Team MANTA RAY: Marine and Naval Technological Advancements for Robotic AutonomY

TECH 797 Final Report

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Advisor: Dr. May-Win Thein

Graduate Advisors: Oguzhan Oruc, ME PhD, Hannah Arnholt, OE PhD, Nicholas Custer, OE PhD, Igor Vladimirov, OE M.S., Rich Randall, ME M.S.

Students and Delegation— Sub-team leads underlined

- **ASV:** Matt Radzelovage, Jessie Barker, Will Seguin
- **GUPPS:** Will Conner, Caroline Russell, Gavin Cherella, Amanda Enderson, Shelly Lancaster
- **UUV**: Marguerite Kennish, Jack Hamilton, Brendan Ulrich
- **Team Captain:** Jenna Ehnot

Sponsors:

Abstract

Marine And Naval Technological Advancements for Robotic Autonomy (MANTA RAY) is composed of four main subgroups Autonomous Surface Vehicle (ASV), Unpiloted Underwater Vehicle (UUV), Ghost Unpiloted Performance Platform System (GUPPS) and KRILL. The project's goal is to create a modular network of marine robots for missions such as seabed mapping or underwater surveying and inspection. Within this mission is an emphasis on the development of autonomous behavior and underwater perception and communication.

ASV

The purpose of the ASV is to autonomously navigate a given path for seafloor mapping, as well as deploy and retract the Unpiloted Underwater Vehicle (UUV), another vehicle within MANTA RAY used for underwater observation. The ASV subteam's objectives this year were to update the mechanical systems used for UUV deployment and recovery, and to develop an algorithm to autonomously activate these systems based on location data from the GPS.

UUV

The UUV is deployed by the ASV, to conduct underwater water investigations within an area of interest. The UUV subteam's objectives this year were to design and manufacture a payload skid, a structure that could be attached to the UUV's existing frame. The skid's purpose is to carry housings for additional sensors and batteries, expanding the perceptive capabilities and endurance of the UUV. In addition to this, the subteam focused on establishing communication between the UUV and the ASV, initial investigations into GAZEBO simulations, as well as aiding in the construction of a new MANTA RAY vehicle known as KRILL.

GUPPS

As a new addition to the MANTA RAY project, the mission of the GUPPS subteam was to design and manufacture a biomimetic robotic fish. Built to resemble a steelhead trout, GUPPS is intended to be used as a nonintrusive habitat observer at AquaFort, a UNH aquaculture enclosure. In addition to this, GUPPS will be used to prototype and test methods of wireless underwater communication being investigated by MANTA RAY.

Introduction and Background

Team MANTA RAY is an interdisciplinary project dedicated to creating, maintaining, and expanding a network of autonomous marine robots for seafloor mapping and underwater perception. The network began as just the autonomous surface vehicle (ASV) and unpiloted underwater vehicle (UUV), but has expanded to include a prototype of the ASV, known as TUPPs, and two kinds of remotely operated vehicles, known as GUPPS and KRILL. With these systems, students worked to improve communication between vehicles, develop autonomous behaviors and algorithms, and upgrade existing mechanical systems to improve precision and performance. A background for each of the three subgroups is provided below.

ASV

The ASV is built to be able to perform a variety of functions in the MANTA RAY fleet autonomously, including seafloor mapping, deployment and recovery of the UUV, and serving as the communication hub for messages between the ASV, the UUV, and shore station. The project began during the 2017-2018 school year, and has been under continuous development since then. To serve as a testbed system for ASV software testing, a smaller vehicle was made. Referred to as the Testing Unpiloted Performance Platforms (TUPPs), this smaller ASV allows the team to test and retest ASV software more efficiently, as it is a lot more manageable to test TUPPs in the Chase Engineering Tank than the full size ASV.

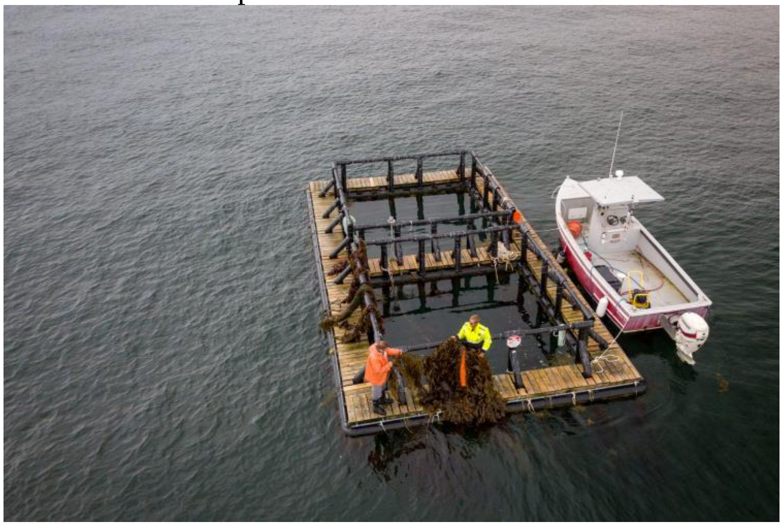
The most essential tasks of the ASV are to autonomously navigate between user specified GPS coordinates and to carry the UUV on mapping missions. Once the ASV reaches a specified coordinate of interest, it deploys the UUV and maintains its position, and retracts the UUV when it has completed its subsurface mission. To accomplish these tasks the ASV has five main subsystems: an on-board computer system, propulsion and control systems, an automated trap door, the Tether Tensioning System (TTS), and an Underwater “GPS” (UGPS). The on-board computer system acts as the “brain” of the ASV, controlling the code for the other subsystems. It also enables the ASV and UUV to communicate with and be monitored by users on shore through a laptop referred to as the Shorestation. The propulsion and control system enables autonomous navigation between waypoints. The automated trapdoor is located in the center of the ASV deck, and opens to allow the UUV to be deployed into the water below. The Tether Tensioning System (TTS) maintains the communication tether that connects the UUV to the ASV. The TTS spools the tether out to allow the UUV to swim freely in the water and retracts tether to retrieve the UUV upon completion of its mission. Lastly, the UGPS is an acoustic positioning system used to track the location of the UUV while it is underwater. The system is comprised of four acoustic nodes and an acoustic beacon. The beacon is fixed to the UUV and the nodes are deployed on four cascading arms when the UUV is in the water. The UGPS system can then triangulate the position of the UUV relative to the ASV.

UUV

Once the ASV reaches a point of interest it autonomously deploys the UUV and four acoustic nodes. The UUV has an additional node attached to the structure. The UUV uses the nodes on the ASV~~,~~ and itself to determine its relative position to the ASV below the surface. The ASV knows its GPS coordinates and relays the information to the UUV. The UUV can extrapolate its global position using the ASV global position and the UUV’s local position. The UUV will then perform autonomous surveying patterns below the surface to record video and other sensory data. After path completion, the UUV will return to the ASV for retrieval.

GUPPS

The Ghost Unpiloted Performance Platform Submersible, or GUPPS for short, is one of newest additions to the MANTA RAY fleet. GUPPS is a biomimetic fish and the broad purpose of its usage is to non-intrusively investigate underwater areas of interest. GUPPS is modeled after a *Oncorhynchus mykiss*, commonly known as a Steelhead trout, as they are native to the United States and are currently being raised in the UNH AquaFort. The UNH AquaFort is an offshore aquaculture farm and research site located at the mouth of the Piscataqua River, and would be the location for the first implementation of GUPPS.



New Hampshire Sea Grant's AquaFort.

The steelhead trout being farmed in the Aquafort have had issues with growth in the past and researchers have tried to understand the potential barriers to their growth using UUVs, but have been unsuccessful as a UUV is a large disturbance to their habitat. GUPPS could be equipped with the required sensors to monitor the Aquafort environment and can be used to monitor the health of the trout without disturbing the habitat or stressing the fish. This could be utilized on a larger scale in locations other than just the AquaFort. Any underwater area of interest that needs to be investigated could utilize a GUPPS school to reduce the human footprint on the environment. This is the motivation behind the project and what the goals of GUPPS are focused around.

Objectives

ASV

The ASV team's objectives during the 2021-2022 school year were to finish developing its subsystems and to integrate them into an autonomous launch protocol to deploy the UUV. While previous teams had begun creating the ASV's subsystems, the tether tensioning system (TTS) and Underwater GPS (UGPS) system were still incomplete and unreliable. Once these systems were completed, an autonomous launch protocol would allow the ASV to operate its subsystems in conjunction with each other upon reaching a specific GPS waypoint during a mission. Without this, the subsystems have to be individually triggered by an onboard user. The development of this protocol would remove the need for user input while the ASV completes a mission, making this a necessary step in creating a more autonomous vehicle. Throughout the year, the mechanical engineering students of TECH 797 collaborated with computer science students Patrick McKinnon and Andrew Weeks to create this launch protocol. In addition to the completion of the subsystems and the launch protocol, the ASV team made it their mission to redesign the Testing Unpiloted Performance Platforms (TUPPs), which are mini-ASVs prototypes used to test sensors before installing them on the ASV. This redesign would better simulate the ASV's software and hardware architecture so that the launch protocol to be tested more frequently and rapidly than having to use the full size ASV.

The purpose of the tether tensioning system (TTS) is to maintain tension on the UUV tether between the winch and the pully system. When the UUV is deployed, enough tether must be released such that it can swim freely but is not in danger of tangling itself. To allow the UUV to swim freely, there must not be any tension in the tether, but the winch cannot properly spool if the tether has no tension. In order to provide slack tether to the UUV but taut tether to the winch, the previous year's team designed a system that uses a rubber compliant wheel that pinches the tether between the winch and the first pull and spins at the same rate that tether is released. The idea is that this would maintain tension between the first tether and winch, allowing it to spool properly, while still feeding slack tether to the UUV. While this had already been designed, it was not yet fully functional. One of the largest issues was that the winch of the TTS was not properly welded, causing it to spin inconsistently and putting additional stress on the motor. The ASV team this year aimed to replace the winch and complete the TTS design from the previous year. Additionally, to enable active spooling of the tether during missions, an encoder needed to be added to the system and integrated into the code. Without the encoder TTS ran purely on time, while an encoder would allow the system to spool and unspool based on distance instead.

Another subsystem that needed to be redesigned was the UGPS. This system was redesigned in the summer of 2021 to use cascading arms with bi-directional spooling to raise and lower acoustic nodes used to track the location of the UUV when underwater. Long PVC pipes with magnetic bolts were fixed to the arms to trigger magnetic limit switches, indicating the arms had completed deploying or retracting. The pipes were unreliable and inconvenient to use, as even the slightest wobble in them could cause the trigger and switch to fall out of alignment, deeming the arm unusable. This year's team completed the UGPS redesign by implementing two additional switches on each arm and rewiring the whole system.

The TUPPs redesign required two major changes. The first was to redesign its pontoons. The old pontoons were made of Styrofoam with the motors placed next to them. These pontoons were not waterproof and would absorb water as TUPPs was used, making it significantly heavier. With the motors next to the pontoons, they were not deep enough to achieve their full thrust capability, and their turning was less than ideal. The new pontoons needed to be waterproof, be able to hold the motors at a deeper depth, and have better hydrodynamics. The second change involved adding a Pixhawk flight controller, a Raspberry Pi ARM single board computer, and an Arduino microcontroller. These would replicate the Pixhawk already used on the ASV, the Pi would replace the ASV laptop, and the Arduino would simulate the Arduino used to control the subsystems on the ASV.

UUV

PhD candidate Oguzhan Oruc has been developing a controller to enable UUV autonomous mission execution. For this project, the UUV is the Blue Robotics (heavy configuration). The controller requires additional hardware, including a 4-inch diameter capsule, and Doppler Velocity Log (DVL). The DVL can determine the UUV's relative velocity to the seabed floor. The DVL and the UUV position determined by communication with the ASV will be used as sensor feedback to the controller. The additional hardware required new housing below the UUV. The undergraduates designed, simulated, and constructed a payload skid to accommodate the current sensor housing configuration. The team also designed for future sensor housing and configuration modularity.

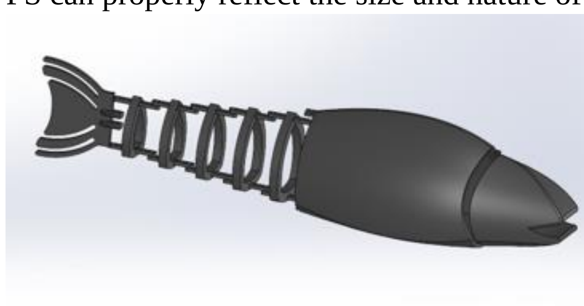
The subteam began initial investigations into robotic simulations using GAZEBO an open-source physics program. The simulation could be used to test subtle controller changes, without requiring the engineering tank, or associated hardware access. This year the goal was to create an introductory manual for SOLIDWORKS to GAZEBO file conversion, basic model creation, and to have team access to a remotely operated vehicle (ROV) version of the UUV in a simulation environment.

Additionally, the team also supported students in developing KRILL processes. KRILL is a Naval Undersea Warfare Center (NUWC) Division Keyport(Keyport, WA) partially funded project. Keyport provided MANTA RAY with a laser 3D-printed hull to recreate their robot. The UUV mechanical engineering students manufactured, reverse engineered, and assembled the platform. The goal this year was to recreate the robot developed on the east coast while determining documentation errors to be fixed.

KRILL is intended to be a robot that can be easily recreated and modulated at other bases. KRILL uses a shaft-less propeller system. Removing the shaft penetrations will reduce the maintenance cost to keep the KRILL operational. The motors are housed within the KRILL body. They are attached to adapters that house Neodymium magnets. The adapters are placed near the hull. The propellers have additional magnets the propeller. The adapters and propellers are attracted to each other across the hull. The magnetic field also allows the motor to cause the propeller rotation. This robot will make an excellent addition to the MANTARAY fleet.

GUPPS

Previous to this year, GUPPS existed solely as an idea with basic drafts of CAD models. The GUPPS team goal this year was to finalize design specifications and bring it to life as a working model in air. This includes adjusting the existing CAD models to fit the biological requirements so that GUPPS can properly reflect the size and nature of a Steelhead trout.



Fully assembled GUPPS CAD model.

In order to evaluate the CAD design and how it would perform in the expected environment, a number of Finite Element Analysis simulations were performed before bringing the design to life. Once the design is finalized the objective for this year is to construct a mechanically working GUPPS in air. This includes using mechanical design to combine all of the required components of the fish and determining a way to achieve proper tail motion so that it can be self-propelling once in water.

Biomimetic tail motion is one of the main goals of the project for this year, to design a method for smooth tail motion in water with enough tensioning and resistance to provide propulsion to the fish, just as a real fish swim using its tail to move forward. Under the umbrella of the tail motion, the electronics used to move the tail must be researched, tested and implemented. This includes writing scripts for a microcontroller and designing a feasible circuit for the system to work on.

Another one of the GUPPS teams' larger goals is the design for modularity. Knowing that this project will be worked on in future years, it is best to allow for ease of changes and not make anything too permanent, especially in terms of the electronics and controls. Considering this, a shelf is designed that the electronics SafetyBox will be Velcroed on to. This will allow the electronics to be removed and altered easily without having to start from scratch. Implementing graduate research and any specific desired sensors can easily be integrated via changing what electronics are inside of the SafteyBox.

Modularity of safety box as it is taken out of the body.

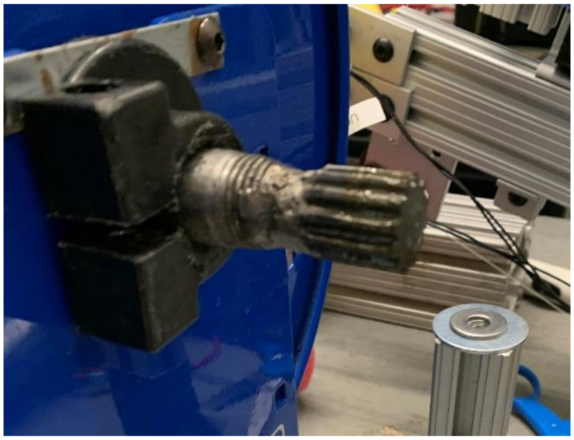
Although it is known that the project will need to be waterproofed to be used in the future, the scope of the project for this year does not include waterproofing or understanding how it will maneuver in water (i.e., buoyancy, pitch, direction) other than the propulsion aspect. These objectives will be considered during design and construction to allow forward progress for future teams but are not considered a focus of the project this year. A perfect example of this is when designing the electronics, waterproofing was kept in mind, and the implementation of a waterproof box, or SafteyBox, discussed above will be used to contain the electronics. These set limitations on the scope of the project are due to time constraints and the desire to set goals that are obtainable. Team MANTA RAY and the sub-team of GUPPS is a project that will continue after this year; therefore, these can be objectives for the future team to accomplish.

Methods

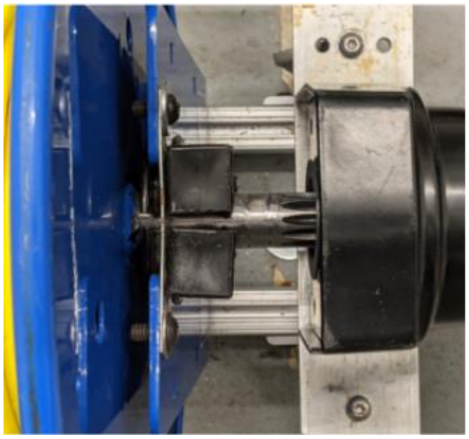
ASV

The Testing Unpiloted Performance Platform (TUPPs), is a micro ASV designed to simulate our full size ASV for a more cost effective and easy to use solution to indoor testing. To resemble the full size ASV architecture, a Pixhawk for autonomous control, Raspberry Pi to replicate the ASV laptop, and Arduino microcontroller to allow for simulation of subsystems was incorporated in to the TUPPs. Using the Arduino microcontroller, sets of LEDs were implemented to simulate each subsystems deployment to show live results during testing. Along with this, TUPPs underwent a pontoon redesign to improve the overall power output and maneuverability. This was done by removing the old Styrofoam cutout pontoons and flimsy motor brackets, replacing them with thin PVC tubing that were sealed on either end with 3D printed end caps. The rear end cap was designed to mount the motor directly with a slight 5-degree pitch, keeping the motor fully submerged and promoting the ability to plane.

At the beginning of the academic year one of the first issues the team noted was the misalignment of the ASV's TTS winch axial. This misalignment was causing the motor to rotate the winch drum unevenly resulting in rattling of the winch drum and uneven spooling of the tether. In order to fix the axial, the winch motor was detached from the drum, the drum detached from the ASV, and the tether was unspooled. The winch drum-axial assembly along with a new motor gear interface were taken to Scott Campell in the CEPS machine shop to be professionally welded. The old motor gear was grinded off to remove any remanence of the previous weld job. A side-by-side image of the old winch axial and the new winch axial is shown below.

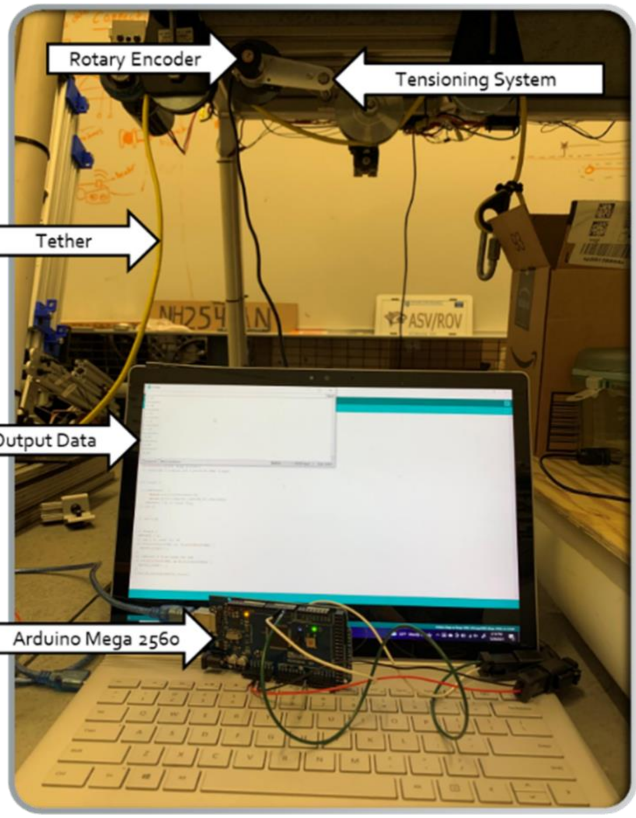


Before



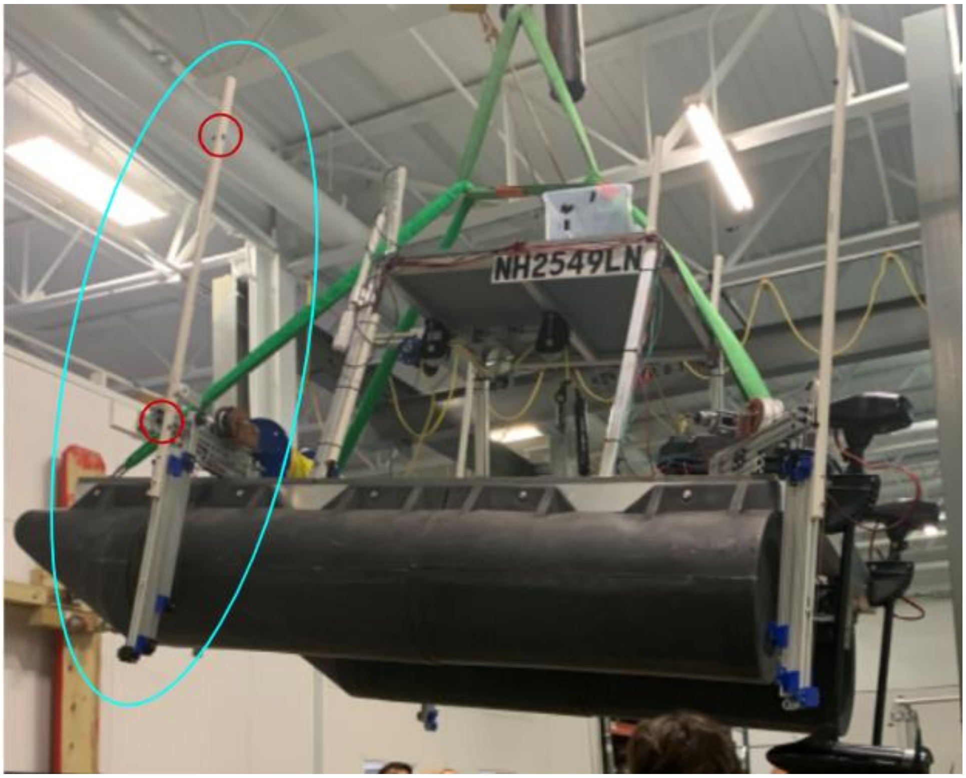
After

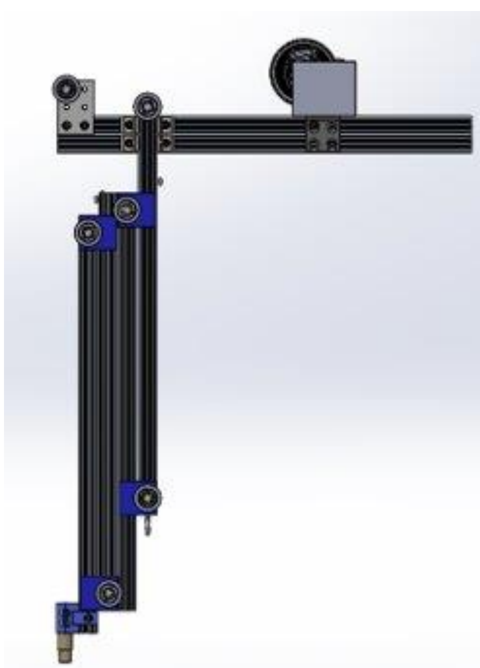
One of the tasks for the tether system on the ASV was to integrate an encoder to measure the exact length of tether deployed. The device used is a pulse rotary encoder that has 1000 pulses per rotation. This is then connected to an Arduino microcontroller that takes advantage of an interrupt sequence. This interrupt allows for the microcontroller to only process the moment the pulse changes, allowing for the microcontroller to not get bogged down by processing every output of the rotary encoder. These pulses are then put through a simple counter that works in the positive and negative direction, allowing for accurate live tracking of the tether.

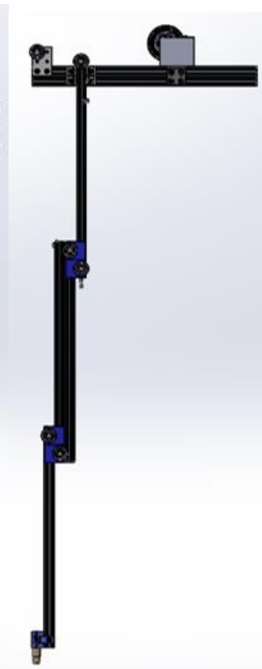



```
#define CHA 2
#define CHB 3


volatile int master_count = 0; // universal count
volatile byte INTFLAG1 = 0; // interrupt status flag

void setup() {
  pinMode(CHA, INPUT);
  pinMode(CHB, INPUT);

  Serial.begin(57600);
  //Serial.println(master_count);

  attachInterrupt(0, flag, RISING);
  // interrupt 0 digital pin 2 positive edge trigger
}

void loop() {

  if (INTFLAG1)   {
       Serial.println("Distance:");
       Serial.println(master_count*M_PI*0.064/1000);
     INTFLAG1 = 0; // clear flag
} // end if


} // end loop


void flag() {
  INTFLAG1 = 1;
  // add 1 to count for CW
  if (digitalRead(CHA) && !digitalRead(CHB)) {
    master_count++ ;
  }
  // subtract 1 from count for CCW
  if (digitalRead(CHA) && digitalRead(CHB)) {
    master_count-- ;
  }
  //Serial.println(master_count);
}
```

To further move the UGPS deployment system towards its final design, the temporary PVC pipe limit switch rails (shown below) were removed and the magnetic limit switches, two receivers and one magnet (circled in red), were moved to the aluminum extrusion. Renderings of the final design with new limit switch locations, again circled in red, are shown below the previous design image.







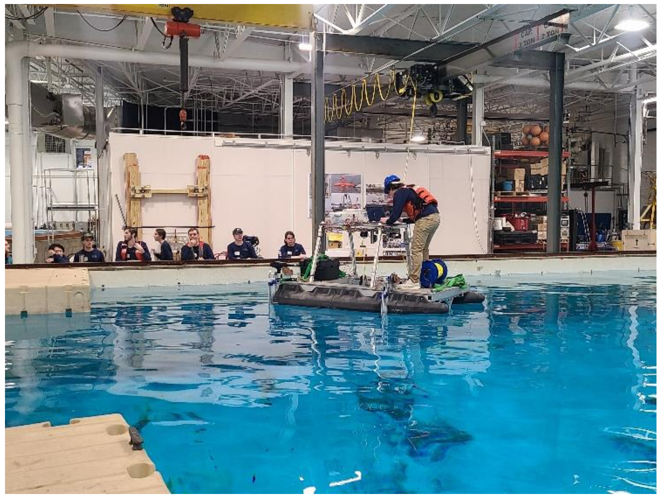
System testing was done in the Chase Engineering tank this year. Open water testing at Mendums pond, Jackson Marine Estuary, and off the UNH research pier in New Castle, was considered, however due to concerns of the water being too cold and thus endangering team members, no open water testing was done. Working in the engineering tank, while not having any environmental issues, did mean that the Pixhawk could not get a GPS signal. To fix this problem, graduate student Nick Custer developed an indoor GPS system that used acoustic nodes set up around the tank and on the vehicle being tested to simulate a GPS signal.

Once this system was operational, a day of testing with TUPPs was done in order to get the launch protocol working in early February. After some troubleshooting with Pixhawk, the protocol was able to run at a specified loiter waypoint.

TUPPS tank testing

With TUPPs able to simulate the launch protocol, a full-scale test of the ASV was done at the end of February. There were several findings during this test, the winch motor had faulty connections due to missing insulation, and an unknown problem with Pixhawk not publishing data from a topic that it did with TUPPs. The computer science students working on the ASV team believed it was an issue with Pixhawk configurations that needed to be changed to operate the indoor GPS. Due to this, the launch protocol was not able to run, however the UGPS was able to successfully work.

After working to fix the connections and Pixhawk, another ASV test was done near the end of March. The goal of this was to continue testing the launch protocol. After a dry test inside the MANTA RAY lab two of the UGPS arms were unresponsive. After some troubleshooting the team decided to wet test without them. During this wet test the same Pixhawk issues which hindered the last were found. These were unable to be solved and the computer science students believe it was still an issue with configurations. The launch protocol could still be tested by faking the Pixhawk data and it was able to run all the systems in the correct sequence.



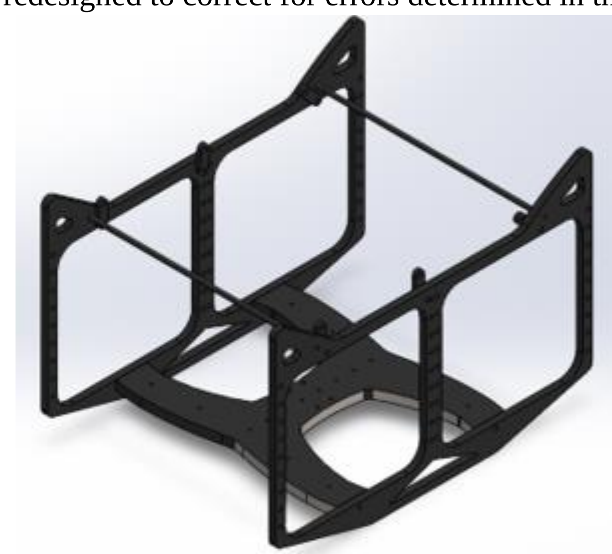
ASV tank testing

UUV

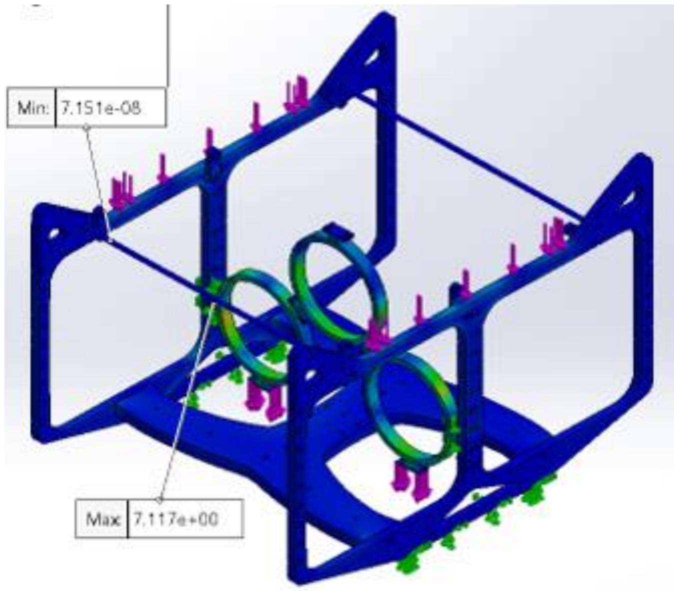
The Payload Skid Design

The payload skid was designed to house the DVL, controller hardware, and other future equipment. The skid had to support 22 lbs., the weight of the UUV in the air. The skid also had to hold 3, 4 in. BlueRobotics watertight tubes. These capsules will contain the controller hardware. The skid also had to have the potential to hold 2, 8 in. BlueRobotics payload tubes for future sensor application. Secondary design parameters included minimal payload skid weight, and size. Both will allow for easier transportation, and ASV loading.

The initial skid designs were inspired by the BlueRobotics skid, available for purchase online. Their skid is too small for the project parameters. Thus, the skid had to be constructed in house. The team design was modeled in SOLIDWORKS. The group used the simulation tools to perform Finite Element Analysis to determine the structure's capability to support the UUV out of water. The skid was then redesigned to correct for errors determined in the simulation.



SOLIDWORKS Payload Skid

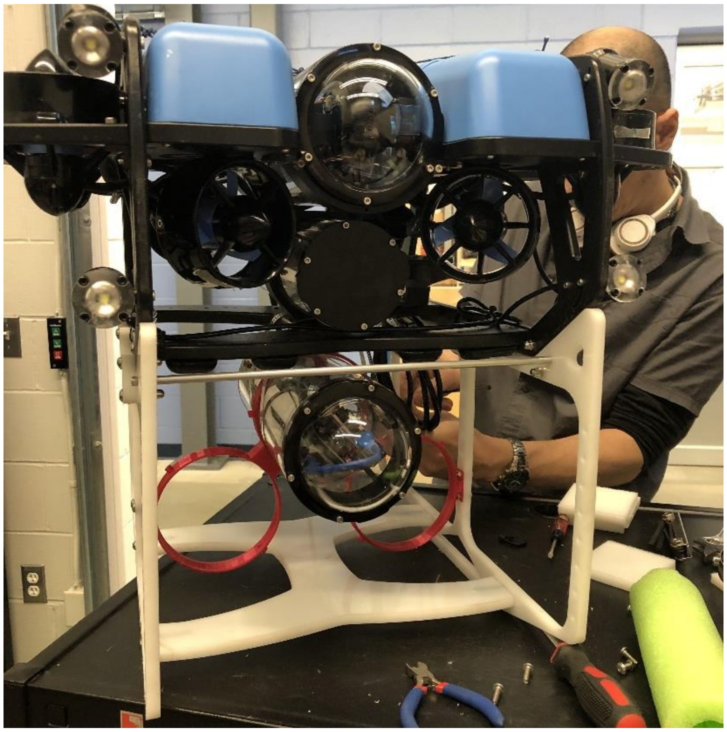


SOLIDWORKS FEA Simulation

The team selected High-Density Polyethylene for the panels because of its elastic modulus, and its well-known corrosion-resistant properties. The design also required aluminum standoffs for lateral support, and stainless-steel fixtures to assemble the features and attach the skid to the UUV.

The panels were manufactured using the CNC Water Jet cutter. The water jet followed a path determined by the SOLIDWORKS files. After the plastic required additional milling for detailed features including through holes for modularity. Some pieces required tapping for assembly. The aluminum rods were turned on the Lathe and tapped for assembly as well.

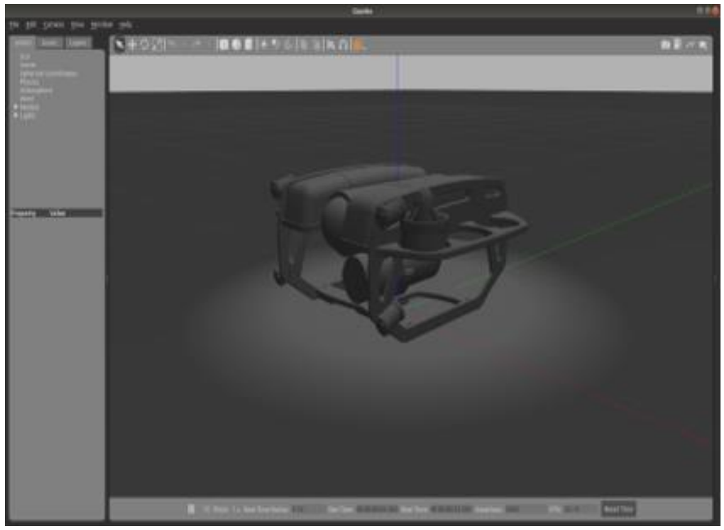
To secure the tubes in place the subgroup 3D printed rings. The rings have the potential to be rearranged and reconfigured to mission specific parameters determined by the equipment required for operation.



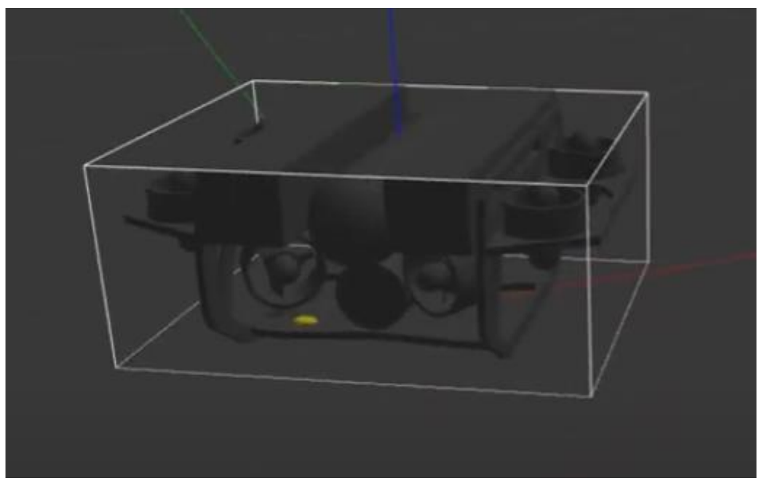
Final Payload Skid Installed on the UUV

Gazebo

The UUV Tech 797 subgroup had limited experience with coding in robotic applications. There was a steep learning curve for the involved researchers to grasp the open-source iOS. Linux Bionic Beaver, the selected MANTA_RAY iOS, allows researchers to use ROS, or Robot Operating System language, for communication between all of the branches of MANTA_RAY. ROS is an observer pattern software, which means it is constantly listening for state changes across a number of other programs. If a state change is detected in one program, ROS can notify the other programs. This technology allowed the UUV team to run commands in Gazebo using scripts written in Python. ROS also allows researchers to communicate with Gazebo software to run base simulations. These simulations predict how autonomous robots will behave in different environments. The team began by teaching themselves UUV SOLIDWORKS file conversion to Gazebo. The first simulation attempts taxed the computer's calculation capabilities. The UUV SOLIDWORKS model was simplified to function more effectively in Gazebo, but the real-time factor remained ineffective. The model was reworked again into much simpler geometries, such as base domes and rectangles, in order to increase the real-time factor to an acceptable value, resulting in a more realistic simulation.

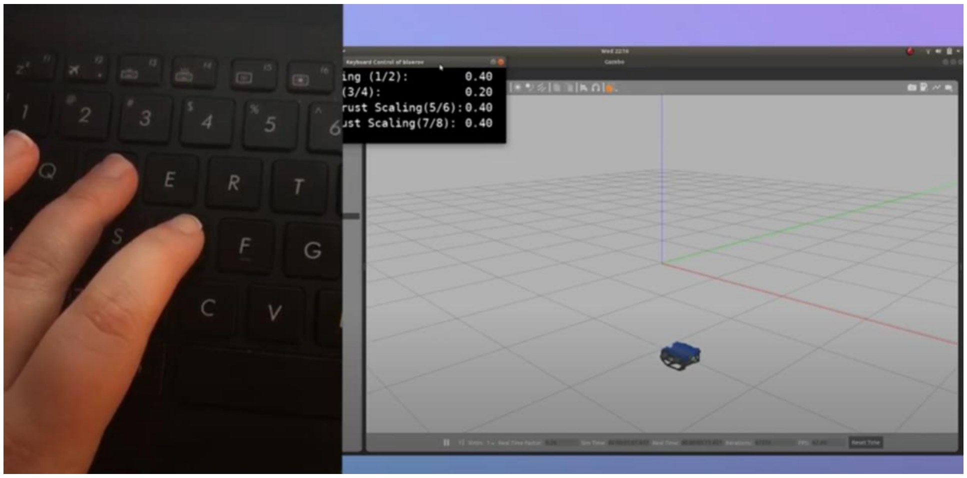


Reduced File v1 UUV Geometry in Gazebo Simulation, 2 rotational joints defined, low real-time factor



Reduced File v2 UUV Geometry in Gazebo Simulation, 8 rotational joints defined, high real-time factor

Once the modeling process was more fine-tuned, the TECH 797 group found autonomous vehicle tutorials to study. Using the tutorials hippocampusrobotics, the team was able to adapt their scaffolding to MANTA RAY’s current ROS version Melodic. The team was able to install and operate the BlueRobotics ROV in Gazebo using keyboard commands. The team also found some literature on how to receive feedback from coded sensors in Gazebo.



Keyboard controlled ROV model, using hippocampusrobotics scafolding

After the completion of these goals, the team created a more tha page document. The document is titled “Beginner’s Guide to Utilizing Gazebo v3”. The main body of the document outlines how to efficiently build custom models. The guide also holds details on joint definitions and paths towards additional model functionality. The document acts as a link resource base for supplemental information and navigation quick keys.

KRILL

NUWC Keyport gave the team a plastic hull, bill of materials, and CAD modeling. Using the bill of materials, components necessary to the KRILLs functionality were purchased. Some of the necessary materials included acrylic domes, rubber O-rings, servos, motors, threaded heat inserts, and neodymium magnets. The neodymium magnets are used to reduce penetrations in the hull, which significantly reduces maintenance and waterproofing issues. A magnet attached to the motors and servos on the inside of the hull will spin, causing magnets on the outside of the hull attached to the propellers to spin in turn.

Manufacturing components was done using the Kingsbury machine shop, The UNH Makerspace, and the John Olson Advanced Manufacturing Center. The acrylic dome needed additional through holes, which were milled out using numeric systems for accuracy at Kingsbury Hall. The top and forward module gaskets had to be custom cut in-house using the Makerspace laser cutting tool. The exterior pressure plates used in the hull assembly modules were water-jet cut at the John Olson Center. Additional assembly components for the build were created in the MANTARAY labs at Chase laboratory. The Chase machine shop also assisted in motor shaft reduction during the final assembly.

Using the provided CAD models, the team was able to familiarize themselves with the assembly of the body components by exploring individual subassemblies. To properly waterproof the body, the threaded heat inserts were set into the hull using a soldering iron.

Threaded Heat Inserts Installation into the Hull

The acrylic dome, gaskets, and pressure plates were then attached to the hull using bolts. After completing a complete hull assembly, the penetrations were leak tested in the engineering tank. Once waterproof preparation for the visiting NUWC engineers was completed.

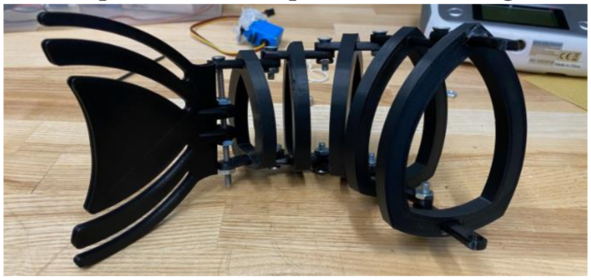
With the help of NUWC Keyport engineers, the team ~~used epoxy~~ was able to properly attach (via epoxy) the magnets to the propellers and inner adaptors. With the entirety of the hull completed, the electrical engineering students were able to wire the electrical components that run all the subsystems on the KRILL and test functionality.

GUPPS

The first objective in constructing GUPPS was to modify the existing CAD files. The designs that existed at the beginning of the project were drafts and needed to be remodeled to fit the required size dimensions of an average Steelhead trout. These files were archived onto the Team MANTA RAY box account so there is proper documentation to allow the future members of the team to re-print or make adjustments to the design as needed.

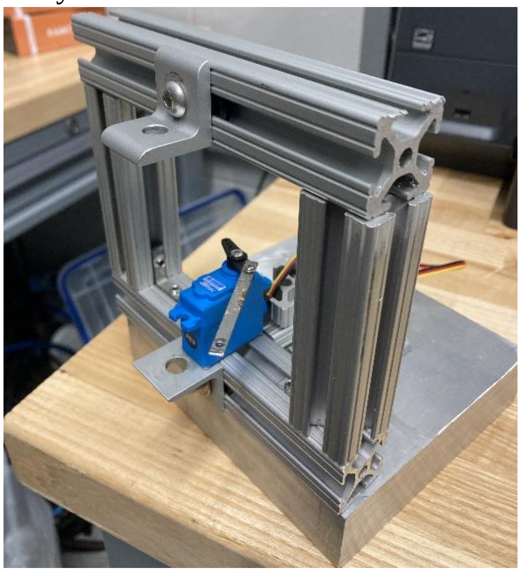
To evaluate the design, a number of simulations were conducted before moving into the construction phase and bringing the 3D CAD model to life. A number of iterations of a static simplified flow simulation in SolidWorks was run to investigate potential turbulent regions of flow in the design. If any were identified, the design could be modified to minimize the turbulence if it seemed as if it was going to be an issue on how GUPPS would perform in water. Another simulation conducted was the thermal evaluation to make sure that based on an average temperature of water and average temperature of the electronics that none of the components would fail if they were to all be 3D printed out of PLA plastic. There were no signs of highly turbulent areas of flow or any thermal issues, so the next stage of the project was to 3D print each CAD component.

The existing assembly in SolidWorks is 20 separate components that once put together build a complete GUPPS model. With a high focus on tail motion, 17 of the 20 components are used to construct the tail. There are 5 spine pieces, 10 connector pieces, and 2 halves to the caudal fin. The other 3 components include the head, body and the shelf insert that sits inside the body. Knowing that a large amount of time needed to be spend on tail movement and mechanics, those 17 components that make up the tail were printed first using the ME department printer.



The 17 tail components printed off and constructed into the tail.

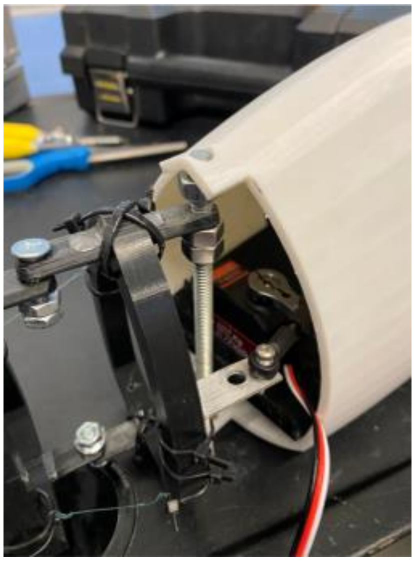
This was a difficult task to complete as the ME department printer was not reliable in producing quality 3D printed pieces, but after a few trials all required tail components were successfully printed. Since there was difficulty with printing off the rest of the body and head for a full construction, a tail mount was manufactured to have an easier time testing the tail motion. Rather than wait for the body to print which would have put the progress of the project on hold, the tail mount was constructed to imitate the body. The servo would be attached to the mount just like it would for the planned body.



Manufactured tail mount.

For the future components, the 3D printed in the Mechanical Engineering Advanced Controls Lab was used, and then eventually team MANTA RAY purchased a 3D printed that for the lab which printed the final components for GUPPS.

To secure the spines together when constructing the tail, a nut cross tightening technique was utilized. After the components were mechanically constructed, a Servo was integrated into the design. A small waterproof servo, breadboard, and Arduino Uno found in the lab were used to construct the preliminary circuit that provided the tail motion. Before the body of GUPPS was printed off, the Servo was connected to the last spine piece via a scrap metal connector arm. A small L-bracket was zip-tied onto the last spine piece with one side of the connector arm was screwed into that, and the other side was screwed into the mounted Servo.



Servo arm attachment to first spine piece.

As discussed above, the tail is the sole method of propulsion for GUPPS. It was very important to mimic the fluid tail motion of fish. To obtain the best results for this, a tail tensioning system had to be added to the spine pieces to create this back-and-forth snapping motion seen by real steelhead trout. A few iterations began with rubber bands in different configurations along each spine piece but there was problem with them getting worn out and breaking. Furthermore, although it is primarily being tested in air for motion, looking ahead in the future for water tests brings up the infeasibility of rubber bands. Fishing line tied to each spine yielded much better results. When tested it provided the most life like movement, a more reliable material, improved resistance, and made more sense for water tests. Even testing in air, this tensioning can provide damping that would be a factor submerged in water.

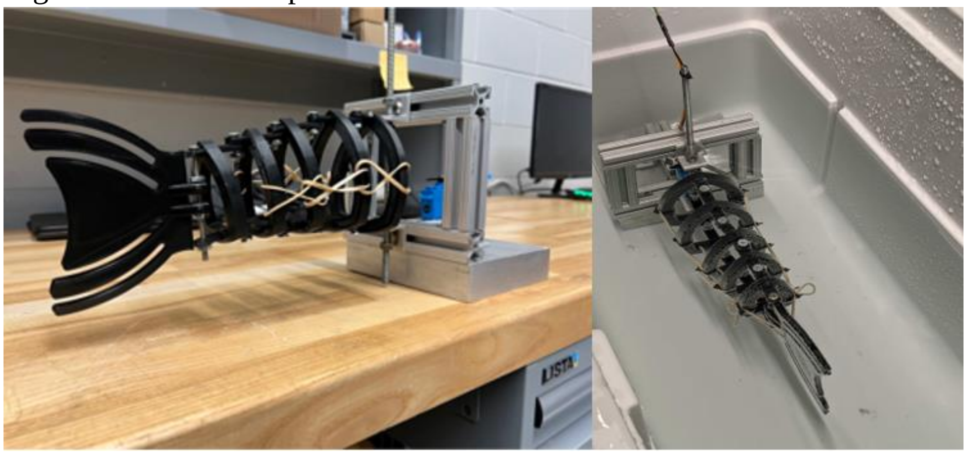
Various tensioning iterations performed on tail.

The caudal fin was printed in two pieces with gaps that allow the fin to flex to some degree just like a steelhead trout's caudal fin. Incorporating these gaps means producing less propulsion so to account for this, there was a thin soft plastic film attached between the fin pieces to provide more resistance, and consequently more propulsion when in the water.

Caudal fins assembled with plastic film in between.

Along with the tail construction and tensioning being finalized, the testing of a couple servos and its various configurations in the body or tail mount to the spine pieces were being performed. An Arduino IDE servo sweep code was used to provide the back-and-forth motion.

While it was primarily tested in air, there were also preliminary tests in water to see the effects of being submerged and how it will perform.



Test done in air and water.

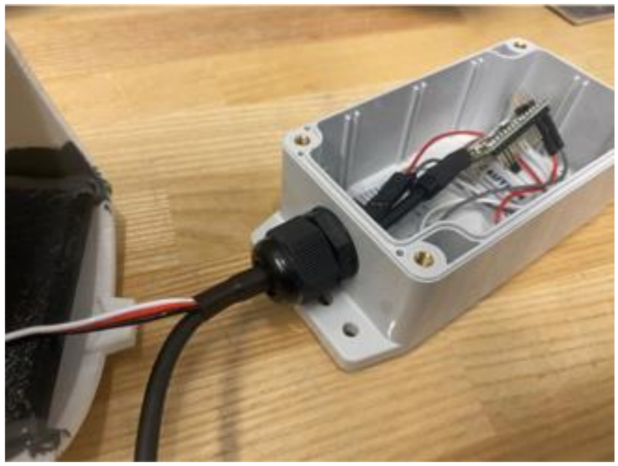
Upon trialing different degree changes per delay and degree sweep range, it was finalized at 1° change per 2.5 milliseconds for a full range of 155°. This translates to about a 60° range from the servo arm to the first spine piece, and this was adequate for a full sweep of the tail without hitting the either side of the body. Additionally, a new servo was ordered for improved latency and to increase the strength of the servo arm to effectively push the tail to either side.

The body was printed into two pieces; therefore, the halves were combined using J-B Weld. The inside shelf, along with the servo, were attached using the same method of J-B Weld to the body.

Inside shelf and servo attached to the interior of the body.

Once those were dried, it was time to attach the tail to the body using a small screw rod and a few nuts cross tightened through the back tabs to fully secure it. The servo arm was then screwed into the L-bracket on the first spine piece.

The next step was to waterproof the safety box for the electronics to stay within the body. Using one of the smaller safety boxes that were purchased with an Arduino Nano allowed for compactness. The side of safety box was drilled into and a waterproof gland was inserted for the servo wires to go in and the USB tether to come out. The safety box was secured inside on the shelf using marine grade Velcro.



Waterproofed safety box with electronics.

Lastly, the head was printed and attached through the front two body tabs by a manufactured pin with a small screw on the top. This allows for an easy process of removing the head to access the insides of the body. This final step concluded the assembly and gave a fully constructed GUPPS with a moving and working tail and a fully waterproofed constructed design.

Fully constructed GUPPS.

Results

ASV

With the newly implemented pontoon, the TUPPs is now enabled to take advantage of the full ability of the thrusters. With the slick exterior and more hydrodynamic exterior, the TUPPs is able to get up on plane with ease and reach higher top speeds. Also, because the thrusters sit lower in the water, and at a proper pitch, the thrusters are able to provide their maximum power capability while also reducing their ware. Along with these achievements, the TUPPs is able to have full maneuverability function with the new spacing of the thrusters. Finally, the TUPPs was able to successfully replicate all the subsystems and launch protocol of the ASV.

With the new axle the ASV winch spool is now able to correctly align with its motor, allowing it to spin on axis. The encoder hardware is installed, and its Arduino code is able to track the amount of tether released into the water. The TTS hardware has now been fully integrated with each other and is ready for active spooling. The Arduino code is also complete for both motors and the encoder, all that remains is for the encoder to be integrated into the ROS network and the launch protocol.

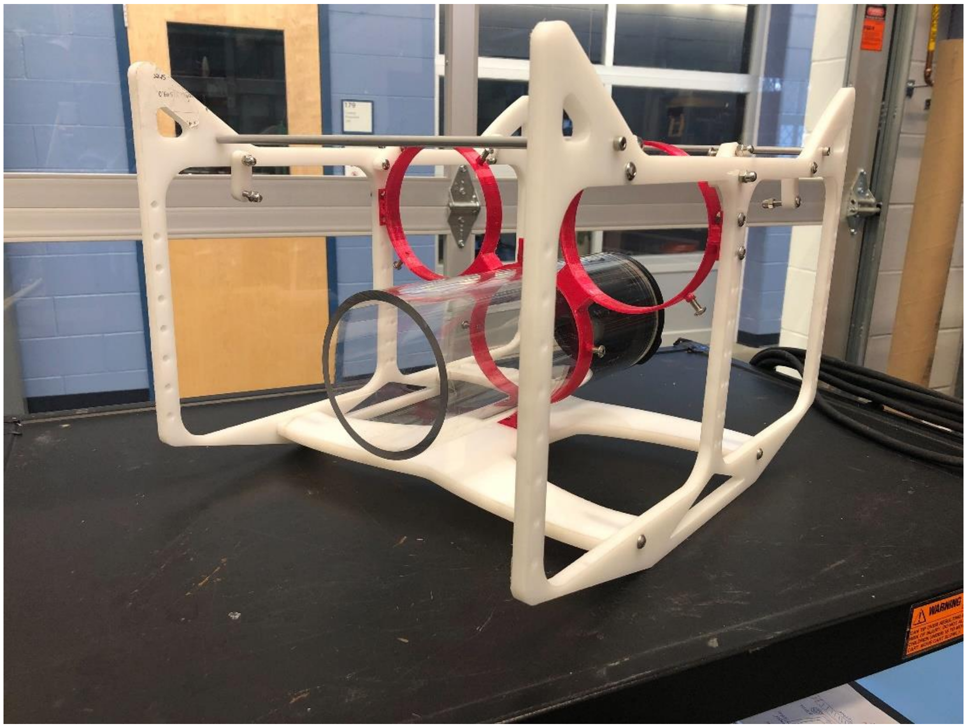
Upon the relocation of the limit switches, the UGPS deployment arms are now able to deploy and retract one at a time and all at once with scripted autonomy as well as deploy and retract collectively as part of the fully autonomous launch and recovery sequences. Some of the limit switches have worn wiring connections and are not fully reliable, resulting in inconsistent deployment and retraction triggers, which has gotten worse as testing proceeded. The summer research team will be tasked with replacing these limit switches with more robust ones.

After the three tank test days the ASV team has found that the TUPPS~~s~~ was successful at finding several issues the ASV would ha~~'~~ve faced. However, it was unable to show others encountered during the ASV tests. Overall, the majority of the subsystems worked, though UGPS was found to have reliability issues due to faulty wiring and limit switches. The launch protocol was able to be run, but it still does not run off real Pixhawk waypoints.

UUV

Payload Skid

The initial payload skid assembly went smoothly with no major issues to be reported. When attempting to install the payload rings that were designed to hold the BlueRobotics payload tubes in the skid, it was discovered that they were not large enough to hold the tubes. Not only were the rings not large enough to hold the tubes but the rings could not be fastened together because of tight tolerances that did not allow for screws to fit. This required a redesign of the rings that included 3-D printing the rings so that they were already fastened together, which eliminated the need for external fasteners. Limited by the printer shelf size, only a full ring and half of a ring could be printed at a time, so fasteners were used to secure the two halves of the third ring.



Payload Skid with Payload Rings Attached

After the payload rings were installed, the skid was installed onto the UUV. It was found that the skid had a horizontal rock when the UUV was moved, so extra supports were added horizontally to eliminate this issue.

The payload skid was tested in the Chase Engineering tank while the UUV performed basic operations, and it was determined that no additional improvements needed to be added.

Installed Payload Skid in Chase Engineering Tank

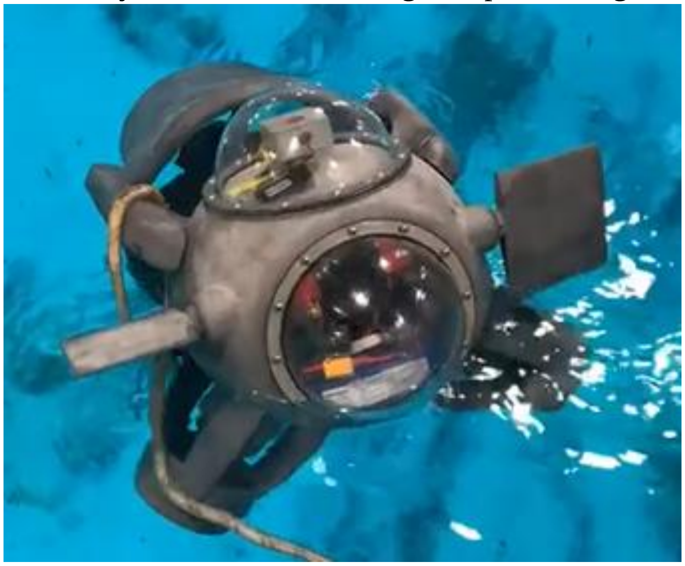
During this test the computer science majors also found success in implementing their new command functions sent from the shore station to the UUV. These commands will eventually be used the ASV at points of interest to arm disarm and perform base operations. The commands should also scale for modularity when additional UUVs are added to the fleet.

<u>GAZEBO</u>

The team created an 8 joint UUV model, a base environment, and converted online controller resources that next year's team can build off of. Graduate students are building off of the Beginners Gazebo guide the team created to try and simulate sensor feedback.

KRILL

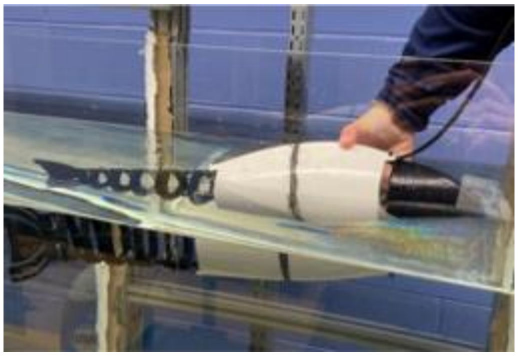
After fully assembling the KRILL UUV, preliminary tank tests were performed. During the test, the main thruster lacked power, and the fin actuators did not output correct motion based on the RC controller used. It was later found that the battery that powered the main thruster and fin actuators was low on charge, which may have caused issues with those subsystems. Once the batteries were fully charged, both the main thruster and the fin actuators performed to expectations in a second tank test. During the tank tests, the hull remained completely waterproof, confirming that the acrylic domes with O-rings are performing as expected.



First KRILL Tank Test

GUPPS

The project this year yielded a moving GUPPS in water, which goes beyond the goal of a moving and working GUPPS in air. The final design is constructed using solely 3D printed parts and a few components ordered from online. The tail is held together using a nuts and washers, and a continuous piece of marine grade fishing line is used to tension the tail. A threaded rod is used to connect the tail and the body with nuts and washers in place to secure the rod in place. Inside the body, a 3D printed shelf with a is epoxied to the inside. The shelf contains a cutout which is the proper size for a press fit for the waterproof 25KG high torque RC Servo. The servo arm is connected to the tail spine piece to provide the necessary movement using a 60mm servo linkage designed for this specific servo.



First water test for fully constructed GUPPS.

A Polycase SafetyBox that measures 4.53 x 2.56 x 1.57 inches in size was purchased to house the electronics. This is Velcroed onto the shelf using marine grade Velcro from the lab. The head is connected to the body using a self-manufactured pin with a nut on the threaded end. All of these components are required to construct the GUPPS model that was built over the past year.

The final design of GUPPS was painted a to look more like a Steelhead trout and then sealed for environmental purposes. A mount for GUPPS was 3D printed and attached to an aluminum and rubber base to secure the project and allow for proper display.

Final presentable design for GUPPS.

Discussion

ASV

The hardware of the ASV tether tensioning system has been finalized during this semester, the winch and compliant wheel can spin in unison to release tether, and they can run during the launch protocol. The encoder can currently track the length of tether released, and integrating it into the launch protocol should not be challenging. It just needs to publish as a ROS node. This is the last step in creating active spooling of the tether. With active spooling the ASV will be able to provide station keeping of the UUV during missions, an important function of the ASV.

The new UGPS deployment system was designed by the summer research team in 2020, construction began in the Fall semester of the same year, all by now senior members of the team. As construction progressed, complications in the design were uncovered, troubleshot, and resolved. The largest of these design flaws uncovered during this year's phase of construction were the intended locations of the limit switches. Once the locations were resolved and the final design of the system was completed, the system worked as indented for a few months before some of the switches began to fail. In the future, the summer research team is going to be tasked with upgrading the limit switches with more robust magnetic and waterproof limit switches.

Tank testing throughout the year has been effective at revealing issues with the subsystems and has been instrumental in creating the launch protocol of the UUV. It has allowed the ASV team to wet test in a controlled environment without having to move the ASV far. The launch protocol was able to run, though without GPS waypoints, which was due to an unknown issue with configurations. The biggest contribution from testing was showing what electrical components failed often and that they should be replaced with hardier electronics.

UUV

Skid

After tank testing the UUV with the payload skid attached, it has been determined that no more work needs to be done to the payload skid. The new skid is lighter, smaller, and more aesthetically pleasing than the previous skid prototypes. It can also hold the UUV securely out of the water and resist torquing forces applied when the UUV rotates in the yaw direction during water testing.

Gazebo

With the completed documentation outlining the installation and basic functionality of the Gazebo program, the team feels comfortable that future teams can build off of the documentation created. The documentation has already been utilized for basic sensor feedback simulations as well as future work for importing custom SOLIDWORKS models. MANTARAY also has access to a 8 jointed gazebo model UUV that has a reasonable real-time factor, and a separate operating ROV simulation.

Krill

KRILL was designed by NUWC Keyport to be a modular vehicle that can be manufactured and assembled with relative ease. The UUV team's successful assembly of KRILL has proved that the design is sufficiently modular, and it can be recreated with access to equipment available at most universities or machine shops, aside from several pieces which were manufactured in Keyport using 3D printing capabilities not currently available at UNH.

Throughout the assembly process, the UUV team was able to improve upon the available KRILL documentation by correcting mistakes in the bill of materials and making informed decisions to alter parts or choose different materials where appropriate.

GUPPS

This was a collaborative project across a number of disciplines. Being able to work cohesively with people from different academic backgrounds and different areas of interest added to the value of this project on a number of different levels. Learning about the biology behind the project and how it can be used to aid in solving a particular problem emphasized the importance of the work being done. This provided a deeper meaning to the project.

The results from this year's project provides a sound design for the next group of individuals working on the project to continue with. This is a mechanically working GUPPS model that has foreseeable future usage and already known steps to be accomplished before it can be implemented in the UNH AquaFort environment. This design can be used as a model to show how a GUPPS can be constructed, what is beneficial about the design, and what can be improved so that the manufacturing of future iterations can be streamlined and have the most optimal design. There are always aspects of projects that can be improved, but there is no way to know what unless a trial run has been performed. This year acted almost as a test run for the project, but accomplished a number of tasks that will help future teams able to achieve more and continue to improve GUPPS.

Future Plans

ASV

At its current stage of development, the ASV has its hardware designs finalized. They are able to individually perform their functions under dry lab conditions. Throughout the year however, it has become apparent that more reliable electrical components (limit switches, wiring, relays etc.) are needed. Previously lower quality electronics have been used because hardware designs have changed significantly from year to year. Thus, future work should focus on installing more reliable components on current systems instead of trying to develop different designs, otherwise similar reliability issues may be encountered. Specifically, the UGPS arms need limit switches with stronger magnets, the relays and wiring in the electronics box should be redone as a PCB circuit board, and wiring overall on the ASV needs better connections and waterproofing.

Besides reliability the encoder needs to be integrated in ROS and the launch protocol, which is the final step in creating active spooling of the tether. Additionally, the UGPS acoustic nodes need to be integrated with the ROS network. Preliminary work on parsing acoustic data has been done, however no testing with the actual UGPS acoustic system could be performed as it was being used for graduate research during the second semester. It should be available during the summer of 2022.

Once the reliability concerns have been met, the team plans on performing open water tests off the UNH research pier in New Castle, NH, which will involve driving it in a tidal system to assess its ability to handle currents and non-laboratory conditions.

UUV

Skid

Due to the modular design of the payload skid, future teams will be able to easily modify and add components as necessary. Some of these modifications may include printing larger diameter payload collars to hold larger payload tubes.

Gazebo

Future teams will be able to use Gazebo to build upon the research carried out by this year's team. Gazebo will, eventually, be applied to the GUPPS and KRILL subgroups. Both use specific custom geometries. The documentation compiled throughout the year is not specific to the UUV team alone, meaning it can be applied to a number of applications across all MANTA RAY sub-groups.

Krill

A thorough buoyancy analysis will need to be conducted on KRILL in order to determine the proper amount of ballast needed for optimal operating conditions. Due to KRILL's round shape, it naturally displaces a large amount of water. Additionally, most of the components are very lightweight, meaning there is not much internal weight to counteract the natural buoyant force. Due to these factors, a significant amount of ballast will need to be added to ensure the successful operation of KRILL. The ballast will also have to counteract the imbalance of KRILL in the pitch rotation.

A main goal for future teams will be to determine where the ballast needs to be added, whether that be inside the hull or attached to the outside of the hull, and how the weight distribution affects the orientation of the vehicle in the water.

Another future project will be determining whether or not the KRILL interior gets too hot during long missions. This can potentially be done using a SOLIDWORKS simulation as well as tank tests. If this is an issue, a method of cooling will need to be designed and tested.

GUPPS

The current model of GUPPS is a mechanically sound 3D printed robofish that is fully waterproofed. This extends beyond this year's goal of a moving and working GUPPS model in air. Before use of GUPPS can be implemented in the UNH AquaFort, or in any other application – a number of tasks regarding design must still be completed.

These additional tasks include buoyancy and ballasting as well as designing for direction and pitch. Buoyancy and ballast will require a number of calculations and research into how to provide the best buoyancy solution for the GUPPS design. Some research has been done into the use of a swim bladder and continued research on this topic will help determine if this is feasible for the current design or if other alternatives should be explored.

To account for the direction and pitch that GUPPS can navigate at, pectoral fins will be added to the design. Work has already begun on the design and 3D printing of pectoral fins, and the team has brainstormed potential ways to mechanically connect the fins to the controls system. This will be continued by next year's team. Another task in terms of design will be to investigate soft robotics, a silicon encasing that would make GUPPS look more lifelike compared to a fish.

In the future, GUPPS will be capable of housing a number of different sensors and will be a vehicle for testing graduate research. The modularity of the design developed by this year's team will allow for ease of integration of these sensors. This system can then be tethered to TUPPS for telemetry just as the UUV is tethered to the ASV.

In completing the project, a number of things were learned that can be implemented in future team's work. The first item is the difficulty and uncertainty that comes with the task of 3D printing. It is important to always have a backup plan in mind when it comes to 3D printing components – whether it be a backup 3D printer to use or an alternative method of achieving goals. Along with this, another piece of advice is to always allot more time than necessary on the project timeline. Often there are unforeseen issues, such as failed 3D prints that can set the timeline of the project back a few days, or even a week. Being able to adapt and work on other aspects of the project in the meantime is beneficial to still improve on the project even if there are set backs.

Another item to consider for future teams is when designing, be sure to think of any possible design wants, issues or failures that could occur and design to avoid them. An example of this is that it would have been valuable to have included the shelf already designed to sit in the body when printing the body. That way the shelf would have already been included in the body frame instead of having to secure it using the JB weld.

The opportunities for growth and development on this project are endless. Being in the first few years of existence, there are so many directions this project can be taken in which is both daunting yet exciting in terms of what is to come.

Acknowledgements
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