Team Marine Robotics TECH 797

Final Report 2020-2021

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Abstract

Team Marine robotics is a team of senior mechanical engineers on team MANTAY which stands for Marine And Naval Technological Advancements for Robotic AutonomY. Team MANTARAY is an interdisciplinary team consisting of mechanical, ocean, and electrical engineers, along with computer science majors. Among all of the different majors on the large team there are also students across all 4 undergraduate grades. The project for TECH 797 combines the goals of the teams that were previously known as ASV and ROV. The homologation of the two teams allows the team members to learn about systems on top and underneath water.

The overall goal of the MANTARAY project is to complete the first grant from a Naval base in Keyport, Washington where an Autonomous Surface Vehicle (ASV) will complete a seafloor mapping mission and deploy a Unmanned Underwater Vehicle (UUV) to take a video and photos of a point of interest. Team MANTARAY has also been awarded a second grant that started in January 2021. This grant it to create vehicle to vehicle communications as well as create a new platform that is a biomimetic fish.

The Marine Robotics team consisting of just the senior mechanical engineers had three overall goals for this year. The first one is to finish the proof of concept mission completing the first grant from the Naval base in Keyport, Washington. The second goal is to implement the graduate research of Allisa Dalpe in autonomous path planning. The third goal is the creation of a new platform called GUPPS/Robo-Fish to aid at University of New Hampshire's Aquafort in monitoring the Steelhead Trout.

This team has worked throughout the 2020-2021 school year along with seniors and underclassmen in other majors to complete these goals and provide teams in the future platforms to improve and perfect.

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Introduction

The Earth is about 70% ocean and seas, but we do not know about a lot of the ocean. The ocean floor is currently not fully mapped there is about 10% that still needs mapping. While there are a lot of private companies that do sea floor mapping the US Navy is also interested in learning about the parts of the ocean we do not know. The problem with this is it does not make sense for them to send out a crew of people to do a sea floor mapping mission when there are more pressing matters out there. The Navy created the overall project of creating a ASV UUV combination on a small scale budget but still get accurate results. If a group of college students can create accurate results using a low cost platform the Navy can most certainly create a platform that is low cost for a military budget. The reasoning for an autonomous system to do this is because if the system is fully autonomous the Navy could put sailors on mission where human intervention is absolutely nessacary where sea floor mapping is just data collection and there is not a need for human intervention once the mission starts.

This year the team is in between two grants the first grant was from 2017-2020 and the second one is from 2021-2023. The goal of the first grant is to create the system that can do the sea floor mapping mission and deploy a UUV to take pictures and videos of a point of interest after the sea floor mapping is completed. This is the grant that the previous ASV and ROV teams have been working under. The next grant is to improve and expand the fleet of autonomous platforms and have vehicle to vehicle communications between them. This will be helpful to be able to map more of the sea floor at once with the vehicles doing the sea floor mapping knowing where each other are so a place does not get mapped twice or it can get mapped twice but the vehicles can be outfitted with different sensors to create a more detailed map of the sea floor.

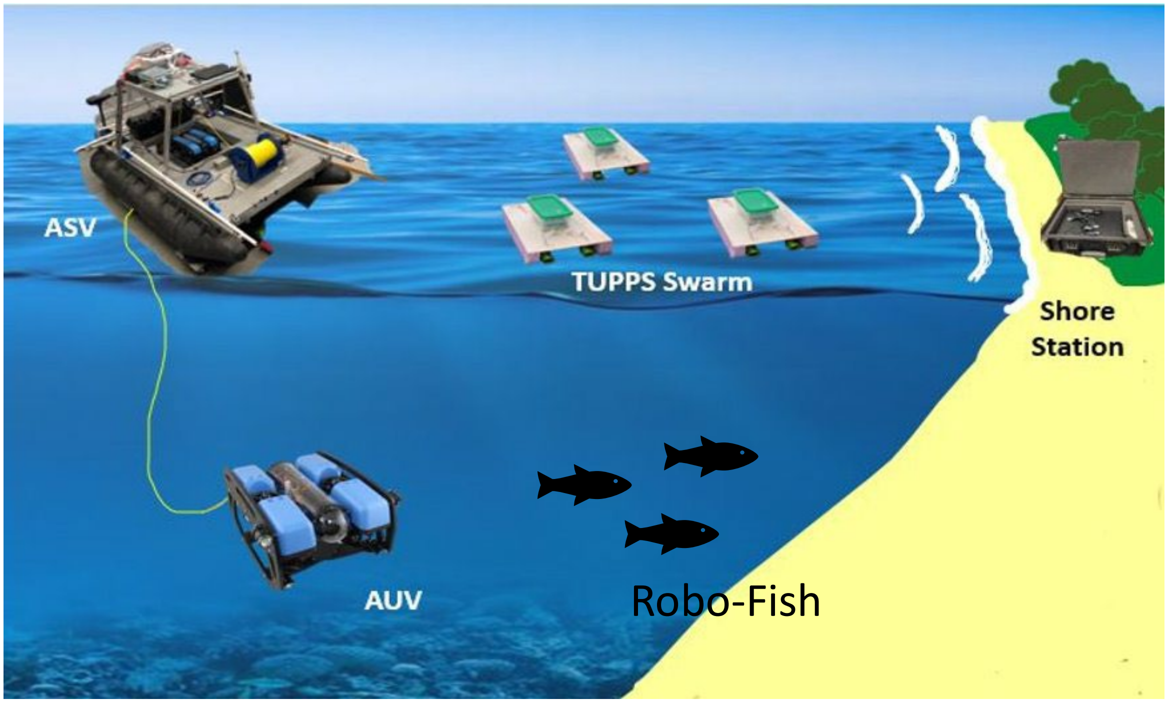

figure 1: Diagram of all Marine Robotics platforms

ASV Overview

The Autonomous Surface Vehicle that the team uses was built by the 2018-2019 ASV

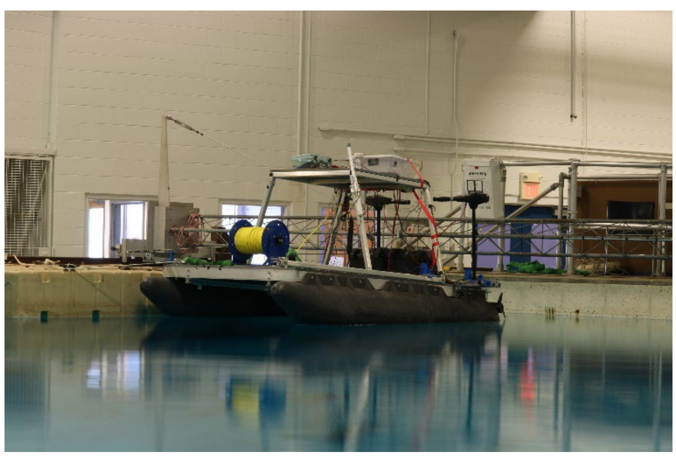

figure 2: The ASV in the Chase Engineering Tank

team. The vessel is a catamaran style hull because of the extra stability in the ocean. A catamaran style hull is stable because instead of having a single hull that the boat is built around a catamaran is built on top of two hulls allowing the boat to break more of the wave and while sitting it will not roll as much of the wave because of the width of the boat. The ASV is not a large boat it is about 7 feet 9 inches with a beam 5 foot 6 inches. The beam of the boat is a measurement of width at the widest point of the vessel. The boats wide beam helps with the stability in the water. Along with the ASV's hull being built previous teams have added various subsystems to aid in the proof of concept mission. These subsystems are a trap door to deploy the UUV from the ASV, a tether tensioning system to allow for the tether to not have slack while the UUV is in the water and is able to be brought back to the ASV without back spooling. The final subsystem is the UGPS arms, the UGPS is how the UUV's location is determined when it is in the water. These arms go into the water to send the signal to the UUV and the ASV determines the position using acoustic sensing.

UUV Overview

The UUV for the team is a premade Blue Robotics BlueROV2 Heavy. This UUV was converted from a Remotely Operated Vehicle (ROV) to an Unmanned Underwater Vehicle (UUV) by the ROV team of 2019-2020. The BlueROV2 has dimensions of

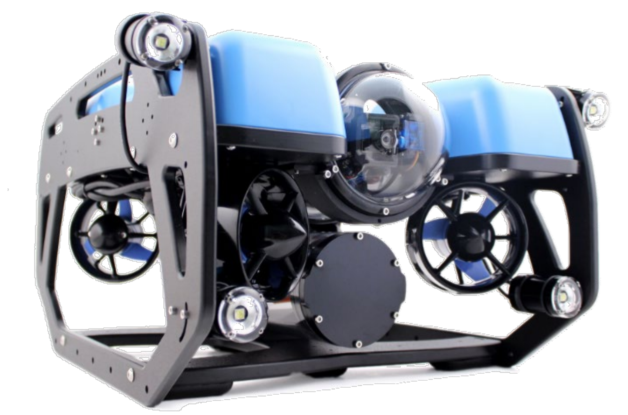

figure 3: Image of the Blue Robotics BlueROV2 Heavy

18”x13.3”x10”. The now UUV is equipped with 8 Blue Robotics T200 thrusters to allow for 6 degrees of freedom under the water to keep the vessel stable in the ocean. The UUV also has factory lighting that allows the user to see while using the live video feed or watching back the video taken by the UUV. The BlueROV2 is a completely open source Observation Class ROV meaning it is easy to replace and upgrade parts on the UUV.

Proof of Concept Mission

The previous years' ASV and ROV teams had performed their work of developing the Autonomous Surface Vehicle (ASV) and Unmanned Underwater Vehicle (UUV) and

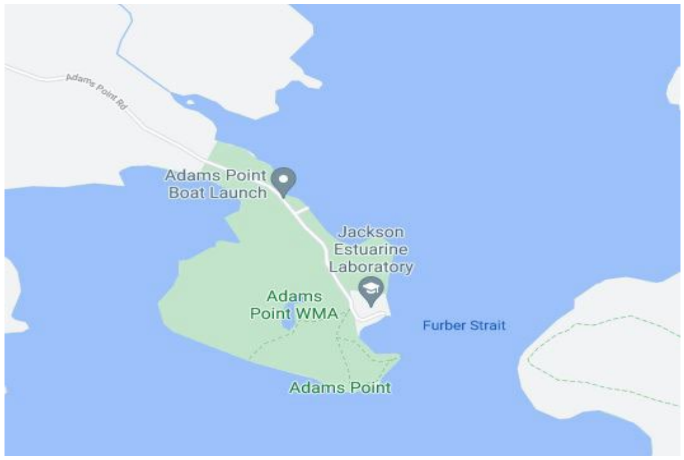

figure 4: Location of Adams Point

collaborated in order to perform a Proof-of-Concept seafloor mapping mission. This mission would be completed in the Great Bay, where the ASV would complete a lawnmower pattern of an area of interest, identify a point of interest, and autonomously deploy the UUV which would navigate to the point of interest and collect video footage as well as photos of the point of interest. This mission was planned to be completed in the spring of 2020, but due to the pandemic was postponed for this year's team.

Originally, the mission was planned to be completed in the fall. However, the mission must be performed during slack high tide, which is when the tidal currents in the great bay are the calmest. This slack tide happens periodically at a time where it would be realistic and safe to perform the test, which meant that weather permitting, there were few days in the fall to perform the proof of concept. As winter approached, we, alongside MANTA RAY, made the decision to postpone the mission to the springtime for the safety of the team as well as the weather conditions.

The postponement of the mission let the team focus on the development and upkeep of the platforms in the MANTA RAY fleet. The ASV needed work and repairs on various subsystems, including the wiring, heading controls, Underwater GPS arms, and Tether Tensioning System. These subsystems were improved and repaired throughout the fall and winter.

The team is targeting a May/June date to perform the proof-of-concept mission, which will wrap up the first NEEC grant we have been working on and allow future teams the use of the MANTA RAY fleet to work on UUV communications in the coming years.

TUPPS

Testing Unmanned Performance Platform (TUPPs) is a low cost, small scale ASV designed for use in the Chase Engineering Tank. TUPPs was designed by previous

figure 5: Current Styrofoam and plywood iteration of TUPPs

years' teams as well as graduate students to allow for testing of autonomy systems as well as sensors, as the ASV is much too large for most tests of that type in the tank.

TUPPs is much cheaper and easier to work with than the ASV, making it much better for tests of those types.

There are multiple designs of TUPPs which vary depending on the mission of the TUPPs. For the most part, TUPPs is constructed out of plywood and Styrofoam in a catamaran style craft to add stability. It carries the same basic electronics components: either a small laptop or a Raspberry Pi, serving as the brain of the TUPPs and is able to receive communications from the Shore Station. The computer is connected with an Arduino, which is used to interface with the sensors and speed controllers onboard the TUPPs. TUPPs is powered in two parts, the low voltage side (5V) by a portable charging bank, and the higher voltage side (12V) being powered by a LiPo battery. These components are very cheap and allowed the team to construct many TUPPs.

The main uses of TUPPs this year were the testing of PID heading controls for the ASV, and testing of an automated path planning system. The first half of the year was spent on the heading controls. Last year's team had developed TUPPs' heading controls using Proportional-Integral-Derivative (PID) control, but they were never tested nor implemented due to the pandemic. Extensive work was done to test these controls this

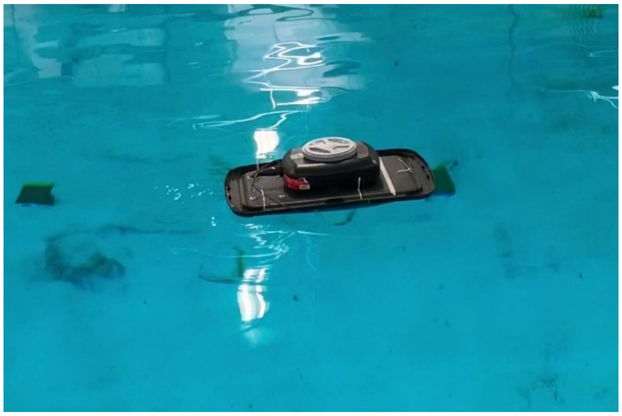

figure 6: TUPPs with path planning

year. The previous year's team had designed the code with the idea that this year's team would select and choose a particular inertial measurement unit (IMU) to test with. The team tested the code with multiple IMUs and were able to control the heading and adjust the gains to reduce the steady state error of the heading and the overshoot. Tele-op keyboard controls were also implemented last year, and tested extensively this year, and was found to be fully functional. The TUPPs heading control scheme was then handed to the computer scientists on MANTA RAY to develop the frontseat and backseat of the autonomy on the ASV. TUPPs, in the future, will be used to test more complex controllers for the ASV, such as Full-State Feedback, and Linear Quadratic Regulator (LQR). The team predicts that these controllers will be much more robust and will control the ASV better than PID control.

The second half of the year was spent testing graduate students' automated path planning algorithms on a more complex version of TUPPs, which used a small laptop as the computer instead of the typical Raspberry Pi and can use a LiDAR (Light Detection And Ranging) onboard for obstacle avoidance. This TUPPs utilized indoor GPS receivers to determine its location in the Chase Engineering Tank as well as its heading. The team was able to set up the coordinate system in the engineering tank using a software called Marvelmind and execute the path planning algorithm. The TUPPs completed a waypoint-to-waypoint path, but its obstacle avoidance capabilities were not tested. The algorithm is designed to be modular, so it can be modified to be used on the ASV as well.

TUPPs testing this year was crucial in helping the computer scientists on MANTA RAY develop the autonomy for the ASV that will allow us to complete the proof-of-concept mission this spring. TUPPs will continue to be a vital platform in the MANTA RAY fleet for years to come for testing and other applications. The team envisions using TUPPs to accompany the fleet on missions, serving to carry diver down flags which patrol the area where mission is taking place, or acting as smaller communications hubs for submersibles.

Robo-Fish/GUPPS

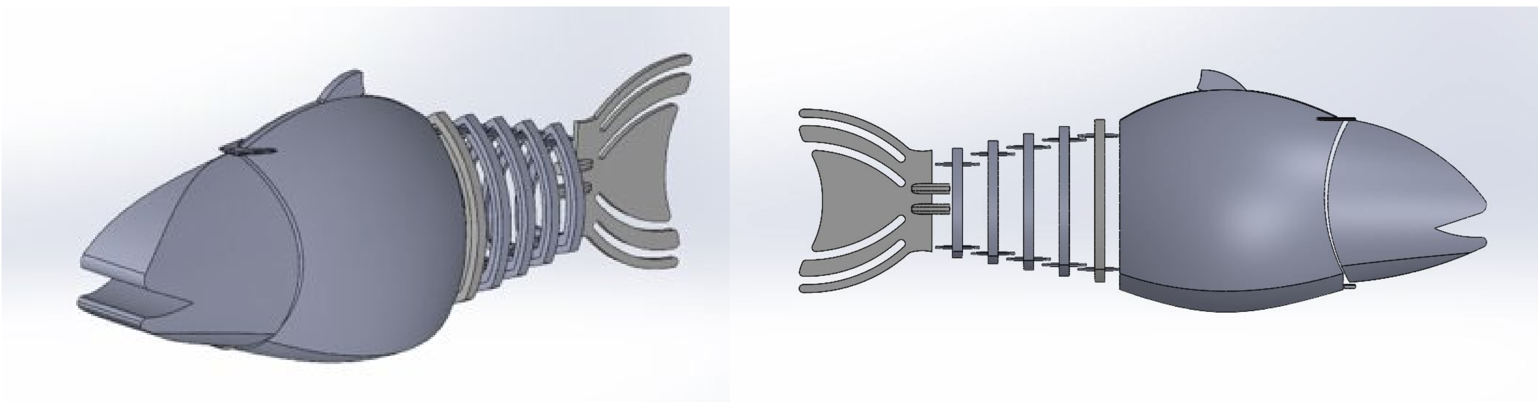

figure 7: Robo-Fish CAD model

Robo-Fish or Ghost Unmanned Performance Platform Submersible (GUPPS) is the newest platform of the Marine Robotics team. The goal of this platform is to create a system of small UUVs that can communicate with each other. Robo-Fish will be a biomimetic fish which means it is a robot this mimics an actual animal. There are some examples of biomimetic UUVs, but it is a type of UUV that is still not a popular as the normal box like or glider shapes normal UUVs. The goal of Robo-Fish within the next year or two is to perform a proof of concept mission in the University of New Hampshire (UNH) Aquaculture Program at the AquaFort at the UNH pier in New Castle, New Hampshire about a mile south of the Isles of Shoals. At the AquaFort Robo-Fish will be monitoring the Steel Head Trout and Lumpfish population. The goal of this proof of concept it to show that it is possible to have multiple UUVs work together to gather data and communicate their locations with each other. The design of Robo-Fish is based off of the Steel Head Trout because the Trout are easily spooked unlike the lumpfish. The average size of a Steel Head Trout is about 2 feet long, so Robo-Fish needs to be around that size as well to create a realistic looking robot. Since this platform is brand new the team created a CAD model of the robot first. The bulk of the time of design was spent on the design of the tail. Since the robot is supposed to be a non-invasive UUV and blend in with the fish at the AquaFort meaning the way the robot moves is a critical component of the robot. The Steel Head Trout is a subcarangiform locomotion fish which just how the fish moves the tail to move forward. The way the tail is design is to have multiple ribs that connect to each other where two servos are also attached creating the fish like motion of the tail. The largest part of the tail is 5.6” tall and 4.5” wide where the smallest rib of the tail is only 2.3” tall and 2” wide. All 6 ribs of the tail were created in Solidworks but designing the biggest tail rib first then using the offset function in Solidworks to create a

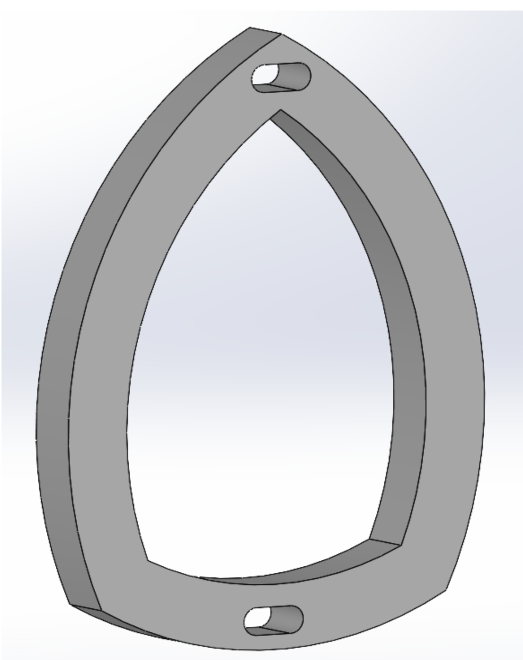

figure 8: CAD Model of the largest tail rib of Robo-Fish

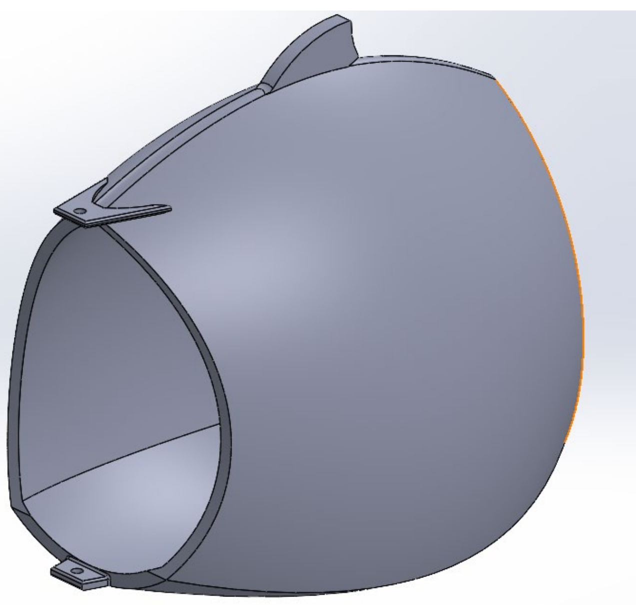

figure 9: CAD Model of the main body for Robo-Fish

smaller version of the bigger rib, this process was repeated till all ribs were completed. Using the offset tool in Solidworks allows for a uniform decrease in the size of the ribs and creates an organic shape. The final tail piece of the tail is the tail fin and creates the locomotion of the robot. The tail fin was designed to connect to the moving tail ribs and

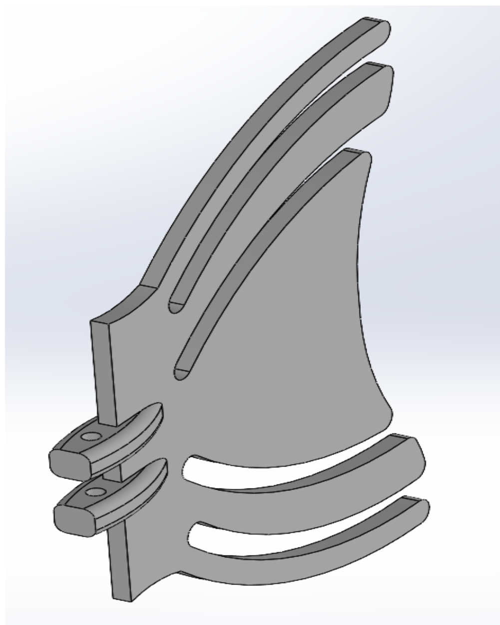

figure 10: CAD Model of the tail fin for Robo-Fish

to look similar to the tail fin of a Steel Head Trout. The reason for the slits in the tail is because there will be a piece of film in those slits to create better propulsion for the robot. Once the tail was completed the middle part of the robot was designed. This part of the robot is where a bulk of the electronics will be stored, meaning this has to be wide enough to fit the two servos for the pectoral fins of the robot but also the controller of the robot which as of now will be an Arduino Mini. This piece of the robot is 4.75” wide 6” tall and 5” long. The middle part of the robot also has a dorsal fin that helps stabilize the robot underwater but also creates a more like life robot to fit in with the Steel Head Trout.

The final piece designed as of now is the head of the fish. The head of the fish is where most of the sensors will be mounted including a camera system and some kind of distance sensor such as LiDAR or an ultrasonic sensor. There are currently no holes in the model for these sensors because the team is unsure of the exact sensor being used because of the inaccurate results that have been acquired so far. This is not a problem because the fish will be 3D printed so drilling a hole for the sensor due to plastic being very easy to machine. Originally the robot was to be 3D printed in PETG (Polyethylene Terephthalate Glycol) which is a common 3D printing filament because it is UV resistant and water resistant. The plastic is also very strong with a yield tensile strength of 50 MPa. The filament also has a water absorption of .13% when submerged in water for 24 hours which is perfect for a robot that will one day spend the whole day in the ocean. The team ordered Overture PETG to start 3D printing the robot. PETG is supposed to be an easy to print material but the printer the team is using had several issues printing this material. The main issue while printing was the filament would clog the nozzle blocking any filament to go onto the build plate and create the print. With the ongoing issues with printing PETG the team decided to print the initial robot in PLA (Polylactic Acid).

figure 11: A failed print using PETG.

figure 12: First rib of Robo-Fish printed in PLA.

figure 13: All three ribs of the initial Robo-Fish tail printed in PLA with the connectors.

This filament is the plastic that most people use to 3D print due to it being easily printable and its low cost. The PLA filament has a yield tensile strength of 35.9 MPa so it is not as strong as PETG but for the initial robot it is ok. PLA is also not water resistant because of it being made from plants and other biomaterials it will eventually degrade in water. For the initial robot having a not water resistant material is ok because there are ways to waterproof PLA, but this robot will most likely only see water for a couple of hours till one is printed fully in PETG. Currently the initial robot will have a very simplified tail where it will only use 3 rib pieces and one servo. The reason for this is to create a code that only has to worry about one servo and fine tunning that to create a smooth fish like movement that will create the propulsion of the robot instead of thrusters like a normal UUV. Once the code is developed for the servo another servo will be added to create the subcarangiform of the Steel Head Trout and all other pieces of the fish will be printed. The are currently no pectoral fins designed because the team wanted to focus on the design and movement of the tail before anything else. The pectoral fins will be designed and printed while the code is being developed for the tail. Sensor procurement has also happened as the design of the fish has happened. There are three main sensors

figure 14: Sensor testing setup

that the team has been looking at the first being a LiDAR sensor for obstacle avoidance, this is crucial for future versions of Robo-Fish because it will be fully autonomous. The next sensor is a camera to provide live video to the shore station and to provide the biologist studying these fish insight to what the fishes behaviors are like. The third type of sensor is an ultrasonic sensor, this will be used for obstacle avoidance but can also be used for determining the position of the fish in the AquaFort. The computer science and electrical engineering seniors on team MANTARAY have done a lot of advancements on these sensors including being able to get accurate data in the air from these sensors and starting to create a code to do sensor fusion between the sensors. Sensor fusion is the ability to put readings from multiple sensors into to one excel sheet, so it is easier to read the data and see if there is an inaccurate reading from a certain sensor. A lot of advancements were made to Robo-Fish in just the short span of this year but there is still a lot more that has to be done. In the coming weeks, the first servo will be mounted to the first three ribs of the tail. Once everything is mounted to the initial tail the code for the servo movement will be tested and fine tuned till it is smooth and somewhat fish like. Once the single servo code is complete the tail fin will be attached to the simplified tail will be attached and tested in the Jere A. Chase Engineering Tank in Chase Engineering building at UNH to see how the tail propels the robot in the water and how efficient it is. Once the robot is propelled in the water efficiently the other 3 ribs and the second servo will be added. The first couple versions of Robo-Fish will be a tether UUV meaning there will not be a battery in the robot but a wire going to the robot supplying power. The reasoning for the tether is a battery will take up space that is not available at the time and the tether will act as a lifeline in case something goes wrong with the robot.

ASV Subsystems

The Autonomous Surface Vehicle was built with multiple subsystems integrated into the design of the vessel. The main subsystems are the trapdoor, the Tether Tensioning System (TTS), and the Underwater GPS arms. At the beginning of the school year the team completed a subsystem test to see what subsystems worked and which did not. It was found that none of the subsystems worked as intended. The trap door would open all the way but would not close, this was found to be a wiring issue which was later resolved when underclassmen on MANTARAY redid all of the wiring to make it more coherent. The Underwater GPS (UGPS) arms partially worked , the 2 arms on the bow of the vessel deployed correctly but the two arms at the stern of the vessel did not. The tether tensioning system was not tested at this time because the UUV was with our graduate advisor to do testing of the autonomy. During the summer underclassmen involved with MANTARAY had redesigned the UGPS arms and the TTS to make the subsystems more efficient and easier to work on. The previous UGPS arm design deployed the arms

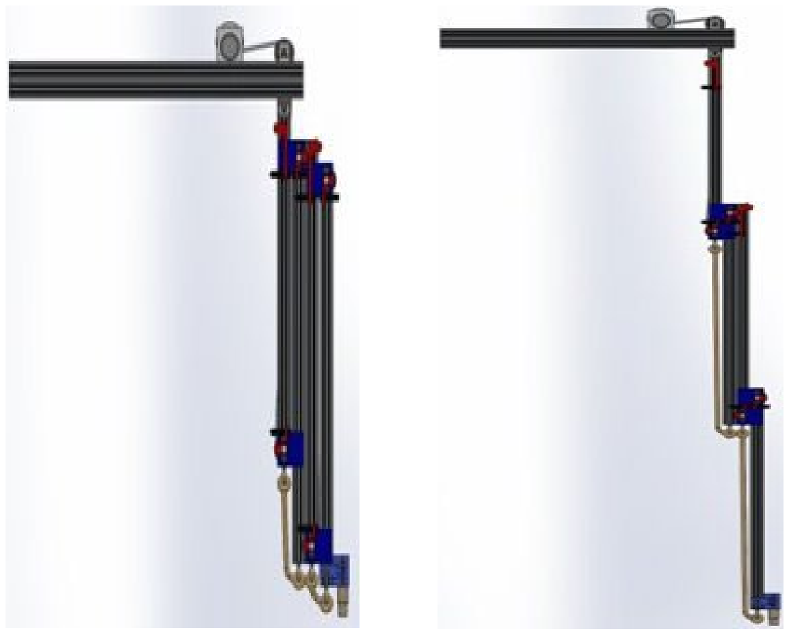

figure 15: New UGPS Arm retracted and deployed.

linearly from the deck of the ASV into the water to allow for the acoustic transducer to send a signal for the receiver on the UUV to receive and relay the location of the UUV back to the ASV. The underwater GPS uses acoustic sensors because a normal GPS signal will not work underwater so a Waterlinked Underwater Ultra-Short Baseline (USBL) System is used to find the location of the UUV while it is deployed. The new UGPS arms instead of going into the water using just one arm it uses a cascading arm to minimize the size while retracted but maximize the size while in the water to get the best signal possible. The new UGPS arms go about a meter deep into the water allowing a solid signal to be sent to the UUV. The marine robotics team helped with the design and construction of the UGPS arms which are almost ready to be put on the ASV and tested, a method of keeping tension on the arms still needs to be resolved but after the arms will be ready to be tested. The next system that got a redesign is the Tether Tensioning System. There has always been a problem with having slack in the tether while the UUV is in the water. If there is slack in the tether while the UUV is being retracted back in it make retracting hard because there is not enough friction to pull the tether back onto the spool. The solution the team came up with is use a compliant wheel that will squeeze the tether against the main pulley while the tether is being deployed and retracted. This system keeps the tether in contact with the pulley constantly creating tension even if there is no movement from the UUV. This subsystem is waiting on the motor for the pulley to be

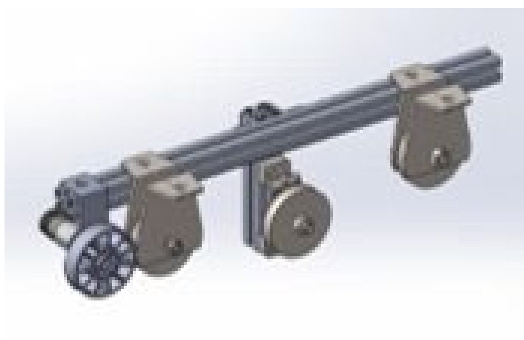

figure 16: CAD design of the new tether tensioning system

fitted then the system will be able to be tested with deploying the UUV. Once the subsystems are in working condition and tested the team can move forward with the proof of concept mission of the ASV mapping the sea floor the deploying the UUV to go to a point of interest and take pictures and videos of that area. These subsystems are crucial for this mission to happen because they keep the UUV safe while deployed and allows the users to know where the UUV is during the mission.

Work to Be Completed by Future Teams

In the upcoming years there is a lot of improvements to be done with the platforms of the Marine Robotics Team. By the beginning of the next school the proof of concept mission should have be completed by the team of summer interns that work on this project. For TUPPS the continuation of working on implementing autonomous path planning and working on other controls for the platform such as Linear-quadratic regulator control and full state feedback control to compare the types of controllers and chose the most efficient one. For GUPPS there is a lot of improvement to be done. The first is to complete the construction of more GUPPS and have a fully working robot. Another advancement will be to create an autonomous code for the robot using the sensors that will also have to be chosen and tuned for being underwater. Team more in the future might want to look into soft robots for the tail of the fish, soft robotics will allow for a more life-like and more efficient movement of the fish. The subsystems on the ASV should be tested regularly and can always use improvement, a more efficient way to place the electronics on the top of the ASV might also be useful to make sure the electronics are safe when on the water.

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