensorCalibration.m*

```
clf
clear
depth = [0 0.05 0.1 0.15 0.2 0.25 0.3 0.35];
volts = [0.472 0.492 0.51 0.53 0.55 0.571 0.592 0.61];
error = 0.05;
figure(1)
p = polyfit(volts,depth,1);
px = [min(volts), max(volts)];
py = polyval(p,px);
plot(px,py,'red','LineWidth',5)
hold on
plot(px, py+error, 'LineStyle','--', 'Color', 'b')
plot(px, py-error, 'LineStyle','--', 'Color', 'b')
scatter(volts,depth,200,'blue','o','filled')
ylabel('Depth [m]','FontSize',50)
xlabel('Voltage [V]','FontSize',50)
title('Pressure Calibration Curve','FontSize',75)
ax = gca;
ax.FontSize = 30;
eqn = sprintf('%f*volts+%f\n',p)
```

D. *linregmaxes.m*

```
% linregmaxes
depth4 = [0.5, 1, 1.5, 2.1];
maxvolt = [2.5 2.8, 3.3, 3.937];
figure(1)
p = polyfit(depth4,maxvolt,1);
px = [min(depth4), max(depth4)];
py = polyval(p,px);
plot(px,py,'red','LineWidth',5)
hold on
scatter(depth4,maxvolt,200,'blue','o','filled')
ylabel('Voltage [V]','FontSize',50)
xlabel('Depth [m]','FontSize',50)
title('Linear Regression For Max Voltages vs.
Depth','FontSize',75)
xlim([0.4 2.2])
ax = gca;
ax.FontSize = 30;
eqn = sprintf('%.3f*depth+%.3f\n',p)
```

E. *e80testloop.m*

The following code was used to load in the desired files recorded from on the Teensy and plot temperature, right angle oriented diode voltage, and 180 degree oriented diode voltage against depth

```
clear;
numb = 2500;
tryind = 2;
alldepth = zeros(numb, tryind);
alltherm = zeros(numb, tryind);
allmin90 = zeros(numb, tryind);
allmax90 = zeros(numb, tryind);
allmintrans = zeros(numb, tryind);
allmaxtrans = zeros(numb, tryind);
files = [143 145];
for trys = 1:length(files)
  filenum = [num2str(files(trys))]; % file number for the
data you want to read
  infofile = strcat('INF', filenum, '.TXT');
  datafile = strcat('LOG', filenum, '.BIN');
```

```
    %% map from datatype to length in bytes
    dataSizes.('float') = 4;
    dataSizes.('ulong') = 4;
    dataSizes.('int') = 4;
    dataSizes.('int32') = 4;
    dataSizes.('uint8') = 1;
    dataSizes.('uint16') = 2;
    dataSizes.('char') = 1;
    dataSizes.('bool') = 1;
    %% read from info file to get log file structure
    fileID = fopen(infofile);
    items =
textscan(fileID,'%s','Delimiter',',','EndOfLine','\r\n');
    fclose(fileID);
    [ncols,~] = size(items{1});
    ncols = ncols/2;
    varNames = items{1}(1:ncols)';
    varTypes = items{1}(ncols+1:end)';
    varLengths = zeros(size(varTypes));
    colLength = 256;
    for i = 1:numel(varTypes)
        varLengths(i) = dataSizes.(varTypes{i});
    end
    R = cell(1,numel(varNames));

    %% read column-by-column from datafile
    fid = fopen(datafile,'rb');
    for i=1:numel(varTypes)
        %# seek to the first field of the first record
        fseek(fid, sum(varLengths(1:i-1)), 'bof');

        %# % read column with specified format, skipping
required number of bytes
        R{i} = fread(fid, Inf, ['*' varTypes{i}],
colLength-varLengths(i));
        eval(strcat(varNames{i},'=','R{',num2str(i),'};'));
    end
    fclose(fid);

    % A00 Pin, Depth Curve
    trialdepth = [];
    for i = 1:length(A00)
        trialdepth(i) =
1/0.397*double(A00(i))*3.3/1023-0.72/0.397;
    end
    alldepth(:, trys) = [zeros(numb-length(trialdepth), 1);
trialdepth'];

    % A01 Pin, Thermistor Curve
    therm = [];
    for i = 1:length(A01)
        therm(i) = 4.78*double(A01(i))*3.3/1023 + 5.94;
    end
    alltherm(:, trys) = [zeros(numb-length(therm), 1); therm'];

    % A02 Pin, 90 Degree Diode Minimum
    min90 = [];
    for i = 1:length(A02)
        min90(i) = double(A02(i))*3.3/1023;
    end
    allmin90(:, trys) = [zeros(numb-length(min90), 1);
min90'];

    % A03 Pin, 90 Degree Diode Maximum
    max90 = [];
    for i = 1:length(A03)
        max90(i) = double(A03(i))*3.3/1023;
    end
    allmax90(:, trys) = [zeros(numb-length(max90), 1);
max90'];

    % A11 Pin, Transmittance Diode Minimum
    mintrans = [];
    for i = 1:length(A11)
        mintrans(i) = double(A11(i))*3.3/1023;
    end
    allmintrans(:, trys) = [zeros(numb-length(mintrans), 1);
mintrans'];

    % A12 Pin, Transmittance Diode Maximum
    maxtrans = [];
    for i = 1:length(A12)
        maxtrans(i) = double(A12(i))*3.3/1023;
    end
    allmaxtrans(:, trys) = [zeros(numb-length(maxtrans), 1);
maxtrans'];
end
samptotime = 1:length(alldepth(:, 1));
samptotime = samptotime/10;
N = length(alltherm(:, 2));
T0 = samptotime(end);
Fs = N/T0;
[X,f] = fdomain(alltherm(:, 2),Fs);
%stem(f,abs(X))
filtered_X = X;
for i = 1:length(f)
    if abs(f(i))>0.5
        filtered_X(i) = 0 + 0i;
    end
end
[x,t] = tdomain(filtered_X,Fs);
xlims = [0.2 2.45];
figure(1)
plot(alldepth(:, 2), alltherm(:, 2))
hold on
plot(alldepth(:, 2), x, "LineWidth",3)
plot(alldepth(:, 1), alltherm(:, 1))
xlim(xlims)
legend('Test2 Unfiltered', 'Test2 Filtered', 'Test1')
xlabel('Depth (m)')
ylabel('Temperature (C)')
title('Temperature vs. Depth')
grid on
```

```
figure(2)
plot(alldepth(:, 1), allmin90(:, 1))
hold on
plot(alldepth(:, 1), allmax90(:, 1))
plot(alldepth(:, 2), allmin90(:, 2))
plot(alldepth(:, 2), allmax90(:, 2))
xlim(xlims)
legend('Test1 Minimum', 'Test1 Maximum', 'Test2
Minimum', 'Test2 Maximum')
xlabel('Depth (m)')
ylabel('Voltage (V)')
title('Voltage From Right Angle Oriented Diode vs. Depth')
grid on
figure(3)
plot(alldepth(:, 1), allmintrans(:, 1))
hold on
plot(alldepth(:, 1), allmaxtrans(:, 1))
plot(alldepth(:, 2), allmintrans(:, 2))
plot(alldepth(:, 2), allmaxtrans(:, 2))
xlim(xlims)
legend('Test1 Minimum', 'Test1 Maximum', 'Test2
Minimum', 'Test2 Maximum')
xlabel('Depth (m)')
ylabel('Voltage (V)')
title('Voltage From 180 Degree Oriented Diode vs. Depth')
grid on

avg_x = mean(x(2000:24000))
```