Eric Sigg
Summer 2022 Research Report

One Paragraph Summary:

This summer, I had the opportunity to work in Douglas Jerolmack's lab on the Underwater Weather project. I worked with a team of experts in river science and robotics to design and deploy autonomous boats. These autonomous boats carry a sensor suite, which collects many parameters about the river including not only typical water quality measurements such as pH, but also suspended sediment concentration, and flow velocity at various depths. With these data, the team hopes to gain a better understanding of the Schuylkill river's characteristics, enabling predictions of underwater conditions affecting river health or that could lead to impacts on the surrounding area, such as floods. My contributions to the project focused on the boat's suspended sediment sensor. I firstly studied the sensor's ability to detect particles of various sizes through several experiments that I helped to design. The resulting data indicated that the sensor was not very sensitive to particles of sizes below 10 microns. To both calibrate and determine whether or not the sensor would be effective to measure the suspended sediment content in the river, I developed a process flow for collecting and analyzing river samples. Upon analyzing the river samples, the particle size analysis data showed that about half the particles present were in the size range that the sensor could measure accurately, and thus, the team assumed that the measurement by the sensor only measured the concentration of particles larger than around 20 microns. During boat deployments, I followed the boat in a kayak, making adjustments to the boat's systems to adapt to changing conditions. As a result, I learned how all parts of the boat worked, such that I could adjust any component as the boat was operating. Finally, I also assisted with the analysis of the data that the boat collected, helping to recognize and determine the origin of trends in the data. Through this opportunity I gained experience working with a research team and insight into both research robotics and river dynamics, two topics that I was not as familiar with before beginning this summer work. With my newfound interest and knowledge in these fields, I hope to continue contributing to the project through the fall semester.

Photo for MEAM website:
Me in the kayak, preparing to adjust the boat's systems:

Introduction:

In an attempt to gain a more detailed understanding of the characteristics of the Schuylkill River, Professors Douglas Jerolmack and Ani Hseih started the Underwater Weather project, bringing together experts in river science and robotics. The project aimed to design and deploy Autonomous Surface Vehicles (ASVs) carrying arrays of sensors to study many water quality parameters, including not only typical water quality measurements such as pH, but also sensors to detect suspended sediment content, and water flow velocity at various depths. Existing data from the Schuylkill River does exist, but the data that is currently available is collected by instruments that are either mounted in stationary locations or on large boats, which survey the river infrequently. As the currently available data is only collected at sparse locations and time intervals, it is not detailed enough to allow a true understanding of the river's characteristics. Equipped with a better understanding of the Schuylkill river's state, it would be possible to, for example, predict how mud might deposit on the bottom of the river as a result of a change in flow speed, tides, or water chemistry, increasing flood risk. Many other predictions might be possible with the data collected, which could be extremely helpful in understanding and protecting the Schuylkill river's health.

To effectively collect data using these ASVs, the group addressed many challenges, such as autonomous navigation, deployment under vastly different conditions, and the methods of both carrying the sensors on the boat and interpreting the data they collect. I was involved in the challenge revolving understanding the river's sediment content, in particular how sediment concentration could be accurately measured. The ASV uses an acoustic device called the LISST-ABS sensor, which emits acoustic waves, and measures their backscatter resulting from sediment present in the water. Based on this backscatter, the instrument calculates the sediment concentration. However, as the sediment in the river consists of particles of many materials, shapes, and sizes, I designed experiments to determine whether the sensor could give an accurate concentration value regardless of variation in any of these parameters.

Figure 1: The LISST sensor mounted on the boat.

I was also involved in the development of process flows for collecting and analyzing water samples in the lab for the calibration of the sensors. As the LISST sensor must be calibrated before every data collection procedure in the river, a water sample must be taken and analyzed to determine its sediment concentration. This value is then compared with the value the LISST sensor measures, and the two are correlated by the calibration factor.

My involvement in the project also extended to analyzing and addressing problems with collecting reliable data from other sensors. I considered and developed ideas for how the boat could move in a grid pattern and execute this movement in a short enough period of time such that the resulting data could be considered a snapshot in time. I also worked to analyze the data and understand how it might appear different due to the greatly varying conditions during which the boat was deployed. Finally, I was also involved in the field component of this project, by assisting during deployments, by following the boat around in a kayak, and making adjustments to the ASV's sensor suite as conditions changed and issues arose.

Processes and Developed Solutions:

In the examination of the suspended sediment sensor (LISST sensor)'s properties and limits, I developed and ran several experiments. As mentioned in the introduction, the sediment suspended in the river varies greatly in size. Thus, I first studied the sensor's ability to reliably detect grains of sizes between 0 and 106 microns, which are the sizes of particles most commonly suspended in the river. The particles were divided into three size groups, 0-8 microns, 8-53 microns, and 53-106 microns. Tests were then conducted with known concentrations of each size group, and the sensor's ability to detect changes in concentration was assessed. Following these experiments, mixtures of the particles, in known proportions were tested, to determine if the sensor could detect particles of one size range better than those of another size range.

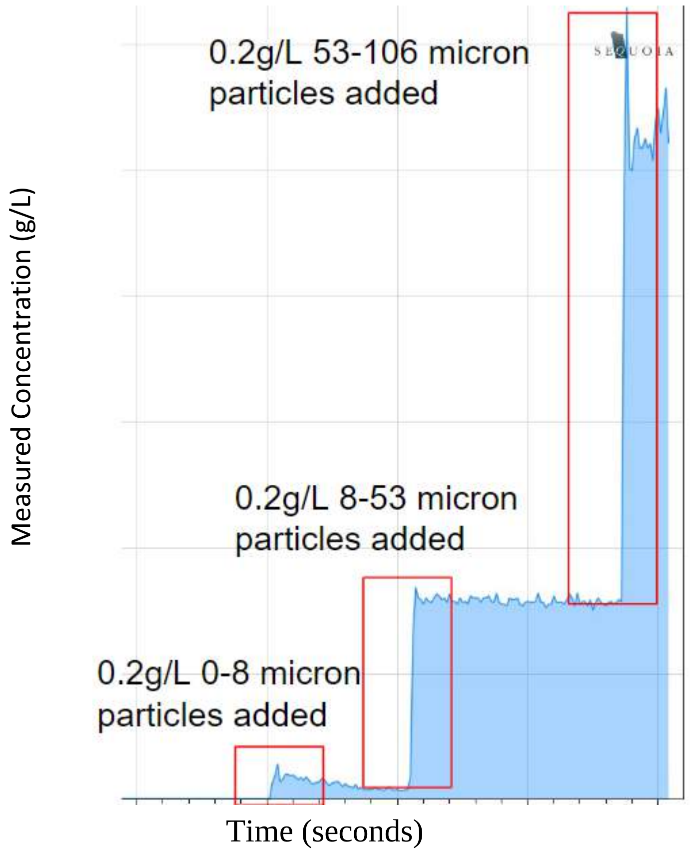
I also developed process flows for the analysis of water samples from the river. Water samples were collected in large, three-liter bottles, to maximize the amount of sediment present in the sample. The exact volume of water in the sample was measured, and the sample was divided among several smaller beakers and placed into an oven, until all the water had evaporated. The oven was set to around 90 degrees Celsius, to ensure that water evaporated slowly to avoid ejecting particles from the beaker, and that once the water had evaporated entirely, the particles would not burn. Once the samples were dried, the mass of the particles was measured, and when combined with the volume measurement a known concentration value was calculated, thereby calibrating the LISST sensor. The particles were then passed into a laser particle size analyzer, to determine the size range of particles present in the sample. This was done to both better understand the sediment present in the river on the day the sample was collected, but also to ensure that the LISST sensor was able to detect the sediment, as tests showed that the LISST sensor was not very sensitive to smaller particles.

Results:

The tests with the LISST sensor clearly showed that it had a high sensitivity to variations in particle size. At the smallest particle size tested, 0-8 micron, the calibration factor was 76. This means that the concentration measured by the sensor was 76 times lower than the actual concentration. In the 8–53 micron size range, the calibration factor was 3.1. This meant that the concentration measured by the sensor was only 3 times lower than the actual concentration. Finally, for the 53-106 micron size range, the calibration factor was 0.688. This indicated that the sensor was measuring a concentration higher than the actual concentration. Thus, the sensor is highly sensitive to variations in the size of the particles.

To further investigate this, the sensor was tested in mixtures of particles. Particles of each size range were added in known quantities into a mixture, and the sensor's readings were observed. In a test in which an equal quantity of particles of each size range were added to the test mixture, the sensor had a calibration factor of 1.84. However, in a mixture in which the mixture contained 50% particles from the 0-8 micron size range, 33.3% particles of the 8-53 micron size range, and 16.6% particles of the 53-106 micron size range, in the same total concentrations as in the previous test, the calibration factor was 3.75. These results indicated that in mixtures, the concentration of the largest particles had the greatest impact on the measured value. This was even more apparent when graphing the sensor's measured value as particles were added to the test mixture. This graph can be seen in figure 2 below. The first small bump represents the addition of 0.4 g of 0-8 micron sized particles. The second larger bump represents the addition of 0.4 g of 8-53 micron sized particles. The final, large jump occurred as a result of the addition of 0.4 g of 53-106 micron sized particles.

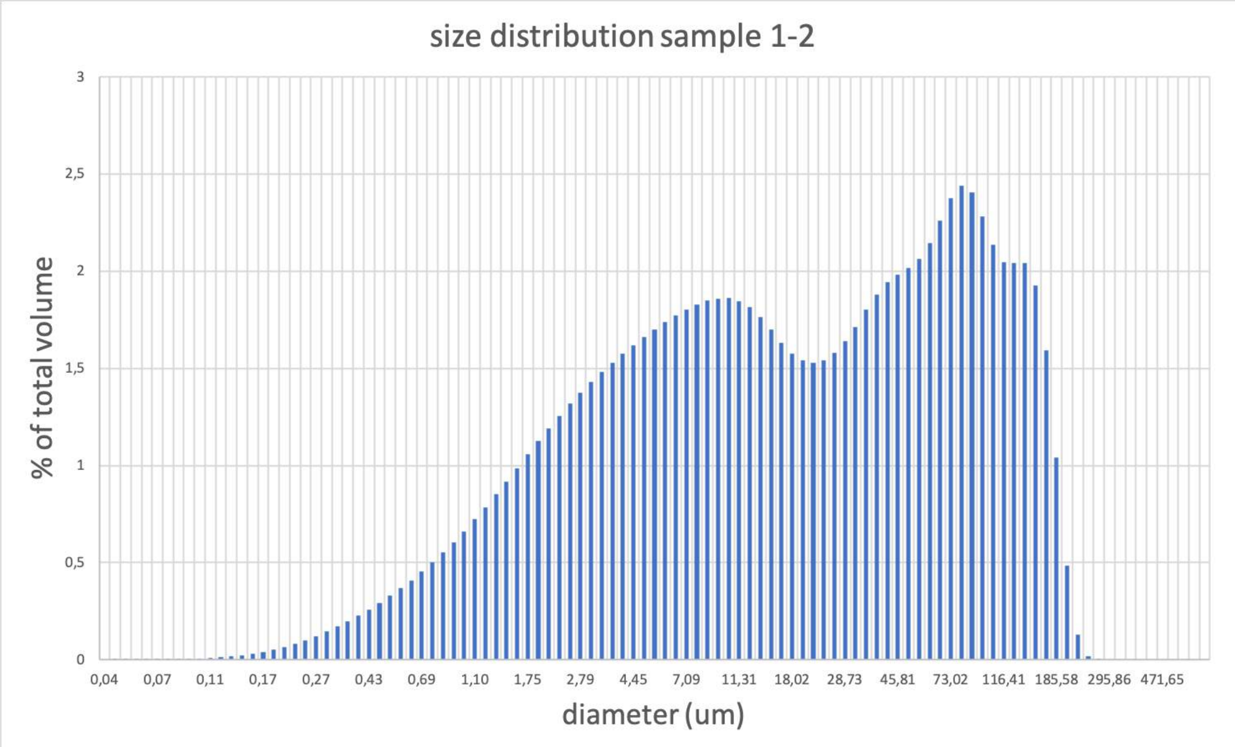
Figure 2: LISST Sensor's Measured Value Variation with Time as Particles Added.



The First small bump in this plot results from the addition of the 0-8 micron particles. The second and third jumps result from the addition of 8-53 and 53-106 micron particles, respectively.

From the water samples, a measurement of the range of suspended sediment particle sizes in the river was also found. Over the four samples that were collected and the three tests that were run for each sample, the results remained mostly consistent. The particles ranged in size from 5-100 microns, with two peaks occurring, one at around 10 microns, and one at around 100 microns. The peak at 10 microns likely results from clays present in the river, and the peak at 100 microns likely results from particles broken off from rocks and ground down to smaller sizes. The particle size distribution can be seen in figure 3 below.

Figure 3: Particle Size Distribution



This plot shows the size distribution of particles found in one of the river samples. The other samples had a comparable size distribution.

This particle size distribution, when combined with the knowledge that the sensor is not very sensitive to particles of small sizes, in particular, indicates that, when the sensor is taking measurements in the river, it is likely outputting a concentration value for those sediments that have ground down from rocks, but is unlikely to present a clear indication of the concentration of the clays present in the river.

From the deployments, other data about the river, including water depth, chlorophyll content, pH, water temperature, and other parameters have been collected, but those data are still being interpreted. As more deployments are completed, it will be possible to better understand this data and how it is relevant to the river's properties. Figure 4 shows some of the water depth data collected.

Figure 4: Water Depth Data Collected on 7/28/22

The boat followed a "lawn mower" trajectory, to ensure it covered the entire rectangular area. The depth varies between around 7 meters near the far bank to around 9.5 meters near the center of the river.

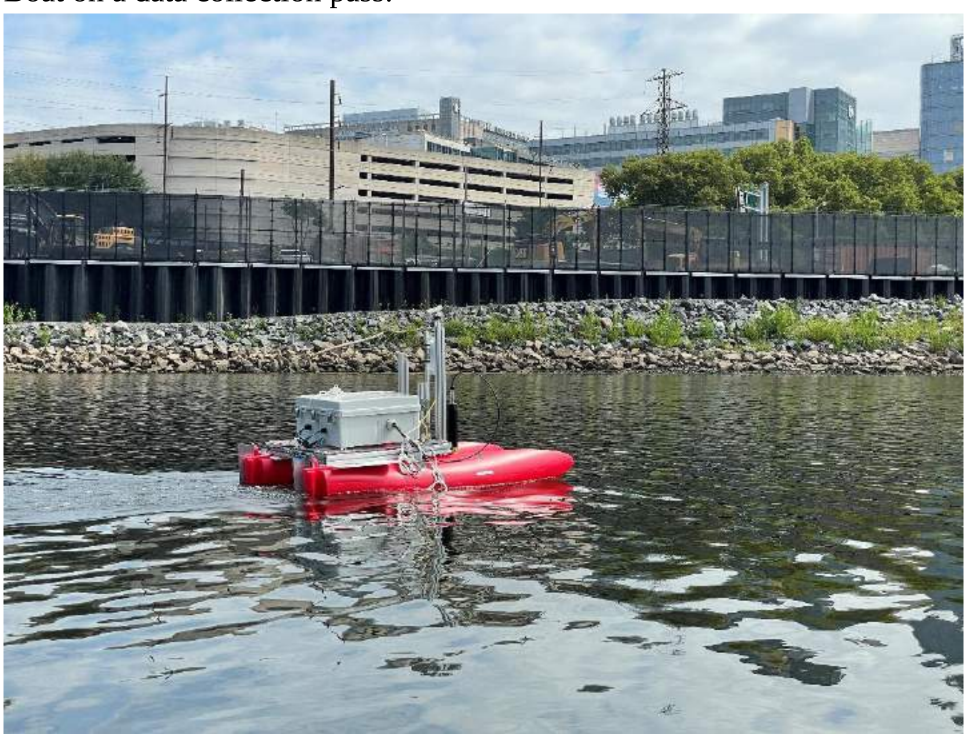
Conclusion:

In this research experience I have been involved in both lab and field components of research. In the lab component of this work, I learned how to develop lab experiments, analyze the resulting data, produce the relevant plots, and interpret those plots. I then frequently presented these plots and my conclusions to other lab group members. In the robotics and field components, I learned to work with a team of people. I helped design certain components of the boat, ensuring that my parts would work with those created by other team members. During field deployments I worked with the team to safely transport the boat to the river, and deploy it from the pier, which was a complex process which required significant coordination among team members to execute effectively. During some deployments I also followed the boat around in a kayak, adjusting the boat's systems as it was operating. This required me to learn about how all the boat's systems worked, such that I could adjust them. By integrating all these experiences, I have gained a better understanding of how scientific research is conducted and how robots operating autonomously in unknown environments can function. I also had the opportunity to speak with many incredibly knowledgeable graduate students, who greatly helped me further my knowledge of both river science and robotics. From this experience I have gained new insight into river dynamics, and autonomous boats, two topics which, at the start of this summer I knew little about, and did not know I had an interest in. I hope to continue working on this project throughout the fall, as I have become quite interested in further contributing to the project with the knowledge I have gained this summer.

Additional Photos:

Boat deployed in the river:

Boat on a data collection pass:



The team deploying the boat from the pier (I am not in this picture):