Tech Triton: RoboSub 2024: Technical Design Report

Erin Beazley, Agatta Betancourth-Pollett, Shawn Coutinho, Jeffrey Fang, Zachary Greenberg
Manuel Roglan, Thanapol Tantagunninat, Christopher Tio, Matthew Woodward, Aaron Wu
Georgia Tech Marine Robotics Group
Atlanta, Georgia

***Abstract*—In preparation for the RoboSub 2024 competition: Logarithmic Spiral, the Georgia Tech Marine Robotics Group constructed the *Tech Triton* Autonomous Underwater Vehicle platform, which will make its debut at RoboSub 2024. This year, the primary design goal was to create a platform that is simultaneously competitive at RoboSub 2024 and enables ease of future development. *Tech Triton* features a cast acrylic hull surrounded by eight polycarbonate guide rods on which various subsystems and sensors can be mounted, including the powertrain and various sensors. The interior of the hull features a drawer-like system to allow for easy access and maintenance of the vehicle's electrical components which include a PCB, fuses, buck converters, and more. Major effort was taken to enable parallel mechanical and software development through a medium-fidelity simulation utilizing Gazebo Garden.**

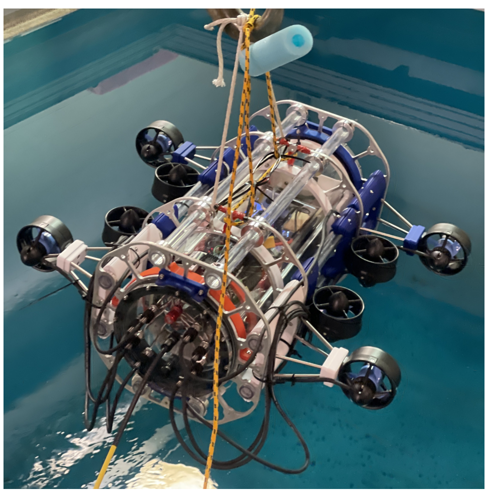

Fig. 1: *Tech Triton* out of the water

I. Technical Strategy

GT Marine Robotics Group's (GT MRG) approach for RoboSub 2024 was to create a new platform, *Tech Triton*, focused primarily on modularity to allow the team to be competitive at RoboSub 2024 while simultaneously allowing for future capability expansion. This meant building from the ground up, adapting the team's knowledge and experience from Autonomous Surface Vehicles (ASV) into a new modality, namely Autonomous Underwater Vehicles (AUV). To accomplish this, the team divided the competition up into three categories of tasks, each of which would require different subsystems and therefore different levels of work from its three main subteams: mechanical, software, and electrical. The major task categories identified by the team are as follows: navigation (encompassing Tasks 1, 2, 3, and 6), launching torpedoes (covering Tasks 3 and 5), and object manipulation (involving Tasks 4 and 6). For this year, the team decided to design mechanisms for every task; however, tasks under navigation remain the highest priority and therefore are the main tasks the team will be attempting at RoboSub 2024.

II. Competition Strategy

A. Navigation Tasks

Navigation tasks typically involve navigating through gates (Enter the Pacific-Gate and surfacing in Collect Samples), around buoys (Hydrothermal Vent-Buoy), and between tasks (Coin Flip). For the various tasks at RoboSub 2024, *Tech Triton* utilizes local navigation via its stereo camera and sonars to identify the position of relevant targets. Once a target's position has been identified, the autonomous system then generates body velocity commands to maneuver the AUV relative to the object, updating the commands based on updated sensor data. This allows *Tech Triton* to maneuver without considering potential position odometry drift which could lead to missing targets or accidental collisions. This strategy, while useful for navigation once a target's position is identified, doesn't account for when the AUV must search for a new target, such as when maneuvering between tasks. To accomplish this, *Tech Triton*'s odometry system keeps track of where the AUV is relative to the previous task, improving the potential utility of path markers in providing a general direction to the next task. For traveling to tasks without a path marker, *Tech Triton* employs a simple search algorithm, prioritizing areas away from the previous tasks, utilizing its Sonoptix ECHO Multibeam Imaging Sonar [1] to scan the bottom of the venue for raised features which could indicate undiscovered tasks.

B. Launching Torpedoes Tasks

The Launching Torpedoes Tasks category, which includes Hydrothermal Vent and Mapping tasks, would be accomplished by the AUV first identifying the target using a combination of its sonars and stereo cameras. Once the target has been identified, the AUV then would turn to local navigation to get within firing range and aim the launcher at the target using computer vision techniques. Once aiming is determined to be complete, the AUV would launch its torpedoes at/through the target. The mechanism for accomplishing this, namely the torpedo launcher, was completed; however, due to insufficient testing time, the team decided against deploying it on the AUV for RoboSub 2024. The team instead is targeting its utilization at RoboSub 2025 after it has gone through far more rigorous testing and design iterations. The Computer Aided Design (CAD) model for the torpedo launcher can be seen in Figure 2, featuring a dual spring-loaded system that fires by uncovering one of its two torpedo tubes using its rotating cover.

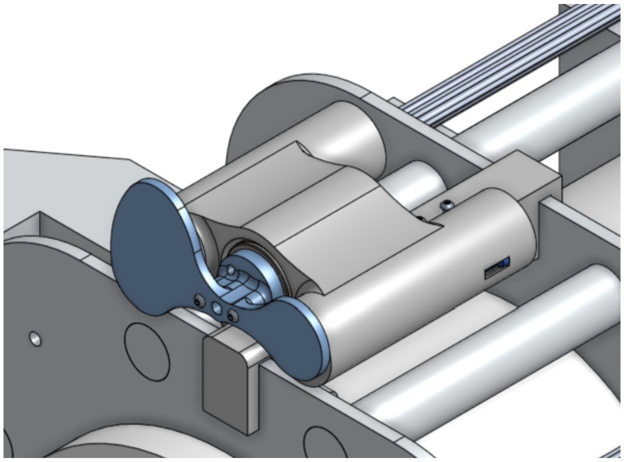

Fig. 2: CAD model of the torpedo shooter

C. *Object Manipulation Tasks*

The Object Manipulation task category encompasses the Ocean Temperature and Collect Samples tasks. The team identified that these two tasks could theoretically be accomplished by the same mechanism and therefore, in the interest of keeping a small profile on the AUV, attempted to design a mechanism to accomplish both tasks. This mechanism would feature a 4-bar arm accompanied by an actuated gripper that could grasp both the markers and samples. The vehicle would start preloaded with both markers, storing them in the gripper which would remain actuated until the AUV detected the Ocean Temperature bins. Once the bins were detected, the AUV would plot a course until it was directly above them via local navigation through its sonars and downward-facing camera. Once in position, the arm would extend to the appropriate side of the bin, then drop both markers. The AUV would then continue going through various tasks until it reached the Collect Samples task. Here, once again, the AUV would position itself directly above the task and identify the various samples using a combination of its sonars and downward facing camera. With the various samples identified, the AUV would utilize a combination of its arm and powertrain to collect a sample and then place it in its appropriate bin to the side of the main task.

D. *Managing Complexity*

Given this is the team's first year returning to RoboSub since 2020, the team decided early on to maintain simplicity in system design to ensure integration later on went smoothly. To accomplish this, the team created a priority list, considering the various tasks as well as the potential mechanisms needed to complete these tasks. As a result, the decision was made to prototype mechanisms for all tasks but only those that demonstrated a high degree of consistency as well as maintainability would go on the final vehicle, *Tech Triton*. To this end, the team's software subsystems feature a variety of distinct algorithms for accomplishing simpler behaviors identified as key components of the larger tasks such as identifying buoys or navigating to goals. In order to ensure no single point of failure within the software system, the team created parameter files that allow for easy tuning of existing algorithms or swapping algorithms out for others. This redundancy will enable higher performance during competition as backup algorithms can be employed while theoretically better ones can be debugged later. Additionally, the mechanical design prioritized consistency of mechanisms over potential for scoring, employing a simple powertrain configuration capable of five axis of motion, modular component design of the interior for easy maintenance at competition, and an overall modular design with the ability to quickly add/remove every subsystem.

III. Design Strategy

A. *Mechanical Design*

Tech Triton was designed to feature a minimum number of points of failure in all respects, focusing on having multiple sources of structural stability for every component, ensuring no components are lost during a run. *Tech Triton* was also designed to be more maneuverable than prior vehicles developed by GT MRG due to a more powerful powertrain while simultaneously not sacrificing stability in any of the three dimensions. The AUV was also built to protect its electronics at all costs such that no costly mistakes either by humans or the autonomous systems can occur. Finally, *Tech Triton* was also designed with modularity in mind with every component being able to mount anywhere on the exterior of the AUV, enabling firm size parameters and simultaneous development due to firm design restrictions.

1) Platform: The driving concept behind the overall design of *Tech Triton* is modularity where various subsystems and sensors can all plug and play in an easily reconfigurable environment. To this end, the team created a symmetrical base structure consisting of a 24" long cast acrylic tube with four square-shaped 1/4"-thick aluminum plates secured along its length. These plates have been water-jetted to include large lightening holes, enhancing the AUV's hydrodynamic efficiency while also reducing its weight. These plates are connected to the main body of the AUV utilizing multiple 3D-printed clamps with chloroprene rubber lining which provide a strong friction fit to prevent potential slipping or rotating. Connecting these plates are the eight impact-resistant, stiff polycarbonate tubes referenced hereafter as guide rods, seen in Figure 3 as the light yellow rods spanning the length of the AUV.

These guide rods are the core component of the modularity of *Tech Triton* as they provide rigid, standardized mounting surfaces for all subsystems and sensors. Given their even distribution around the AUV, as seen in Figure 3, the AUV maintains its symmetry which allows various subsystems, including those yet to be developed, to be freely mounted around the perimeter of the vehicle. This design theory also enables optimizations for sensor placement to get the most accurate data while also maintaining weight balance. Beyond modularity, the aluminum plates and external rails also serve a protective function for the electronics enclosure, ensuring the integrity and watertightness of critical systems during operation.

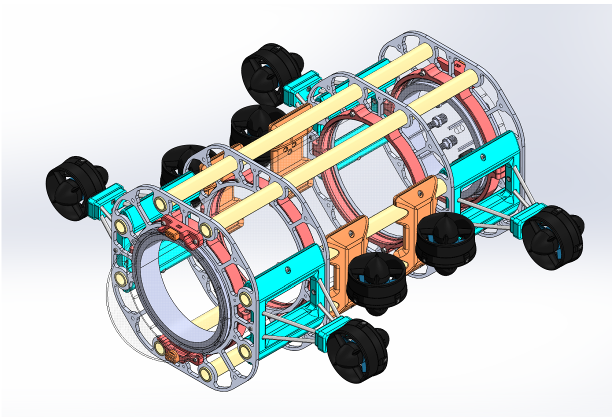

Fig. 3: CAD model of external assembly of the sub

2) Powertrain: The team opted for an 8-thruster tank-drive configuration, as shown in Figure 3, featuring 4 horizontal and 4 vertical thrusters. This setup offers simplicity in design and standardization between mounts, as well as a simple, reliable, and robust control system. The 4 vertical thrusters allow for simultaneous roll and pitch correction while the four horizontal thrusters maneuver the AUV for the various tasks. Testing has demonstrated that this configuration enables high-performance, hydrodynamic, and stable maneuvering, along with efficient forward and backward motion, allowing tasks to be completed in minimal time.

3) Internal retractable electronics housing: Tech Triton's internal electronics housing, shown in Figure 4, was designed with specific constraints to accommodate the numerous electronic components, wiring, and the need for future detachability, modifications, maintenance, and upgrades. The team chose a retractable electronic bay design, utilizing retractable drawer rails to provide easy access to the electronics bay from the back of the AUV. This bay is securely constrained by the external assembly using a transition-fit constraining ring, which is bolted onto the enclosure flange. This ensures perfect alignment of the external and internal components, resulting in superior passive stability and balance of the system.

B. Software Design

Tech Triton uses a newly created ROS 2 (Robot Operating System) software stack called Pontus which provides various packages for autonomy, localization, perception, navigation, and control. Pontus is heavily inspired by the GT MRG's RoboBoat software stack, Virtuoso [2], but is heavily redesigned to better suit the three-dimensional underwater environment of RoboSub.

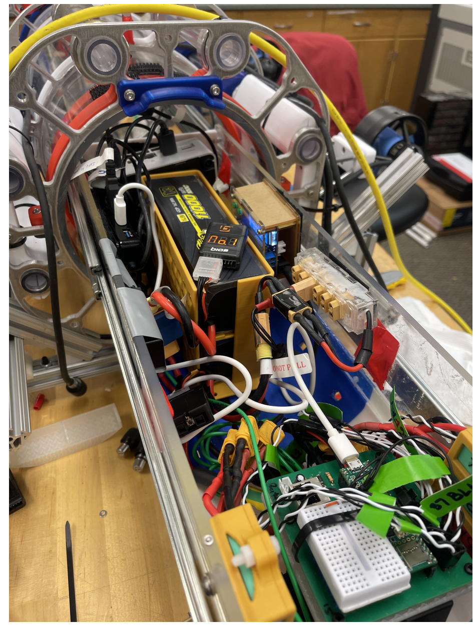

Fig. 4: Internal retractable electronic drawer of the sub

1) Autonomy: The autonomy package provides simple inheritable classes to allow for quick creation of new behaviors or modification of existing ones. Each competition task the AUV will be attempting is implemented as an extension of the `BaseTask` ROS node which provides limited default functionality, namely for generating a Task future and default publishing of debug and status information. The system is built such that any architecture that can trigger the `complete` function is a valid implementation with Pontus primarily utilizing state machines. From there, different types of Runs (Qualification, Semi-Final, Final, etc.) can be implemented by extending the `BaseRun` ROS node which provides functionality for generating and running new Task nodes to completion while monitoring their status. This enables flexibility when creating Runs of varying levels of complexity. For example, the Prequalification Run simply runs the Gate Task and Vertical Marker Tasks sequentially while the Finals Run can implement a more complicated state machine with various fallbacks and contingencies.

2) Localization: Currently, the localization package is entirely odometry based, which is accomplished by fusing velocity data from the Doppler Velocity Logger (DVL) and acceleration data from the Inertial Motion Unit (IMU) using the Extended Kalman Filter provided by the open-source Robot Localization package. In the future, the team intends to add Simultaneous Localization And Mapping (SLAM) based on data from the camera and sonars to supplement the DVL and IMU sensor tracks.

3) Perception: The perception package utilizes a variety of techniques to detect and classify objects of interest in the environment. First, camera data is fed through a preprocessing node to reduce noise, sharpen edges, and enhance contrast. Then, a YOLO model is run to attempt to identify the object. Due to limited data for training and testing, a simpler method of color matching is also employed for some tasks where the YOLO model struggles. These identified objects are then matched with detections by the sonar or stereo camera to actively tag objects, thereby providing the autonomous system position data of potential tasks.

4) Navigation: Due to not having a SLAM map of the environment for path planning, navigation is left up to the individual Task state machines to move locally relative to the objects they are interacting with. Inter-task navigation is accomplished by a Task which attempts to identify and follow the heading of the path markers. For tasks without a path marker the robot simply sweeps the pool floor with its downward-angled sonar looking for any notable vertical features distinct from the bottom of the venue floor.

5) Control: The control package provides a simple cascaded PID controller. First, a position PID controller is used to generate body velocity commands which are then used as the input to a velocity PID controller. This controller then outputs body acceleration commands to the thruster controller which uses the thruster positions provided by a URDF file to calculate individual thruster commands. To avoid thruster saturation, the thruster controller also separately rescales the vertical and horizontal thruster commands relative to the highest thrust value in each respective set.

6) Firmware: The firmware links the autonomy to the physical motors on the AUV. Firmware running on the Teensy 4.1 microcontroller takes in motor commands for moving the AUV from the autonomy stack and converts them into Pulse Width Modulated signals. The firmware utilizes the micro-ROS library to interact with the autonomy stack through a mix of publisher and subscriber topics. The firmware also provides valuable debug information to the team on land when the AUV runs untethered through a variety of LED lights placed throughout the AUV. Additionally, the firmware enables remote emergency stopping the AUV when connected via a tether which has proved useful during tests in the acoustic tank.

C. Electrical Design

The submarine's electrical system is divided into two electrically isolated circuits: the thruster power system and the computation power system. The thruster power system supplies the vehicle's thrusters, external motors, and related sensors via LiPo batteries. The computation power system supplies the vehicle's main computing unit and other delicate sensor electronics.

1) Thruster Power System: The Thruster Power system consumes around 800 Watts to power the eight Blue Robotics T200 thrusters on the vehicle, as well as any other motors. It is supplied by a 16.8V LiPo battery. The most important functionality in the Thruster Power system is the E-stop. The main portion of the E-Stop is implemented in a set of four automotive relays, with each relay controlling the power to two motors. Other external motors are controlled through additional automotive relays. These relays are opened and closed via a magnetic reed switch on the outside of the sub. Once disconnected, the thrusters and all other motors are completely isolated from the battery supply. The Teensy 4.1 acting as the motor control unit is also powered by the Thruster Power system.

2) Computation Power System: The Computation Power system consumes around 50 Watts to power the Jetson Orin Nano and any associated sensor on the submarine, such as the Oak-D stereo-vision camera and Lord Microstrain Inertial Measurement Unit. It is also supplied by an identical 16.8V LiPo Battery powering the Thruster Power System. The same battery is used to preserve equal weight distribution on the sub.

D. 2024 Development Cycle

The main focus of the 2024 development cycle was to build up a stable power system and overall electrical architecture for future iterations of the submarine. This was achieved through the implementation of the Thruster Power System's E-stop and motor controller unit. The E-stop design was adapted from a RoboBoat power distribution system. However, in order to fit to the cylindrical shape of the submarine, many redesigns had to be made. Relays had to be stacked on top of one another and wired such that eight ESCs could draw power from them. The space restrictions imposed by the AUV's design made it very important to minimize the size of the wiring harness connecting each component of the power system. Additional effort was made to ensure electrical protection for important components of our circuits, specifically the relays and motor control unit. This was implemented by placing fuses in line with desired electrical components.

1) Motor Control Unit PCB Design: Big steps were taken to improve how the organization as whole designs PCBs. Regular design review cycles were implemented and a 2-layer board was fabricated professionally via JLC PCB. The board initially implemented a switching regulator using an LM317 MOSFET. Later this was replaced by an MP 1584 so that voltage readouts could be captured from the LiPo batteries and monitored by the main computer. All the pins on the Teensy are broken out to male headers to allow for the integration of more sensors and functionalities over time. Additionally, power and ground lines are run parallel to the I/O pins to make it easy to power small off-the-shelf components from the board.

Below are the two major revisions the motor control unit PCB went through. The primary improvements were the use of a new voltage regulator, additional pinouts for sensors, extra electrical protection, and more efficient layout.

2) Specific Design Notes from 2024:

a) Revision of Power Bus: The initial iteration of the power system implemented a power bus that received all power and ground from the relay block and distributed power and ground to the ESCs. The part was composed of a 3D-printed frame and two brass plates. Challenges with the part included

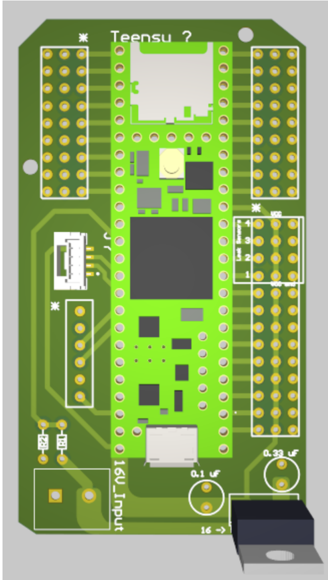

Fig. 5: V1 of the motor control board

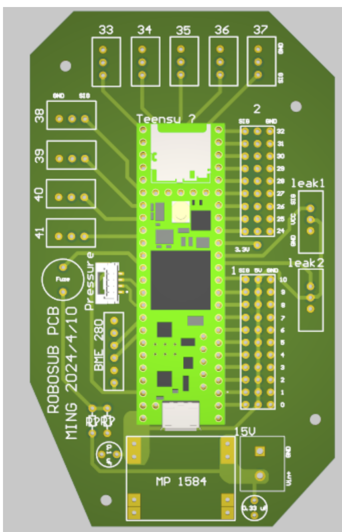

Fig. 6: V2 of the motor control board

difficulty ensuring a connection between the ESCs and the power bus as the wires rotated; the nuts used to secure the spade terminals tended to come loose. Also, the main spade terminal coming from the relays was wedged between the acrylic and the brass of the power bus as a pressure fit. This was not a robust enough connection, and the spade terminal became detached and created an electrical short during testing. To improve the design, the powerbus was phased out in the second iteration. Instead, each relay is soldered to two xt60 power connectors that connect directly to one ESC each. Removing the power bus system decreases the space used by the relay power system and reduces failure points.

b) Space Reduction and Cable Management: The initial power system was larger than anticipated, and the mechanical drawer was smaller than anticipated. Additionally, the original design placed the batteries in external tubes attached to the main cylinder. The external battery tubes were unable to be implemented this semester, so the batteries consume considerable volume within the main cylinder. To address this challenge, the relays were resoldered in a stacked configuration, and the wires were replaced with more malleable alternatives. The signal wires and wires connecting to the backplate were braided to improve organization and decrease space requirements. Mechanical mounts provided by the Mechanical subteam further improved cable organization.

c) Fuses: A 200 Amp ANL fuse was installed between the XT90 connector which leads to the battery and the relay block. Each motor is capable of drawing 24 Amps, so the fuse will blow if full power for all eight motors is commanded by autonomy.

IV. Testing Goals

A. Simulation

As a new team, the ability to test code even before the vehicle was ready for water testing has proved extremely valuable. This is accomplished via Gazebo Garden and its built-in hydrodynamics plugin. Simulating cameras and the IMU/DVL was accomplished using primarily existing sensors in the simulation while the sonars were modeled using LIDARs configured with similar parameters as the sonars on *Tech Triton* (number of beams, update rate, range, etc.). Through the simulation, the team was able to access immediate feedback from all sensors and autonomous systems, enabling debugging in a more controlled environment, and saving precious time during water tests. One area the team is targeting for improvement is better simulation of sensor noise *Tech Triton* encounters in the real world, most notably with camera data looking far darker/murkier and the sonars having far greater accuracy than in the real world as shown in Fig. 8.

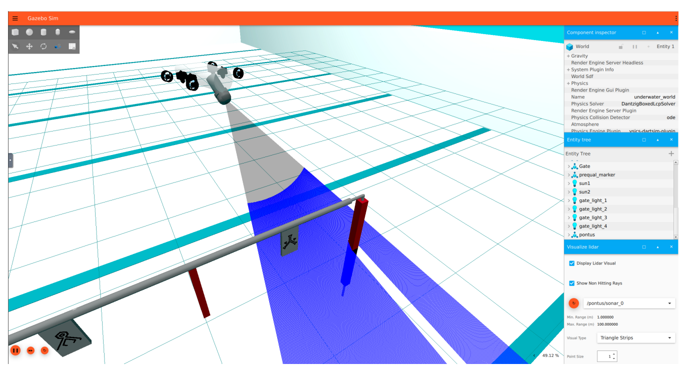

Fig. 7: Gazebo Simulation Environment

B. Dry Testing

Dry tests take place a few days before water tests, focusing on four main goals: the hardware is secured properly (including waterproof testing), the electrical system is functioning properly, the software system and relevant sensors are working, and the communication layer between the software and electrical system is functional. Ensuring the hardware is secured

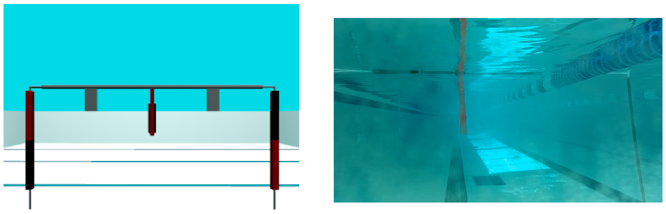

Fig. 8: Image of the gate in simulation (left) compared to an actual image of the gate recorded by the vehicle (right)

properly involves testing the waterproof seal for the electronics drawer, ensuring none of the subsystem mounts are loose, and everything is secured down in preparation for more extreme maneuvers such as rolling or pitching. Testing the electrical system focuses primarily on ensuring the physical and remote emergency stops are functioning properly, all components are outputting the desired data, and no connections are exposed. On the software side, the main concern is that the code compiles and runs out of water along with seeing and receiving data from its relevant sensors. Finally, the communication layer tests ensure that the autonomous system can communicate to the firmware and the firmware is connected properly to all of its respective components.

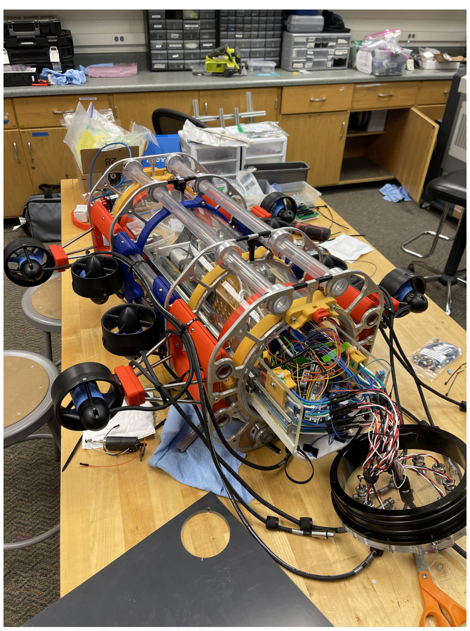

Fig. 9: Dry Test

C. Field Testing

Field tests were largely done to test full system integration in competition-like environments. Tests were done at either our campus acoustic tank, as shown in Figure 10, or recreational gym pool. Firstly, the PID controller for the AUV was tuned at pool tests to ensure safe yet responsive handling by the powertrain. Secondly, basic operations like vertical auto-stabilization were verified such that the AUV is able to maintain its depth in spite of external motion. Thirdly, large amounts of camera data was collected while underwater to tune the color thresholding. Finally, individual tasks were attempted.

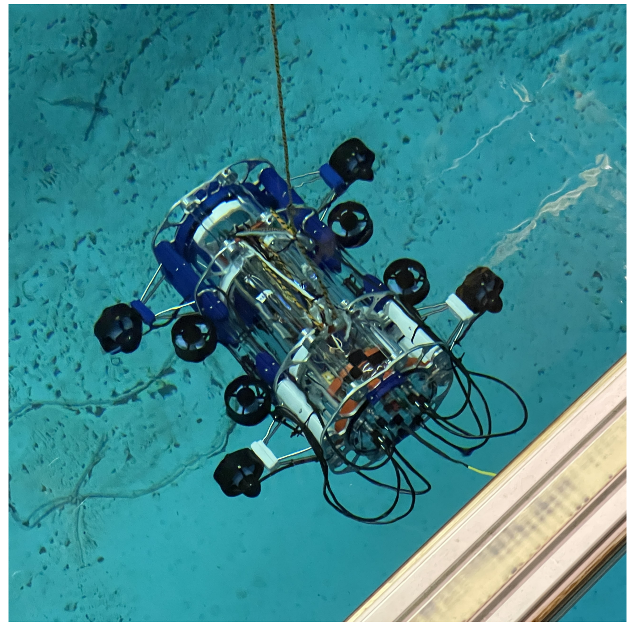

Fig. 10: *Tech Triton* submerged below the surface at the acoustic tank

V. Acknowledgements

A. Sponsors

The Marine Robotics Group thanks all of our sponsoring organizations that have contributed to the team, whether financially, through hardware, or any other form of support demonstrated. Our corporate sponsors and supporters include Greenzie, Altium, Firefly Automatix, and Blue Trail Engineering. Our academic sponsors include the AquaBots Vertically Integrated Project, the Georgia Tech Student Government Association, the Georgia Tech Student Organization Finance Office, the Georgia Tech Student Foundation, the Aerospace Systems and Design Laboratory, and the School of Aerospace Engineering Student Advisory Council.

B. Mentors

The team thanks Carl Johnson for taking over as the primary advisor on the project, Dr. Michael West for his help as an advisor to the team, Tanya Ard-Smith for her help with competition logistics, and Professor Dmitri Mavris for providing for the team at larget.

References

[1] Blue Robotics. *Sonoptix Echo Imaging Sonar*. 2024. URL: https://bluerobotics.com/store/sonars/imaging-sonars/sonoptix-echo/.

[2] GT Marine Robotics Group. *Virtuoso*. 2021. URL: https://github.com/gt-marine-robotics-group/Virtuoso.

APPENDIX A
COMPONENT LIST

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
ASV Hull Form / Platform	Blue Robotics	Cylindrical Watertight Enclosure	8" Inner Diam, 8.5" Outer Diam, 24" long	Purchased	$438.22	2023
Waterproof Connectors	BlueTrail Engineering	Cobalt Series Bulkhead Connector	3 Pin Power	Purchased	$460	2023
Propulsion	Blue Robotics	T200 Thruster	T200 Website	Purchased	$200	2023
Power System	Multistar	4S 12C LiPo	4S1P, 14.8V, 10Ah	Purchased	$120	2023
Motor Controls	Teensy	Teensy 4.1	Teensy 4.1 Specs	Purchase	$31.50	2023
CPU	Nvidia	Orin Nano	Orin Nano Specs	Purchased	$500	2023
Teleoperation	—	—	—	—	—	—
Compass	—	—	—	—	—	—
Inertial Measurement Unit (IMU)	LORD MicroStrain	3DM-GX3-25	IMU Specs	Purchased	$2640	2017
Doppler Velocity Logger (DVL)	Water Linked	A50	DVL Specs	Purchased	$7650	2024
Camera(s)	Playstation	Eye	640 x 480 60 fps; USB	Purchased	$43.99	2023
Stereo Camera	Luxonis	Oak-D	Oak-D Specs	Purchased	$249	2023
Hydrophones	Sonoptix	ECHO Multibeam Imaging Sonar	Sonoptix ECHO specs	Purchased	$8950	2024
Algorithms	—	—	—	—	—	—
Vision	—	—	Color Thresholding, YOLO	—	—	—
Localization and Mapping	—	—	Extended Kalman Filter	—	—	—
Autonomy	—	—	State Machine	—	—	—
Open-Source Software	—	—	OpenCV, ROS2, Gazebo	—	—	—

APPENDIX B
CAD OF THE AUV

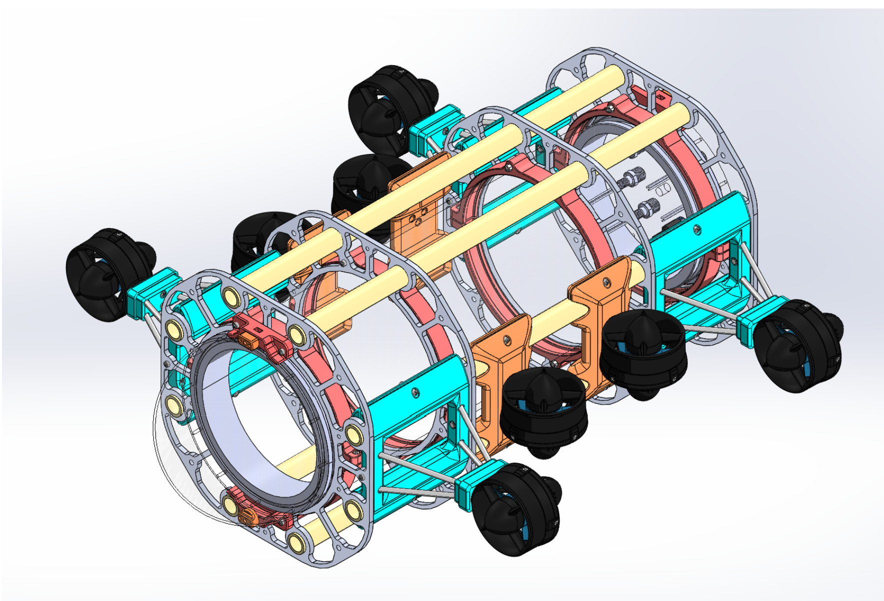

Fig. 11: 3D isometric view of the AUV's external components

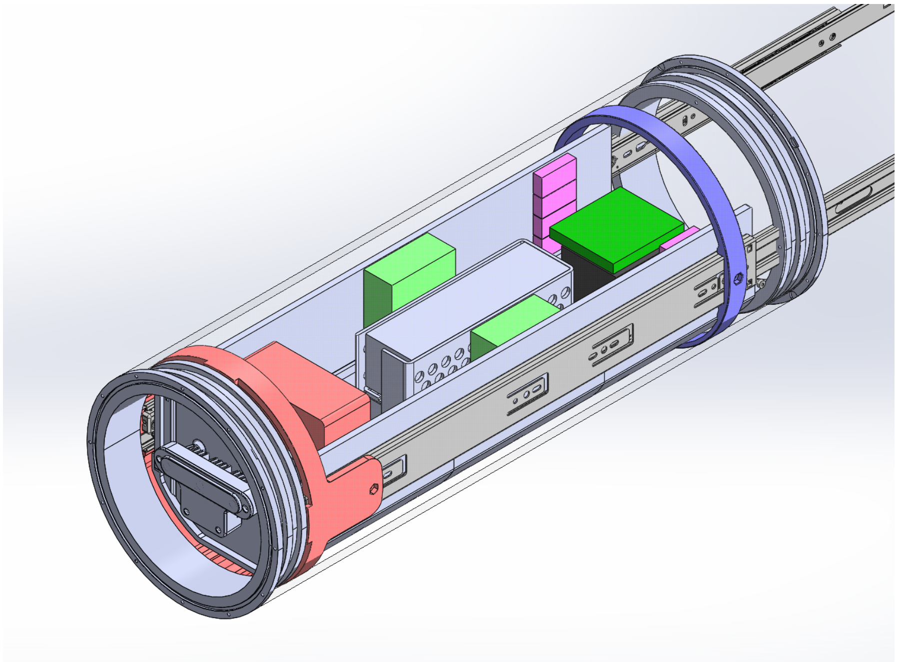

Fig. 12: 3D isometric view of the AUV's internal components

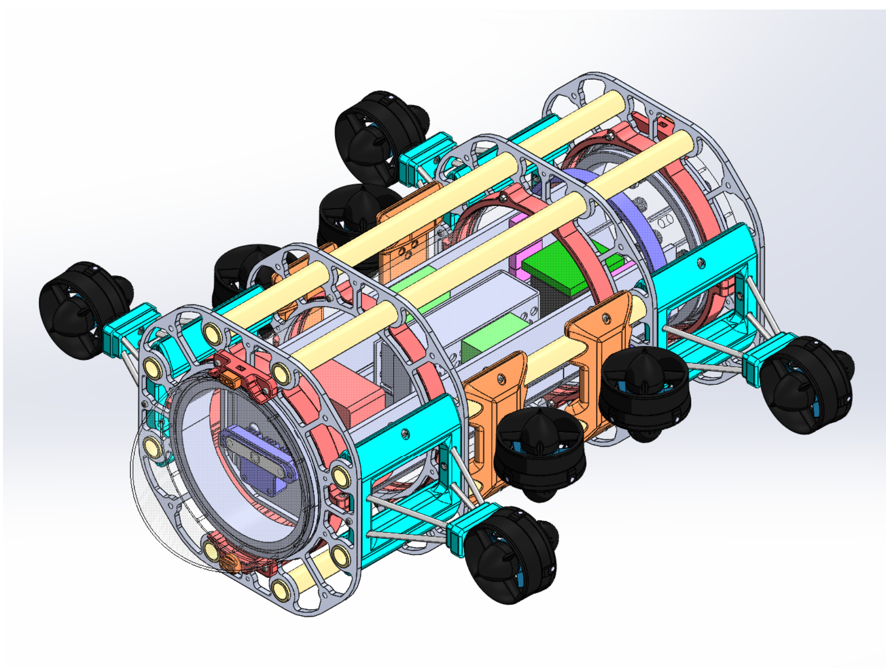

Fig. 13: 3D isometric view of the fully assembled AUV

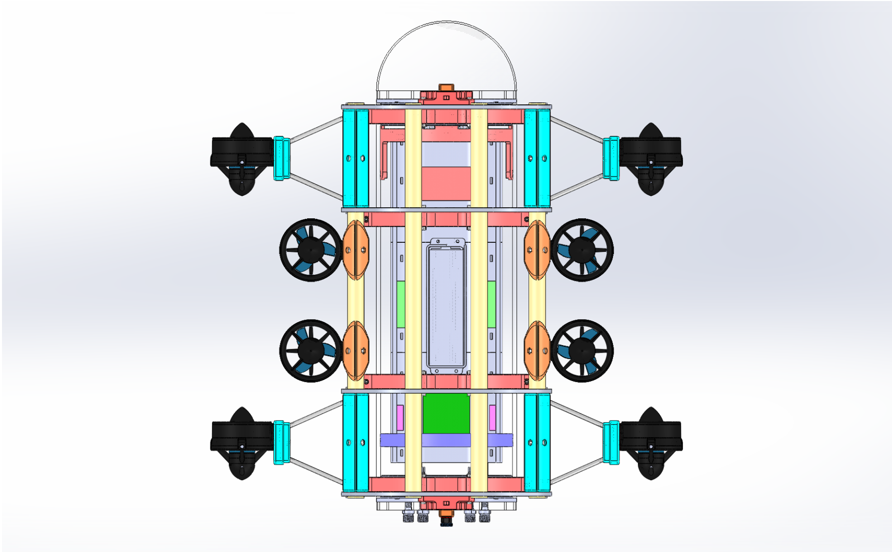

Fig. 14: Top view of the fully assembled AUV

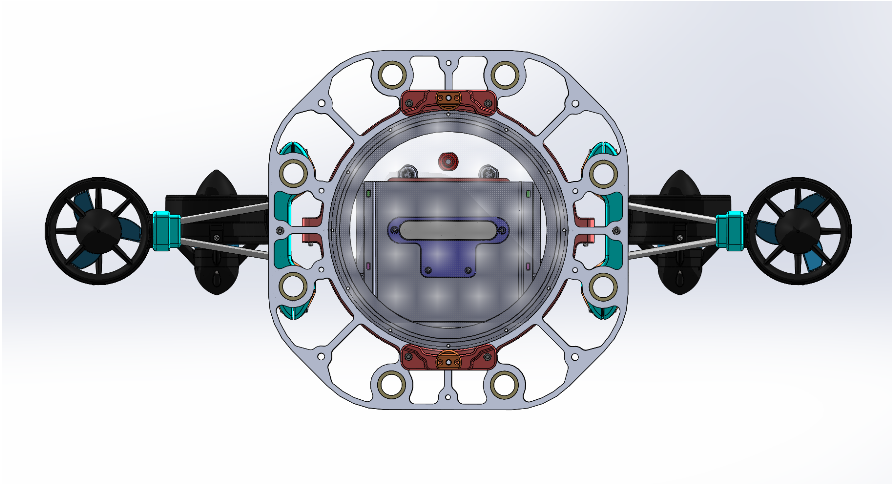

Fig. 15: Front view of the fully assembled AUV

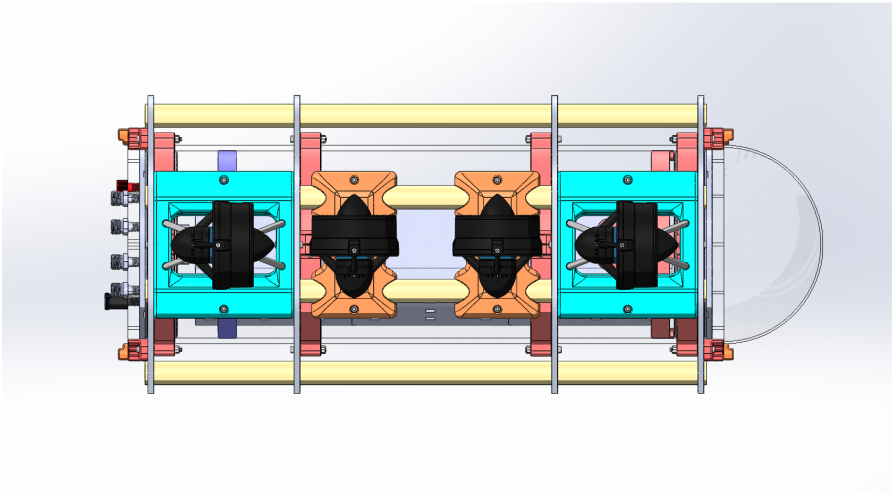

Fig. 16: Side view of the fully assembled AUV