ASV Team Final Project Report
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Table of Contents

Project Overview

The Autonomous Surface Vehicle Team is completing the third and final year of a grant with the Naval Undersea Warfare Center in Keyport, WA. The final goal was to create an Autonomous Surface Vehicle (ASV) and to collaborate with the UNH ROV Team to use an Unmanned Underwater Vehicle (UUV) to perform a seafloor mapping mission in the Great Bay. This year the team had goals of improving autonomy and controls onboard the ASV, finalizing the auxiliary systems aboard the vehicle, and ultimately carrying out a proof-of-concept mission.

Much progress was made on the development of the auxiliary systems, including those necessary for UUV deployment. The small-scale Testing Unmanned Performance Platform (TUPPs) was also used to test code for the ASV's propulsion system in collaboration with students from the Computer Engineering Department. Shore to Vehicle communications were also prototyped in preparation for the proof-of-concept mission with the help of students from the Computer Science Department. An echosounder was also mounted on the ASV to gather water depth data during the mission.

Unfortunately, due to the current world events, the final proof-of-concept mission has been postponed beyond this year's graduation date. However, large amounts of engineering documentation, procedures, and manuals have been prepared to help future teams resume work as efficiently as possible, once the university reopens.

TUPPs

ASV Heading Controller

Due to the size of the ASV, most autonomy testing is not possible in the UNH engineering tank. To help solve this problem, previous teams in collaboration with graduate student advisors created the Testing Unmanned Performance Platform (TUPPs). These vehicles have a small footprint, and a relatively low cost, making procurement and operation of a fleet possible. Several versions of these vehicles have been built to support both undergraduate and graduate research over the last two years.

While electronics vary slightly between each vehicle depending on mission, each one includes the same basic components. The most important of which is a computer, either a small laptop or raspberry pi, which serves as the control terminal for the vehicle and communications with the shore. An Arduino microcontroller is also used to interface with sensors and the speed controllers. The speed controllers receive command signals and drive the thrusters at the corresponding speed. These thrusters and speed controllers are manufactured by Blue Robotics and are commonly used on small ROVs. The low voltage (5V) side of the system (computer, Arduino) is powered by one battery, while the higher voltage (12V) components (speed controllers, thrusters) are powered by three-cell Lithium-Polymer batteries commonly found in hobby RC vehicles.

This year, one vehicle was used by a team of mechanical engineering and computer engineering students to prototype propulsion control code for the ASV. This involved adding an Inertial Measurement Unit (IMU) to provide heading data. The addition of an indoor GPS (radiolocation beacon) system was also proposed but was ultimately not added due to the semester being cut short.

However, with the IMU, a large amount of testing was completed for heading control. This system used the IMU to obtain the current heading, and then calculated the error between the current heading and the desired heading, which was set by the operator. This error was then used as the input to a Proportional-Integral-Derivate (PID) controller to calculate throttle commands to be sent to the speed controllers. While other types of controllers exist, PID control requires minimal computational effort, and with a boat being a low velocity, highly damped system, it was felt that PID would be more than adequate. Initial tests showed this system to work effectively, although the PID gains needed to be properly tuned, as the response was much too slow.

With TUPPs' propulsion configuration being the same as the ASV's, the end goal was to install a heading sensor on the ASV and transfer this code with minimal modifications. Several different heading sensors were being evaluated, and options for linking them into the ASV's systems were being explored. However, due to the closing of campus, this has been sidelined for the next team, as access to the ASV is required.

Low-Cost Fleet

Due to the ongoing situation at the end of the spring 2020 semester, many ASV team members expressed interest in creating a newer version of TUPPs that could be built at home without access to UNH facilities and equipment. A new design for TUPPS was in the process of being created due to the older vehicles lacking the payload capacity and stability required for some of the graduate student research currently in progress. Due to the circumstances, another design requirement was that all components be available at local hardware stores or be purchasable online.

This new design included using plywood and polystyrene foam, instead of storage container lids and pool noodles. These could be purchased at a hardware store for less, and since the new design is a catamaran, instead of a flat bottom, stability should be significantly increased.

The payload was also estimated to be around 6 lbs, more than adequate for large sensors, such as LIDARs used in graduate student research. Additionally, lower cost thrusters were sourced, which further reduced the cost of construction. Altogether, these changes lowered the cost of construction from approximately $450 to $250 per unit.

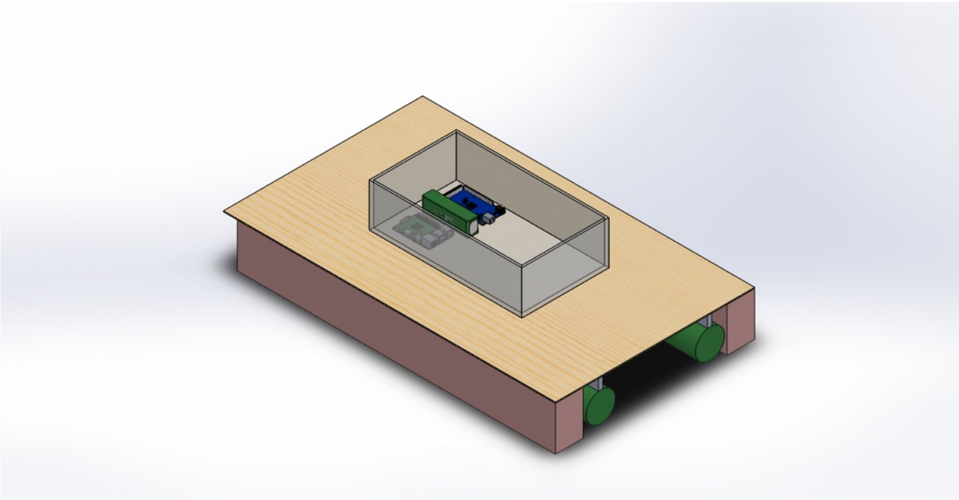

Figure 1: Rendering of new, low-cost TUPPs design.

While there were many hardware changes, care was taken to ensure that earlier versions of the original TUPPs software would work on these newer vehicles. This older software includes no autonomy but does allow for remote control to ensure all systems are working before these vehicles are handed over to next year's team. In the future, navigation equipment such as a GPS receiver and IMU could be added, making autonomy feasible. Communications between the vehicles could also be added, allowing them to function together.

Although not all components have arrived at the time of this writing due to the slowdown in mail service, a few ASV team members have successfully constructed hulls, and an initial buoyancy test had been performed. Using 50% of the available buoyancy, it has been estimated that this new hull design could accommodate a 6-7 lb payload. This is sufficient for the estimated 2 lbs of electronics and batteries, as well as any additional sensors or other equipment in the future.

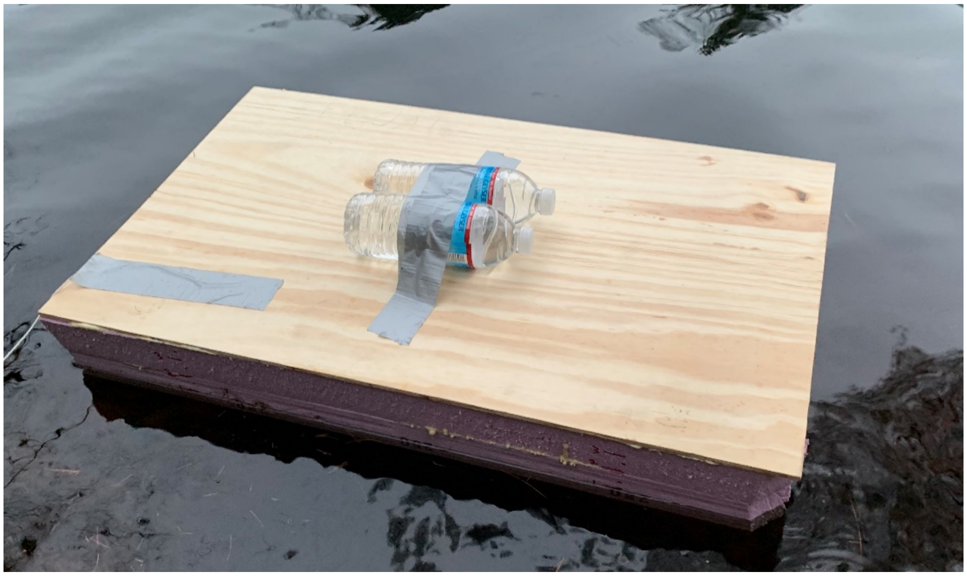

Figure 2: New TUPPs hull design buoyancy testing.

Shore Communications

The shore station's primary purpose is to enable communication between the operator and the vehicle. Although some of the work behind creating a baseline for this communication had already been completed by previous members of the team, it was not well documented or well understood by current members. Thus, the beginning of the year had several meetings that were used to test and understand the current system, as well as brainstorm new approaches that would alter or build off of previous installments.

For instance, the team had inherited two outdoor WIFI antennas from the year prior. These antennas plug directly into the laptops, one of which would be on the ASV, and the other would be used for the shore station. To send information, a point-to-point WIFI bridge connection had to be created between the two laptops after connecting the antennas. Initially, this was planned to be completed by disabling the internal WIFI within one of the laptops and creating a "hotspot" in its place, allowing the antennas to connect to that signal and pass the information. Due to technical difficulties when attempting to connect the antennas to the hotspot, the team decided to purchase an outdoor wireless access point. This equipment came with three forms of connection based on the user's needs, including access point, router, and bridge mode. By turning on router mode, the antennas worked properly, receiving the signal with no issues. The test run was completed by sending live-time sonar data to the shore station from the ASV. Additionally, a studio-grade speaker stand is in the process of being converted to a mounting system for the shore station antenna and router. This holds the equipment high up off the ground in hopes of improved connection quality and range.

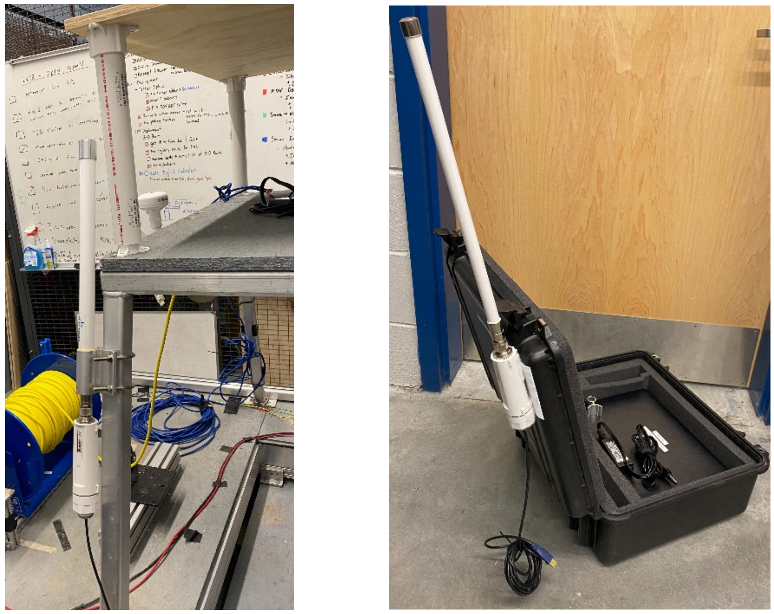

Figure 3: WIFI Antenna on ASV (left); Shore Station Antenna Deployed (right)

With a newly acquired and functioning communication system, the next goal was to decide which information would need to be sent to the shore station and how to send that data over the antennas. Sonar readings and the GPS location of the ASV were decided to be the primary information that would be sent to the shore station. Fortunately, ROS has the potential to be used across multiple machines when connected to the same WIFI signal by simply designating the ASV laptop as the “master” that would send the information and the shore station laptop as the receiver. Therefore, as the GPS and sonar data were automatically being uploaded to ROS during testing, the shore station would actively be receiving the same data. Sonar data would come in the form of depth readings, and GPS data would be longitude and latitude. Along with the transfer of data, another benefit of using ROS across multiple machines is that it would permit the user to send commands from the shore station to the ASV during a mission. This is an important detail because mission goals may be changed while the test is being conducted, or the user may want to recall the ASV back to the basepoint.

Safe procedures were also created in the case that the ASV were to experience a system failure, such as a disconnect in communications. Two "XBee" telemetry radios were used to make this fail-safe by providing a completely separate line of communication between the shore station and the ASV. An Arduino acts as the interface between the XBees and their respective systems. Then the code would automatically run as long as the XBees were connected to a power source such as a laptop. This code was created to resemble a "heartbeat" by consistently checking for valid communication. If communication were to cease, meaning that the "heartbeat" has stopped, the user would be notified at the shore station. Alternately, the ASV could be programmed to recognize the warning from the XBees saying that there is no communication, and then ROS code would tell the ASV to return to a predetermined base location, such as the launch site. It is important to note that the total range of the XBees were not able to be tested to full capacity this year, and that line of sight is needed for the XBees to operate correctly. However, the team decided that line of sight would most likely not be a problem due to the ASV operating in an open-water area where trees or other obstructions would not pose a problem.

Figure 4: XBee telemetry radio

Lastly, for the build of the shore station, the team decided on using a Pelican Case because it is waterproof, dust-proof, and extremely durable. To prevent items in the case from moving during transportation, pick 'n' pluck foam was used because it is a fast and easy way to customize and organize the container to fit the necessary items. Inside, the ASV and shore station laptops can be secured with their respective chargers. The ASV WIFI antenna is modular and can be broken down for secure storage during transit between launch sites.

Figure 5: Shore Station Box packed (left); Shore Station Antenna Deployed (right)

Overall, the shore station is able to communicate with the ASV by transferring all desired data. Future plans can be made to redesign or physically alter the existing antenna and router mounting system to create a more stable solution in the case of strong winds or other environmental factors during mission testing. A larger box may be used to include a place to secure the WIFI router during transportation as well. Documentation has been made such that any user could set up and operate the equipment at the shore station. By providing a working communication system with documentation, future teams may be able to fine-tune the system to their liking in a more timely fashion than our experience.

Tether Tensioning

The Tether Tensioning System (TTS) is the system made up of all the parts supporting the tether between the ASV and the UUV. The TTS is mainly responsible for two things: maintaining a physical connection between the ASV and the UUV and providing a data link from the UUV's sensors back to the ASV.

The system for tether management before the development of the TTS was straightforward. The tether was managed only by a single pulley, which did not give adequate arresting of motion or any way to meter the operation of the tether. This worked fine for simply keeping the tether from running on the deck of the ASV.

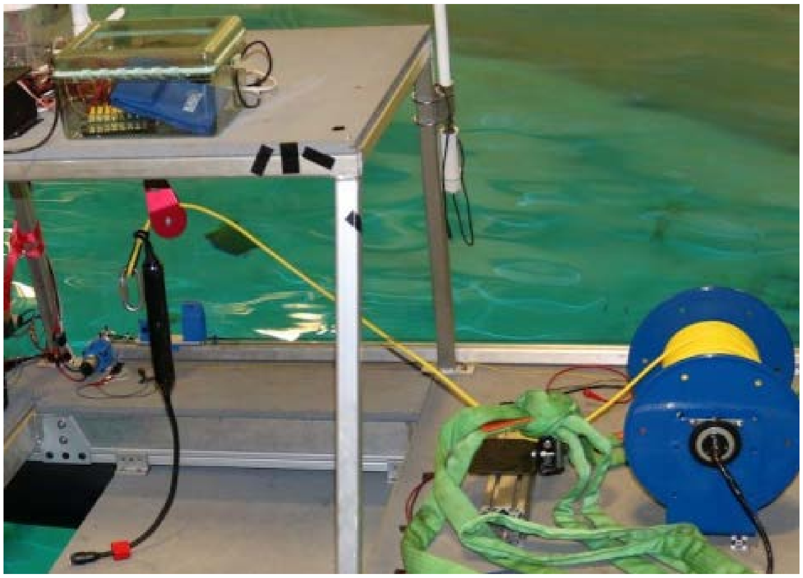

Figure 6: Original system for tether management, with only one pulley

The first design of the new TTS involved an L-bracket to attach the tension pulley to the bottom of the penthouse on the ASV. This was tested in a computer simulation and was determined to be strong enough to support the weight of the tether and the pulling force of the ROV operation, but it was determined to be too inconvenient to develop a custom bracket with the time constraints associated with the project. Therefore, a system was developed that would allow the tensioner to be attached to 80/20 hardware.

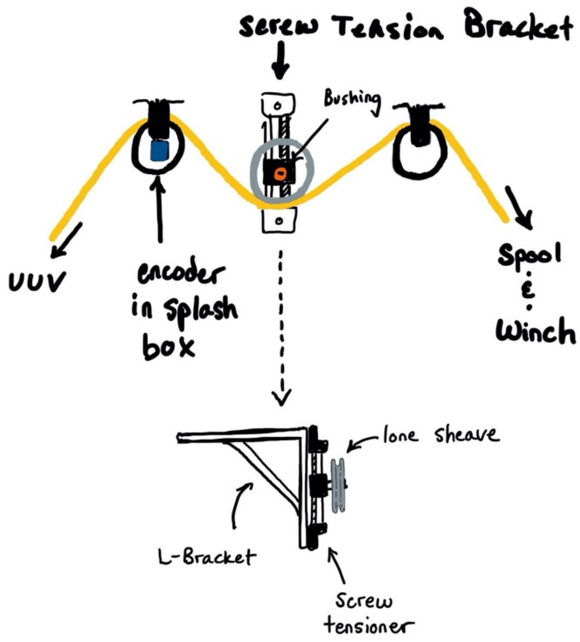

Figure 7: Old design plan of the TTS, using the L-bracket method

The current TTS mount design makes use of the aluminum tubing already present on the bottom of the ASV penthouse, which made for easy mounting. The system is mounted with carriage bolts running through the 80/20 beams, with lock washers to help keep the assembly in place. Using the existing structural hardware allowed for a secure mounting solution.

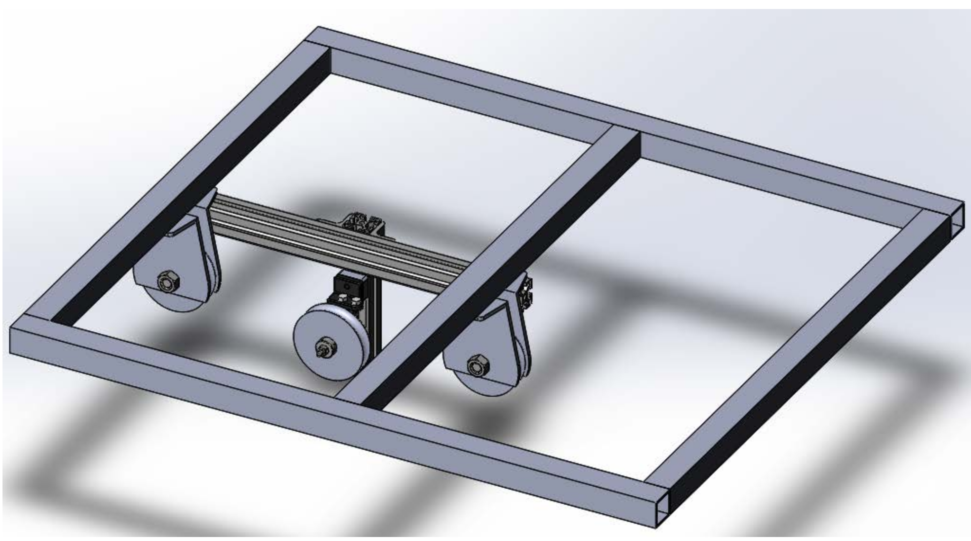

Figure 8: Last design iteration of the TTS mounting hardware, showing the attachment to the aluminum tubing on the bottom of the ASV penthouse

Figure 9: The updated pulley system on the ASV

Another critical update to the TTS was the inclusion of a rotary encoder mounted next to the first static pulley, closest to the tether spool. This encoder was implemented to control the deployment of the tether using tether length rather than controlling with only time-based commands. The encoder consists of a rubberized wheel, which rolls with the movement of the tether, and reads back data corresponding to the distance it has rotated at all points of operation, allowing the ASV to move the tether to a specific depth/position at will. Much effort has been put in to make the programming for the encoder as robust as possible, and there were some difficulties getting this part of the system to work consistently. This significantly improves the operability of the tether during both deployment and retrieval of the UUV from the ASV.

Figure 10: The rotary encoder mounted to run with the tether. Contact with the tether is maintained with a tension spring to ensure the wheel is always moving without slip

Future plans for the TTS would be mostly focused on fixing issues associated with slack tether during operation of the ASV and UUV when deployed. Having too much slack in the tether can cause issues with operation of the tether spool, including tether knotting, overlap, and kinking. This can cause damage to the tether line, which can be detrimental to the physical and data link between the ASV and the UUV. Slack tether could be managed through coordinated operation of the spool and winch with the movements of the UUV while deployed, or with a mechanical solution to constantly hold tension in the line during all operations. More work for the programming of the rotary encoder would have to be put in place to ensure that there are no errors during tether movements. This has been more difficult than expected, but much progress has been made, and the encoder has been properly coded, with comments to explain the operation of the code. This should be very helpful to assist new members of the project in the future.

Tether Management

This past summer, the ASV team had designed a system to help prevent the tether from tangling up in the spool while the UUV was deployed or retracted. The initial design was made to use a self-reversing screw, which forced the tether to move left and right consistently and spool without twisting around itself.

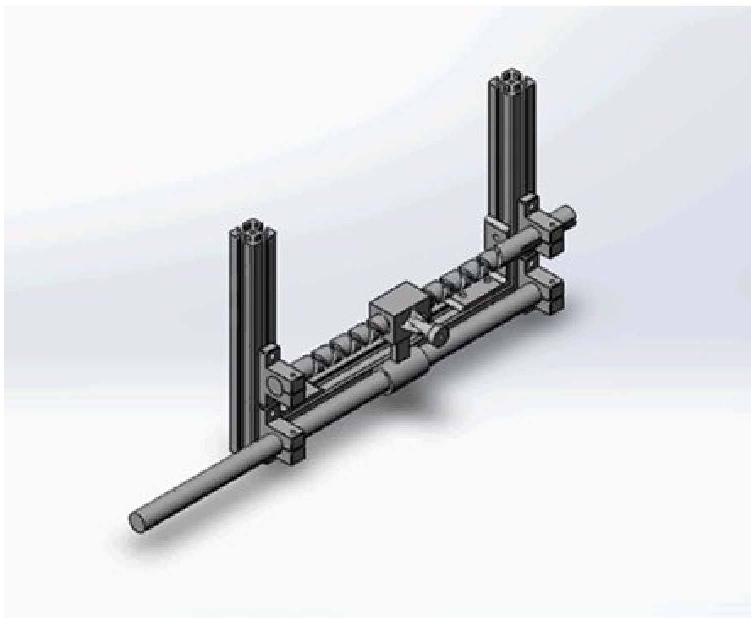

Figure 11: A SolidWorks model of the self-reversing screw design

The initial iteration of the screw was 3D printed in order to test the design. However, the plastic that was used was not durable enough and would bend, causing the mechanism to bind and eventually break the screw. A new iteration was designed with the screw made out of metal, and a local machine shop was contacted in order to determine if the part could be made. The machine shop stated that it could be manufactured, but the cost of production would much higher than our budget allowed.

An alternative method was discussed using a linear actuator instead of the self-reversing screw in the hopes that it would be a more cost-effective solution. A screw actuator did cost less but still would have taken up a large portion of our budget at the time and would have needed extensive work in order to have keep in time with the spooling of the tether. With these problems, it was decided to stop work on the tether management for the time being and focus on higher priority aspects of the ASV.

Wiring

One of the goals set at the beginning of the semester was to clean up the existing wiring on the ASV. During testing of many of the ASV’s systems, wiring connections are often a problem during the tests, which can delay the testing procedures. Even more of a delay usually comes from the process of trying to fix that connection in the field, which includes finding out which connection is at fault and attempting to repair or replace the components involved with the connection. One solution to this problem was to clean up the wiring on the penthouse of the ASV, and improve the wiring diagrams created by past teams.

The least reliable wiring component on the ASV is the sets of relays responsible for controlling the flow of electricity to various components, including the UGPS deployment motors and the motor to operate the trapdoor. Though the relay code is correct, the low-quality relays often fail to operate when needed. These would be the first parts to be replaced and organized in their own box, separate from the additional wires, motor controllers, and microcontrollers. These new relays could also be labeled clearly in order to facilitate faster diagnosis of problems during testing. In future work on the ASV, the wiring will be organized, and the new box containing the relays will be put together as a significant improvement to the wiring as a whole.

Underwater GPS

At the beginning of the year, the Underwater GPS deployment system needed several improvements to function correctly. There are four UGPS deployment assemblies on the ASV, one for each sensor that is sent into the water. The existing design was created as a prototype, so many aspects needed to be updated to meet new design requirements and allow better function. There were four immediate problems that needed to be addressed: system stabilization, axle corrosion, belt rubbing, and the design of the front-end support brackets. As the year progressed, each of these issues were addressed, modified, and fixed until the UGPS system was functioning at the desired level.

The first modifications made were those that would increase the deployment system stabilization. The design utilizes a belt system that travels across four grooved pulleys, allowing a carriage that is attached to the belt to travel from one end of the large channel to the other. The deployment arms are attached to this carriage, and as they travel closer to the front of the channel, the angle at which the arms rest becomes steeper. The steeper the angle, the farther the UGPS sensors are located under the surface of the water. This is good for sensor readings but results in severe amounts of instability in the arms themselves. Currents were torquing the arms and causing damage, so something had to be done to damper that movement as much as possible. This was achieved in two ways, the first of which was done by making modifications to the carriage slider. This slider is what keeps the carriage on the main channel track and had a significant amount of wobble when deployed. The original design had the inside corners at 90-degree angles, but the channel it rests on is filleted. To decrease the amount of movement, the inner corners of the slider were reprinted to include an offset of the filleted channel corners, making them more stable.

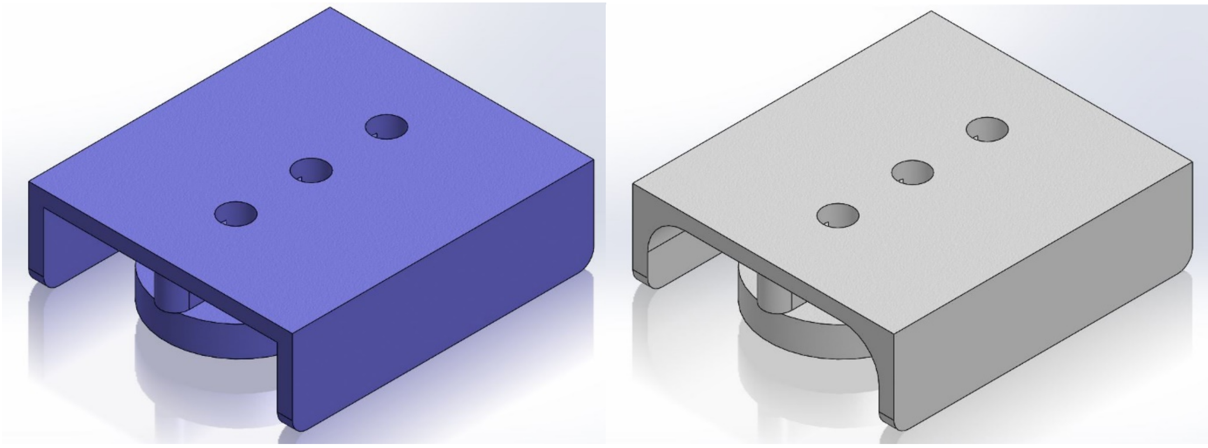

Figure 12: Old (top) and new (bottom) slider models

The second stability improvement was the addition of an arm guide subassembly. The assembly is made up of two tall arm guides, two pairs of nuts and bolts, and one spacer. The assembly is located at the front of the main channel and reduces the amount of movement in the arms when they are torqued by strong currents by providing extra support to the base of the deployment arms. The arm guides attach directly to the main channel and sandwich the track between them. Two pairs of nuts and bolts secure the guides together to prevent them from moving in different directions, one at the top of the guides and one at the bottom. A spacer was placed along the top pair to make sure the guides were always spaced apart enough for the arms to travel smoothly between them. Before its assembly onto the deployment system, simulations were done on the subassembly to make sure it would be able to handle strong currents. These simulations were done using SolidWorks, and it was found that even at strong currents, the subassembly would only deform a few millimeters. Its addition to the full deployment assembly reduced the torque angle for high current waters by a significant amount and has proved to be very useful.

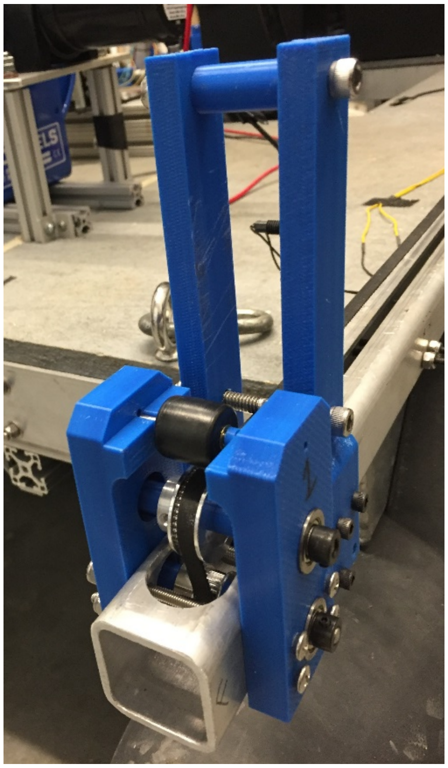

Figure 13: The guide arm assembly on the ASV

The replacement of corroded axles was the next issue to be fixed. Aluminum axles were being used in the prototype design, and after multiple tests, the front axles had rusted and become stuck to the front-end support brackets because of all the water that was dripping on them from the retracted arms. Rust caused binding in front pulleys and restricted belt movement on all four of the deployment systems. Stainless-steel axles were ordered to replace the front axles, as they would not rust and become stuck like the aluminum ones. The axles are housed in bearings on the front-end support brackets, which were going through a redesign at the time. It was decided that all the front support subassemblies, including the axles, would be dismantled, cleaned, and reassembled until the new support brackets were ready to be replaced. After almost seven hours of continuous work, all the aluminum axles were able to be removed and cleaned until they could successfully rotate in their bearings.

Fixing the belt rubbing was also a simple matter of replacement. The belts were rubbing on many of the internal screws, causing them to loosen and, in some instances, fall off the ASV. Nyloc nuts were purchased to replace the existing, regular nuts that were being used. The nyloc nuts are only able to be removed with wrenches, which made them the perfect substitute to fix this issue. Once all the problem areas were identified, the old nuts were removed and replaced with the new nyloc nuts; this process took a few hours, but the result has been well worth the effort.

The final issue to be addressed was the design of the front-end support brackets. While there are two axles placed through these brackets, only one was put through bearings, which was a concern. It was determined that the belts would move more freely if both axles were supported by bearings, which created the need for a redesign. This proved to be a crucial decision, as a few additional parts were added to the front support assembly with the addition of these new brackets. The new design included space for two bearings, one each for the top and bottom axles, as well as a support for a roller. It was decided to add rollers to the assembly to reduce metal on metal friction caused by the arms, as they originally rested on the main channel when being deployed. The rollers are made of rubber and rotate freely along a smaller third axle. When the redesign was complete, the brackets were 3D printed, and the entire front support assembly was once again disassembled and put back together, this time with the stainless-steel axles and new brackets.

Through the multiple disassembly and reassembly processes done to make these changes, a few more changes were made to improve the functionality of the system. The top, front belt pulleys for all four deployment systems were replaced, going from a 20-tooth pulley to a 40-tooth pulley. This reduced belt skipping by a fair amount when the arms were being retracted, as the steep angle and mass of the sensors was producing a fair amount of lifting strain. To reduce the lift angle, a new part was designed to be placed over the limit switch mounts. These parts, called limit switch extenders, allowed the limit switches to be moved back in different increments from their original location. Moving the limit switches back reduced the steepness of the deployment angle, allowing the arms to come out of the water with less difficulty.

The progress on the UGPS deployment system has resulted in smoother operation and more successful tests. Unfortunately, due to the seasonal changes and unpredictable emergence of the pandemic, the system was never able to be tested in the Jackson Estuary to see how it would perform in a real, changing current, but the improvements have none the less made the system better than it has ever been.

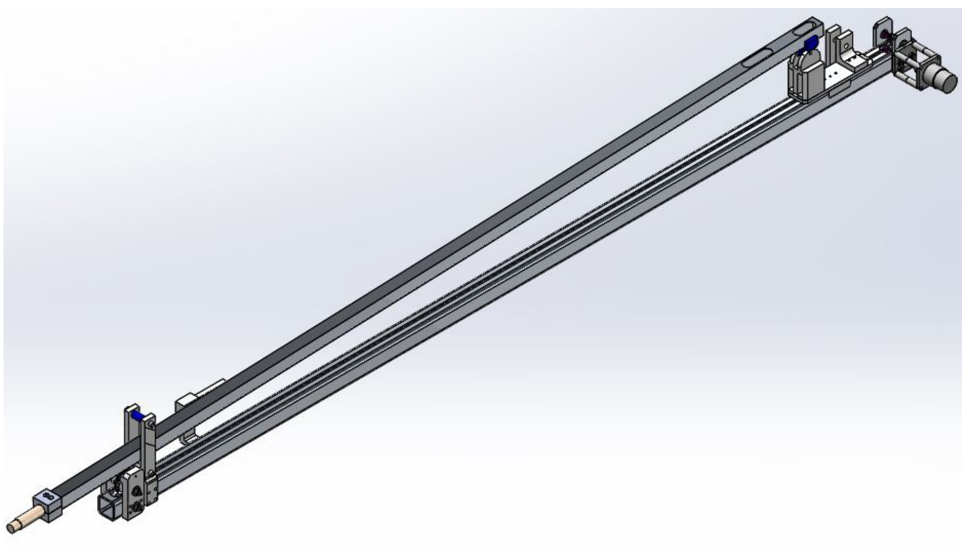

Figure 14: The UGPS SolidWorks model in its retracted position

Sonar Data Acquisition

Object detection was one of the optional objectives included in the primary ASV mission. The concept was to use an acoustic sensor to search for any objects of interest during the primary mapping mission. At the start of the year, the ASV had no acoustic sensors and no permanent way to attach it to the vessel. Naturally, the first task was to find an acoustic sensor at a reasonable price. Since side-scan and multi-beam sonars were out of the budget, a Blue Robotics Ping Sonar echo sounder was selected. This sensor measures the distance to the seafloor, or a lakebed, with a maximum range of 30 meters. It has a 30-degree beamwidth and an open-source software interface that allows for data to been easily viewed and logged. Once the sensor was ordered, it had to be fastened to the ASV.

Since the ASV was completed by a previous team, space was not readily available to mount the echo sounder. To reduce any acoustic interference from the motors mounted on the stern of the ASV, the optimal placement for the mount was near or at the bow. Fortunately, the trapdoor for ROV does not use the full length of its rails, which were bolted to the underside of the ASV. After taking some measurements, it was discovered that there were a few inches of room on the underside of the bow to attach the mount. The mounting structure was designed within SolidWorks and constructed using 80x20 material, and 3-D printed parts. The 80x20 material was selected such that the mount could be easily altered to house a different senor if desired.

While the mount was being constructed, initial tests of the echo sounder were conducted to find the best practice of logging data. All tests were done in the engineering tank in the Chase high bay. Once a standard test method was created, the Blue Robotics echo sounder was tested numerous times for object detection. During these tests, the data from the echo sounder was interpreted by an Arduino, passed to ROS onboard the ASV laptop, and saved for post-test analysis. Throughout these tests, multiple targets, including plywood and mooring buoys, were placed in known locations in the engineering tank. The sonar was fastened to the carriage such that it could move across the tank smoothly. This improved the repeatability of the tests. Unfortunately, the echo sounder was found to be unable to consistently locate a target near the tank wall, which simulated the lake bed. After conducting numerous tests, object identification via the echo sounder was scrapped, and the final mission would have only required the echo sounder to log data.

If the pandemic had not interrupted plans, one last test with a homemade target was planned. The target would have been a thin sheet of metal, suspended off the bottom of the tank by mooring buoys. The echo sounder would have been pointed down to detect the object. The idea was that if the target was away from the tank wall or floor, then it could easily be detected, and the target could be placed in the final mission site. A side-scan sonar was almost purchased as well, which would have aided in object detection. At the end of the year, the echo sounder has only been proved to log data. However, given time, it may be able to fulfill its original purpose.