TECHNICAL REPORT

Northeastern University | Boston, MA USA
NUWAVE ROV '25

NUWAVE

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Abstract

With the increasing effects of climate change on our world's marine ecosystems, the need for underwater monitoring and intervention is at an all time high. In response to this increased need and the MATE RFP, the team at NUWave is proud to present Scylla, an underwater ROV designed to replace sensors on SMART buoys, measure lake acidification, repair offshore wind farms and collect jellyfish samples. With four years of experience building marine robots, from ROVs and Buoyancy-Controlled Floats (BCF)s, to electric-powered Unmanned Surface Vehicles (USVs), NUWave is an interdisciplinary team of 25 marine scientists, software developers and engineers delivering high quality products to tackle marine challenges. In developing Scylla, we stuck to our company's three design pillars of extensibility, serviceability, and precision; pillars that have guided us to success over our four year history.

Scylla is NUWave's third generation of ROV. It features an entirely new laser cut acrylic frame, and a custom set of printed circuit-boards (PCBs) for onboard electronics. However, Scylla goes beyond just providing new features, representing a dramatic increase in the level of professionalism in the company's final product. From the attention to detail in previously overlooked areas like wire routing, to the addition of ease of operation features like carrying handles, this ROV is designed to look and perform like a quality vehicle. With a high precision control system, a three point-of-actuation arm, and an entirely reworked vision system, Scylla is equipped to handle the toughest of underwater operations.

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Teamwork

Company Profile

NUWave is an interdisciplinary company based in Boston, MA, with 25 members across 11 majors. With 8 new members, NUWave has continued to grow substantially in its fourth year, and it has used that size to tackle a wide range of marine research solutions from remote deployment systems for ROVs to subsea LiFi communications systems.

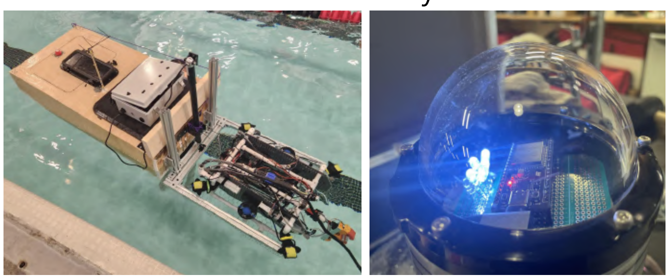


Figure 1: Our company's ROV being deployed from our USV (left) and our underwater LiFi transmitter (right)

The central focus though, has been in honing the company's ROV, offering a precise, polished product for marine ecosystem monitoring and protection.

NUWave is split up into three primary engineering subteams, electrical, mechanical, and software. The core leadership team is made up of the CEO, the team's two mechanical leads, an electrical lead, a software lead, and a CSO. We also designate leadership positions for each non-ROV robot. Positions like our float lead take full ownership of all sub-systems of a robot, and lead a subteam exclusively dedicated to that robot. This establishes a clear chain of command and gives engineers clear focus points each week.

At NUWave, our philosophy is to build not just great robots, but also great roboticists. As such, we emphasize a "teach first, do second" mentality among all of our team's leaders. While it may be slower in terms of short-term progress, we believe that building people up into great engineers will pay dividends down the line.

Project Schedule

Entering this year, the team did an analysis of how the team had planned out its time as compared to how the timeline actually occurred. The team noticed a key gap in our process: we were not making it to our iteration phase with very many subsystems. While research and design are important in engineering, many of the most impactful insights come from the results of testing. Only reaching the testing phase at the end of each year meant that we couldn't refine our solutions on a single season basis, and just had to improve year to year. In designing our schedule, we aimed to change that by starting our research phase over the summer, moving up our timeline to let us reach iteration faster.

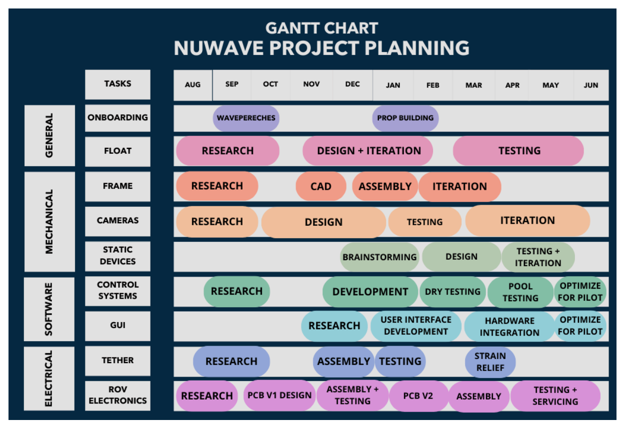


Figure 2: Our team schedule

To actually execute this plan, the team has three meetings every week, two subteam meetings, along with one general meeting. The subteam meetings provide each department time to work on any projects that are specific to their specialty, as well as troubleshoot any issues with other team members, encouraging problem-solving skills and collaboration. Meanwhile, the general meeting starts with status updates on what members are working on, as well as provides a chance for anyone who needs a new task to be assigned one. This is followed by a work period that allows for the integration of components from the different departments into one ROV.

Project Management

In order to better accommodate the large number of new members from all different specialties, the fall is dedicated to NUWave's Waveperch onboarding program. All new members are organized into three teams, each led by a subteam lead or an experienced member. Teams are challenged with creating small-scale ROVs using provided PVC, thrusters, and controllers, along with a $50 budget and access to 3D printers. Each week, a small lesson is taught on a different topic important to marine robotics, such as parts specification, waterproofing, and soldering. The team is then given time to work on their ROV. After 6 weeks, the teams compete against each other to complete tasks in a tank at MIT Sea Grant. After this program, employees leave confident in their abilities and with new ideas to contribute to the team's primary ROV.

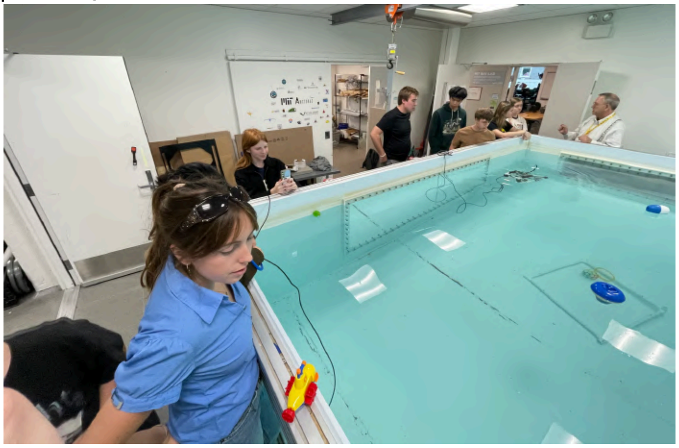


Figure 3: WavePerch competition day at MIT SeaGrant

Throughout the year, NUWave utilizes Notion for task management and assignment. This year, we entirely reworked our Notion setup from the ground up to allow for tracking of tasks with subtasks. This allowed for larger ticket items to have sub-components efficiently delegated and to have progress tracked. The tasks are then organized into a series of Kanban boards to track overall progress and available tasks for members to take on.

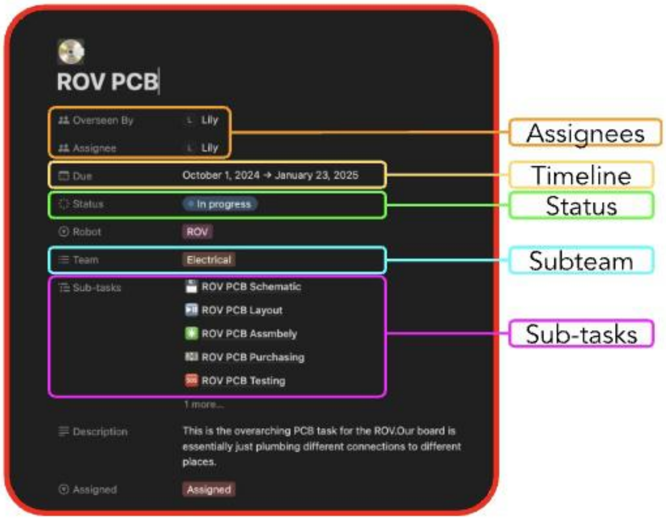


Figure 4: The anatomy of a Notion task

The team utilizes Discord as its primary form of communication, with agendas being sent out before meetings that allow for everyone to arrive on the same page and ready to get started. Our company uses Google Drive for all file storage and information management, SolidWorks for our computer-aided design (CAD) software, as well as Github for code management. Before anything is merged into our central code base, it must be reviewed by two other members of the software team to maintain code quality.

Design Rationale

Design Philosophy

NUWave aims to set itself apart from the rest in its sheer applicability to all situations, and ability to rapidly make adjustments in approach to any challenge. Throughout its four year history, NUWave has stuck to the three design pillars of **extensibility**, **serviceability**, and **precision**, to guide us in achieving that goal.

NUWave also exists within a unique set of circumstances that inform our design decisions toward affordability and compactness. NUWave is a part of Northeastern's larger robotics club: NURobotics. The club has eight other projects and shares a space with both a measurements lab and a mechatronics lab. As such, the team has limited space for both storage and fabrication, so compact solutions are often the only feasible ones. While building an affordable ROV is generally good, NUWave has some exceptional constraints placed on funding. At the end of the 2023 fiscal year, the NURobotics club, which is home to the NUWave team, had its budget reduced very significantly.

Figure 5: Spare Thruster Core Used for Claw Motor

Instead of buying new components, the team has leaned towards the creative reuse of parts that it already has. The open and close motors for both of our claws are made out of the core of our no longer in use TD 1.2 thrusters (Figure 5). Our sample extraction device is made from a small buoyancy syringe used the previous year and a scrapped linear actuator from an alternate claw design. Out-of-the-box solutions like these not only minimize the cost of the ROV but also allow NUWave to adapt to the ever-changing world of Northeastern's club sphere.

Exiting last year's competition, we were given a piece of feedback by a few judges that really struck a chord with the team: "Your robot looks like a prototype." This harsh but very fair assessment of our robot, of course, had a lot of merit. Our wire management was poor, and our PVC frame, while functional, looked like a hobby grade solution.

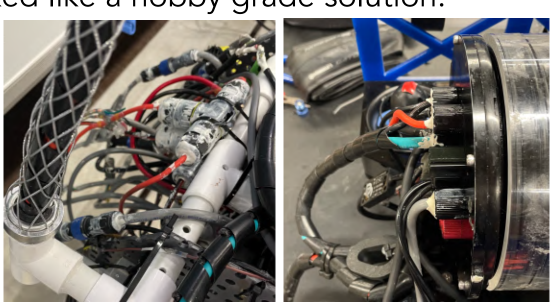


Figure 6: Our old wire management entering the tube (Left) vs our new wire management (Right)

Our team was motivated by this feedback, and brought in the newest piece of our NUWave design formula: professionalism. Many of the changes in our ROV this year were driven by the goal of building a polished, clean product to compete, not just to showcase cool features. In order to achieve our focus on competitive viability, it was not going to be enough to rely on the knowledge of our engineering team members alone, and so the team turned to data as a way to make professionally informed decisions.

Team Name	Points Scored in Pool	Number of Thrusters
Jesuit Robotics	300	6
M.I.A Robotics	290	8
Seahawk	285	8
CWRUbotix	265	8
PolyU Underwater Robotics Team	265	8
CityU Underwater Robotics	255	8
Aquaphoton	254	8

Figure 7: Top Product Demonstration in Kingsport

We identified key decision areas like thruster count and frame shape, and analyzed competition results from the previous year to determine the empirically most successful strategies. From there, we would integrate the expertise of our own engineers and design philosophies to converge on a final design.

Mechanical Design

Propulsion

Perhaps in no place is our current year design philosophy better exemplified than in the overhaul of our propulsion system. In previous models, the team had worked with 6-thruster designs that enabled roll control, but no pitch authority. In looking at the competition scores, there was a marked drop off between the top 7 teams, who all had 250+ point pool runs, and the remaining team who all scored 160 or less points. Of the teams in the top category, all but one of them had 8 thrusters. Of the remaining teams, over 90% had 6 thrusters instead. We largely attributed that gap to 8 thrusters teams both having access to more degrees of freedom in movement, and to the fact that they could traverse more quickly between the surface and the base of the pool. With the competition maximum pool depth being increased to 7m this year instead of 5.5m, the difference in time spent ferrying to and from the surface will be even more pronounced, making the decision to go with 8 thrusters clear.

Now, in moving to 8 thrusters, our power budget math had drastically changed as we could not afford to run four of our standard Diamond Dynamics TD7 thrusters at 24V. In combination with it, just generally simplifying our electrical systems by running fewer voltage levels, moving all thrusters to 12V was the only feasible option for power budget purposes. Given this shift, we now had to reconsider how our thrusters looked at 12V.

Reported Values	Blue Robotics T200 +ESC	Diamond Dynamics TD7	Diamond Dynamics TD1.2
Price	$238.00	$159.99	$64.00
Max Thrust	2.92kg	1.6kg	1.2kg
Max Power Draw	205W	45.6W	60W
In-Water ESC	No	Yes	Yes

Figure 8: Evaluating reported thruster specifications

We also noticed some inconsistencies in the values reported by the companies when compared to their actual output. This led us to build a thruster test stand as discussed in our Critical Analysis section to come. The results of that testing are shown below:

Measured Values	Blue Robotics T200 +ESC	Diamond Dynamics TD7	Diamond Dynamics TD1.2
Price	$238.00	$159.99	$64.00
Max Thrust	2.89kg	1.4kg	1.2kg
Max Power Draw	180W	49.2W	60W
In-Water ESC	No	Yes	Yes

Figure 9: Evaluating measured thruster specifications

Due to both price point and power budget constraints, having 8 BlueRobotics T200s was infeasible. While they provided superior thrust, they were less efficient for that thrust, had ESCs that could build up heat in the tube, and were 30% more expensive. At the same time, that explosive ability to transfer up to the surface was what winning teams had at the competition last year. Sticking with an entirely 12V system, we decided to run our entire make the four vertical thrusters BlueRobotics T200s and the horizontal thrusters Diamond Dynamics TD7s. This preserved the rapid ability to surface and dive down, while keeping to our constraints of reducing heat in the electronics enclosure and fitting in power budget constraints. For pool-bottom based tasks like pulling the pin on the hydrophone, precision is much more important than speed. An ROV pilot will not be going full throttle anyway, so the lower thrust output is ideal in the horizontal plane of movement.

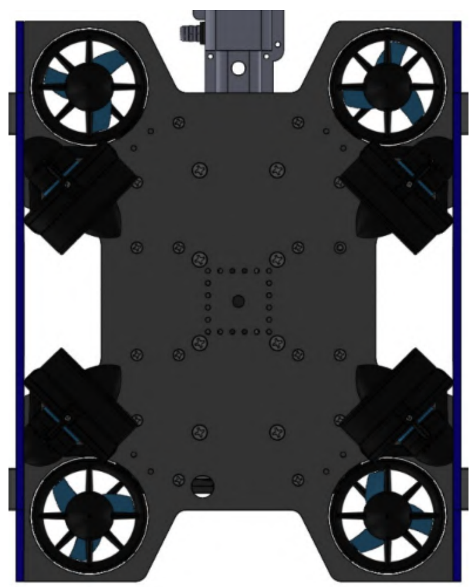


Figure 10: The view of the X-drive thruster setup from below the ROV

As for our thruster configuration, we chose an X-drive setup that allowed us to balance the angled thruster vectors against each other for lateral movement. We could use all four thrusters in tandem for yaw in this configuration, making it our strongest force. In a competition with the removal of the sacrificial anode and the photosphere tasks requiring significant yaw, this additional yaw force increases our efficiency without sacrificing needed lateral movement.

Frame

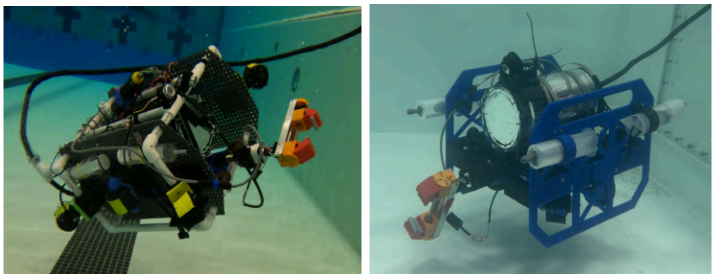
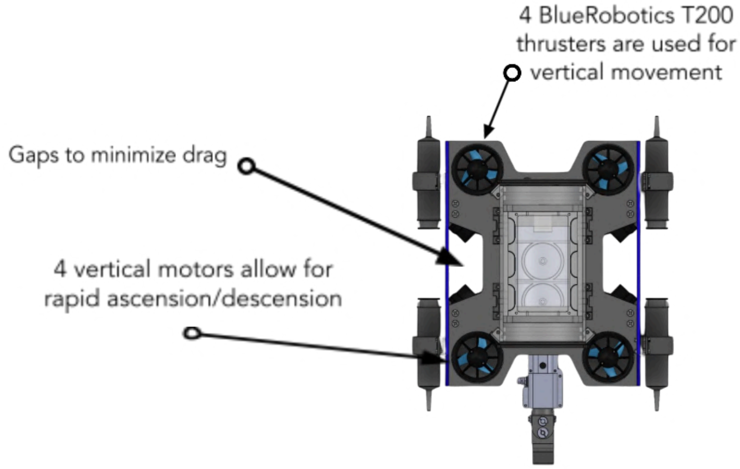
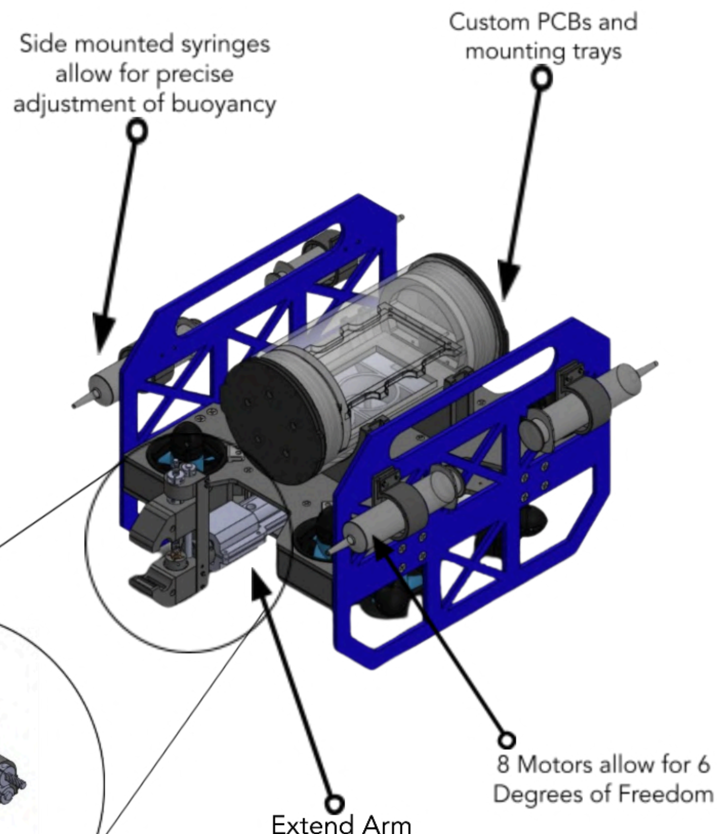


Figure 11: Calypso (Left) and Scylla (Right)

In evaluating the successes and failures of Calypso (Figure 11), the company's previous offering, our primary takeaway was that while the compactness and form factor were an improvement, but the ROV struggled with maneuverability and stability. The perforated plastic was valuable in increasing modularity, but significantly increased drag. In conjunction with only two vertical thrusters, the ROV wasn't stable while ascending, descending, and strafing. Our decision to move to 8 thrusters would help with stability, but we still wanted to improve the integrity of our design. Moving away from PVC, we opted to use 0.635 cm acrylic sheets to create our frame. We compared acrylic and aluminum, two popular frame materials, when considering what the new frame should be made out of. We ultimately settled on acrylic as it is half the density, requiring less buoyancy to become neutral and it is rigid enough for secure mounting as well as vehicle robustness. As for manufacturing, the sheets can be laser cut, expediting production time and cutting down time between revisions.

For our frame structure, we once again took a data driven approach, analyzing top performances over the past few years. Many teams have plate-like structures made from aluminum or acrylic and varying in quantity. These minimize drag but optimize mounting location while providing a rigid base for the electronics and actuators to be assembled. Our team settled on the "tie-fighter" approach. This consists of a plate at the port and starboard side of the vehicle and two sandwiched plates at the center. These are held together by standoffs and 3D printed couplers.





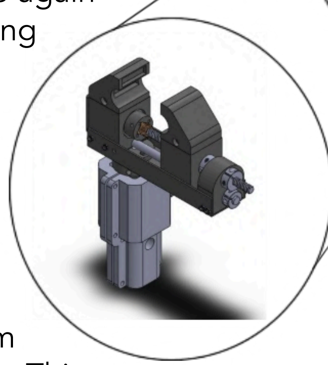


Figure 12: Labeled CAD of the top and full ROV

The standoffs provide rigid structure in maintaining integrity between the side and central plate while also providing key wire routing and management. Keeping the electronics, including the arm, claw, and linear actuator centralized both decreases drag and increases the professional aesthetics of our product. Serviceability has also increased tenfold. With the ROV consisting of only 4 plates, access and assembly are expedited. Other key features for improved operation include carry handles for transportation.

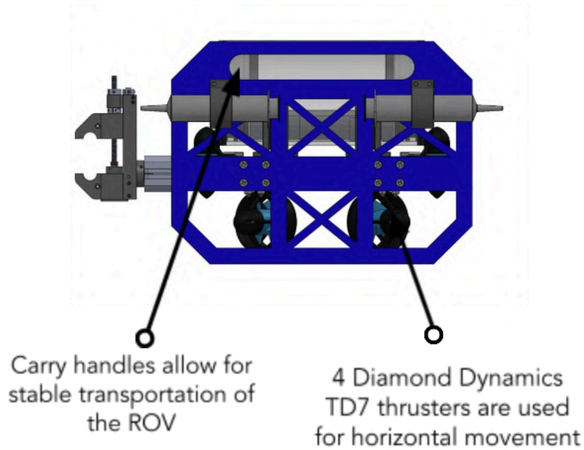


Figure 13: Labeled CAD of the left side of the ROV

Buoyancy

Aligning with our central pillar of extensibility, Scylla comes equipped with a modular buoyancy system designed for in-field adjustments. It starts with NUWave's signature modular buoyancy solution of syringes.

Figure 14: Adjustable syringes for buoyancy

By filling the syringes with air and capping them before submersion, the syringes act as adjustable buoyancy tanks that can be changed quickly and precisely. In placing a syringe in each of the four corners of the ROV, we can adjust the volumes of air to ensure both neutral buoyancy and pitch. We do this before every test in a new configuration, and can even do it during a mission to adjust for carrying heavy items.

In addition to modular buoyancy, we also have modular ballast. The need for ballast comes primarily from the air trapped in our electronics enclosure. In the past, we had used marine washers attached to our PVC frame, but have since improved to a more compact solution: internal mounting features inside the electronics tube beneath our PCB. This eliminates space taken up externally, allowing us to further minimize Scylla's footprint and maintain neutrality of the electronics tube.

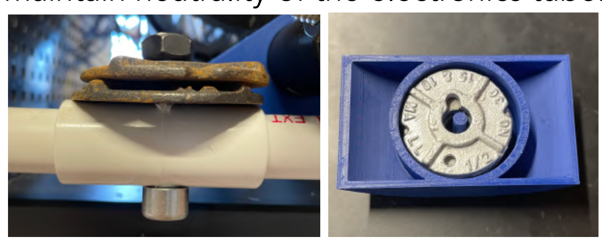


Figure 15: Old and new modular ballast system

Arm

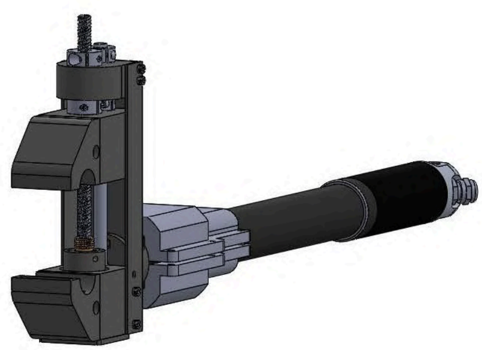


Figure 16: A full CAD rendering of our arm

Scylla is equipped with a three point of actuation arm with wrist rotation and extension capabilities. The arm's focal point though, is a custom gripper designed for rapid actuation with high holding power and low backdrivability.

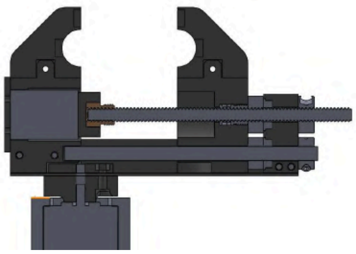


Figure 17: Our claw opened to show the lead screw

The gripper was designed in Solidworks and consists of two sides: static and dynamic. The static side houses the 12V DC driving motor, lead screw coupling, and stainless steel guide rod. The dynamic side has a lead screw nut and a negative cutout of the motor, allowing it to go flush when completely closed. These are then housed in a U-channel frame, increasing the structural integrity of the entire gripper. The lead screw acts as the central actuation point of the gripper, almost like a custom linear actuation. Due to the nature of the lead screw, it requires significant force to backdrive unless acted coaxial to the motor inherently making it non-backdrivable. This allows for high grip strength and increased control over props.

The wrist rotation is driven by a stepper motor and allows Scylla to rotate the gripper continuously, allowing for various ways to interact with tasks. Depending on the orientation of the handle or PVC, Scylla doesn't have to be as precise in flying, as the gripper can be moved to a more favorable position. The motor itself is an IP65 weatherproof stepper motor repurposed from an actuating screw design; IP65 would not be sufficient for pool missions, though, so the team used Loctite Marine Epoxy to seal all the seams on the stepper motor. We chose to use this model and seal it instead of buying a waterproof continuous high torque motor as the options that existed were all over $200. Our extension is driven by an extremely reliable IP67 linear actuator from Progressive Automations. This model is rated for 10kg, allowing it to push any competition prop.

All of this together leads to an extremely robust arm that allows for the arm pilot to correct mistakes of the main pilot with easy, precise adjustments. This strategy is employed when pulling the pin on the hydrophone, as an example, where the pilot only needs to get close to the pin before the arm can extend, wrist rotate to the correct orientation, close on the pin, and retract to finish the task.

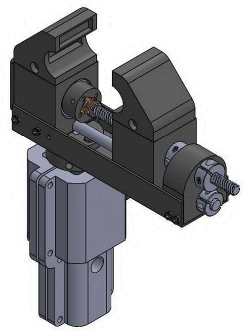


Figure 18: The whole claw and wrist assembly

With the transition time between the surface and the ROV being such a differentiating factor, limiting trips is paramount. This led us to attach a second claw of the exact same model to the side of our ROV. Carrying down or retrieving multiple items per trip can save well over a minute of the total run time. It is identical in design, however it doesn't have wrist actuation.

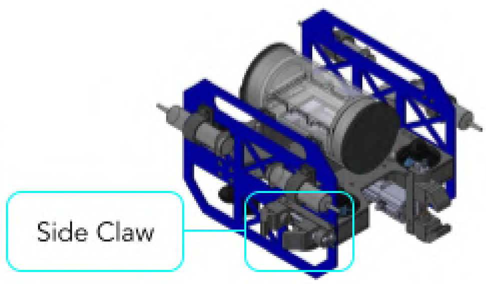


Figure 19: The side claw attached to the ROV

Further adding to the applicability of our claw is its modular claw tip. Our current claw shape is designed to easily grasp the 1.27 cm PVC used to make a large majority of the props, but different claw shapes can be attached with wider holes, with things like holding our Buoyancy-Controlled Float or flat planes for holding board-shaped items.

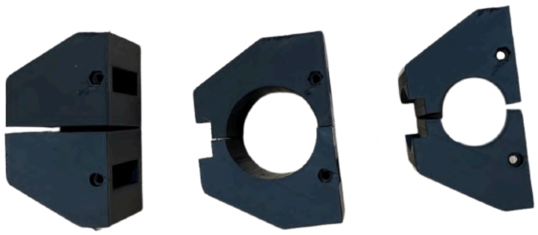


Figure 20: Swappable claw heads

Payload Tools

Our highly extensible arm design and swappable claws have the flexibility to handle most tasks, we have a few additional devices that allow for certain tasks to be completed in a way we couldn't otherwise.

Jellyfish Polyp Sampler

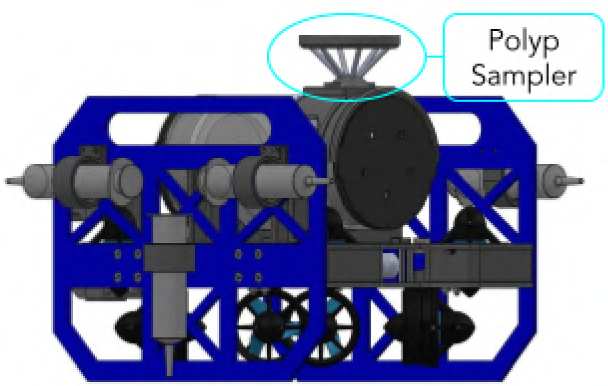


Figure 21: Polyp sampler attachment

For the jellyfish polyp sampler task, we took inspiration from a minnow trap as it allows for one way access of the polyps. The polyp sampler is mounted on the top side electronics enclosure of the ROV with a quick pin release system allowing for easy removal and attachment poolside. Its placement allows the funnel to breach the surface without losing control. Once equipped, the ROV can fly over to the polyp collection area, and the minnow-trap funnel quickly collects the polyps, securing them internally. This allows the pilot to continue completing other tasks without fear of losing the polyp.

Lake Acidification Sampler

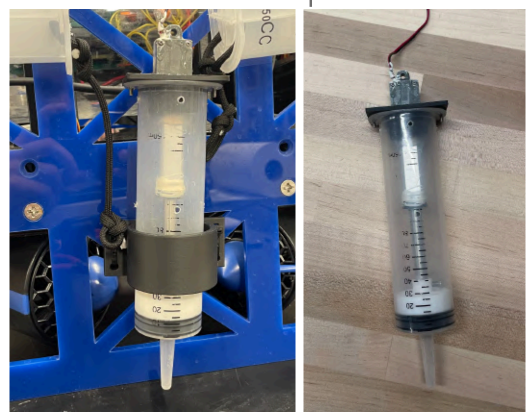


Figure 22: The pH sampler on and off the ROV

Our lake acidification sample uses an actuated syringe to collect pH readings. A linear actuator was chosen to give the team as much mechanical advantage as possible while drawing very little from the power budget. The syringe pierces the foam and then extracts a sample without requiring a trip back to the surface. To save costs, our lake acidification sampler is built entirely from repurposed parts. The syringe is a buoyancy syringe from last year's ROV, with holes drilled to enable the upper part of the syringe to flood, and the linear actuator was repurposed from an alternate closing method for our claw.

Software Design

Our codebase implements a server-client architecture, with modularity and readability as major pillars of focus. The system centers around an asynchronous server that runs on a Raspberry Pi 4, serving as a central hub for data flow, publishing and receiving data packets to and from its clients. This type of event-based system eliminates the need for polling – data refresh frequencies from controllers and sensors can be set by their individual drivers, allowing appropriate allocation of communication resources for each individual component.

The only exception to this set-up is the cameras. Because they send so much data, the TCP protocol employed by the server and clients for its reliability is too slow. Instead, the video feeds are sent in a direct pipeline to the Graphical User Interface (GUI).

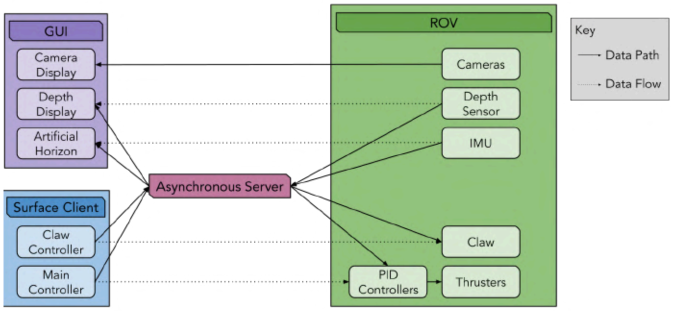


Figure 23: Software Architecture & Data Flow

ROV components are represented with types that can be instantiated in different combinations, making our codebase modular and adaptable to changes in the construction of each iteration of the ROV.

For example, to accommodate Scylla's new vertical thrusters, we simply added two thruster instances to the code representation of the ROV, making the change seamless and unobtrusive. We strive to make underwater robotics accessible to everyone, and that includes using simple, reliable, reusable code and writing it all in Python, an approachable language for beginners.

Controls

Scylla is piloted using XBox controller inputs, allocated in our control scheme as shown in Figures 24 and 25.

Figure 24: ROV Control Scheme: Main Controller

*refers to the bird's eye view camera located on the tether

Figure 25: ROV Control Scheme: Claw Controller

This year, we made two major additions to our control scheme: a vertical precision mode and pitch control. The vertical precision mode limits all four of our vertical thrusters to 20% thrust, enabling Scylla to make smaller, more precise movements when completing tasks like pulling the pin on the hydrophone while keeping a high top speed for traversing the full height of the pool, adding adaptability to our vertical control.

With two extra vertical thrusters, our ROV can now move along new axes, and this is reflected in our control scheme. In addition to enabling maneuvers like the front flip shown in Figure 26, having full pitch, roll, and yaw authority has made Scylla more effective at completing tasks like removing the cargo cover by improving our ability to release the cover without getting stuck on the handle.

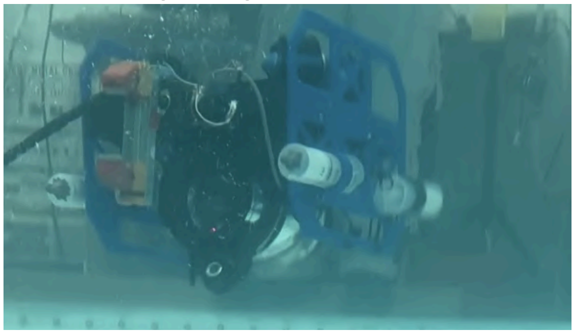


Figure 26: Scylla (intentionally) midway through completing a full front flip

Automatic depth stabilization (auto-depth) is implemented via a proportional-integral-derivative (PID) loop that calculates the various errors between the desired and current depth and combines them to autonomously command the thrusters in a way that maintains the ROV's target depth. Through waterlogging of 3D-printed parts, temperature changes inside the vehicle, and even picking up mission items, Scylla is constantly subject to changes in buoyancy. Auto-depth can help compensate for these changes, providing stability and reliability in the inherent unpredictability of a natural environment.

GUI

This year, Scylla is equipped with a brand new graphical user interface (GUI). Like last year, it features four camera views, an attitude indicator to display our axial position in an easily digestible format, and relevant numerical data like our current velocity and depth, but this year's version sports an updated look and a completely new backend. We previously ran a web-based GUI, hosting our frontend like a traditional website, which created integration, connection, and latency issues. Implemented with PyQt5, the new GUI is more elegant, responsive, and visually pleasing than its predecessors, even whilst maintaining and expanding on all of the features we valued in older versions.

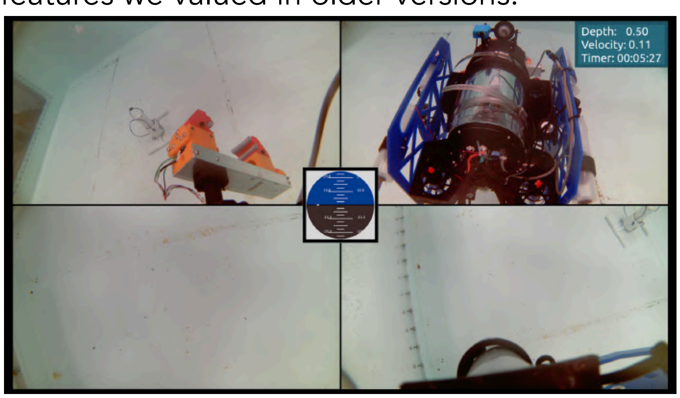


Figure 27: GUI showcasing different perspectives

PyQt5 operates entirely on the local machine using asynchronous updates, which noticeably improves response times, allowing the GUI to display high-definition video and real-time sensor data with minimal latency. It also eliminates the dependency on a web browser and local network, a frequent point of failure in previous versions.

One of the biggest architectural changes to our codebase this year was the integration of the GUI into the server-client architecture. Hosting the previous version of the GUI as a website made communication with the rest of the system complicated and inefficient. During our GUI overhaul this year, we were able to create a client to control communication with the GUI and integrate it into the centralized flow of data. This has not only reduced complexity, but also enabled real-time updates for more parts of our system.

Sensors

The ROV has two primary sensors: a depth sensor and an IMU. Because we use a server-client architecture, each sensor has its own driver, which connects as a client to the bottom-side asynchronous server. For the depth sensor, we use a Blue Robotics Bar02 that communicates via I2C. The IMU is an AdaFruit BNO085, the newer generation of the BNO055, which we were using previously. Last season, we faced significant integration issues with the BNO055 because it was designed for Raspberry Pi 2 and Python 2, and as a result did not work well with our newer hardware and software. The BNO085 is an improvement on its predecessor, a 9-DOF IMU that distinguishes itself by doing a majority of the required data preprocessing on-chip, which reduces the load on our central computer so more processing power can be devoted to resource-intensive tasks like camera streaming.

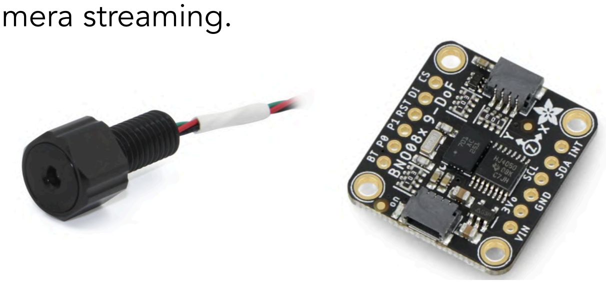


Figure 28: Blue Robotics Bar02 depth sensor (Left) and AdaFruit BNO085 IMU (Right)

These sensors are the backbone of our system, from powering the auto-depth module to providing vital flight information to pilots.

PTGUI

In order to create a 360° photosphere of the shipwreck environment, our team utilizes the PTGUI software. PTGUI is a free panoramic image stitching software that takes in a series of images and creates a photosphere based on the provided photos. However, the software is not often able to stitch the photos together automatically, so instead a member of our team adds control points in the image, essentially indicating a spot in two different photos where there is an overlap, to allow the software to create a connection between those points.

In order to send the photos from the ROV to PTGUI, a shell script sends the seven photos taken by the ROV to a folder, where they can be manually fed into PTGUI to create the control points and generate a photosphere.

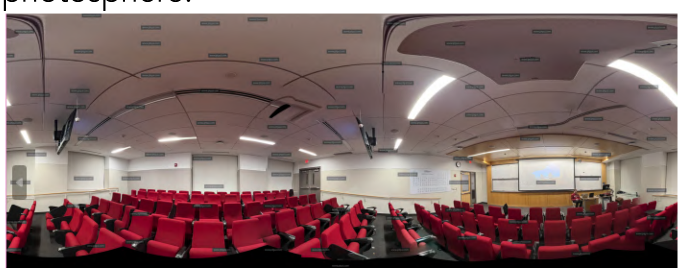


Figure 29: Nine photos of a classroom stitched together to create a photosphere using PTGUI

Electrical Design

Tether

Our tether contains 48V power, ground, and Ethernet lines that run from our topside controls box and power supply to the ROV. We use 12-gauge wire to transport power due to the high current demands of our robot and a CAT5e Ethernet cable from Automation Direct for fast and reliable data communication. These cables were chosen not just for their electrical properties, but their mechanical ones as well. The silicone-jacketed wire and the ethernet cable have the best bend radius at that gauge and price point on the market. Having a flexible cable ensures that turns and tether snags wont tug on the ROV or lead to cable snapping.

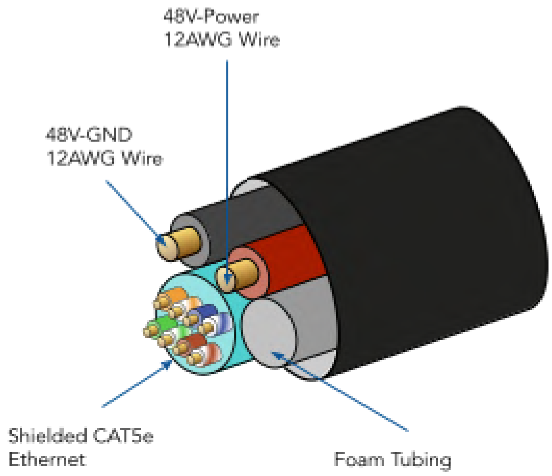


Figure 30: Tether cross-section

To achieve neutral buoyancy, we use foam tubing throughout the length of the tether. The wires and foam tubing are contained by a marine-grade spiral cable wrap and wound around an extension cord reel to make it easy to give and remove slack in the line.

Figure 31: Tether support where the tether connects to the ROV

Where the tether connects to our ROV, we 3D printed a custom thimble. This solution provides strain relief and protects our tether and the critical data and power it delivers.

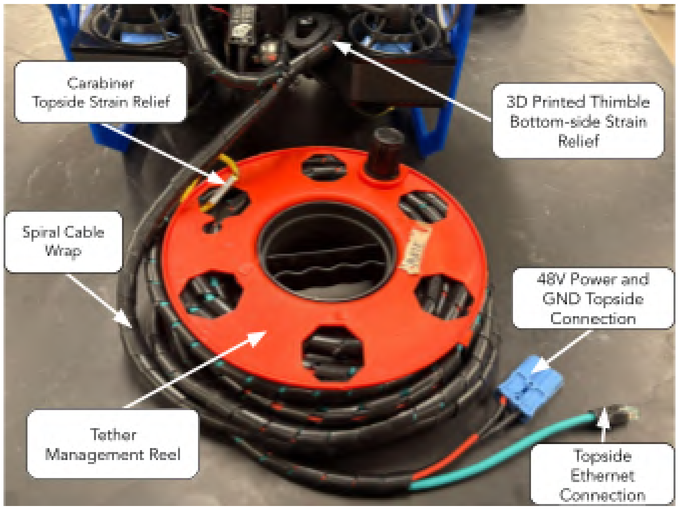


Figure 32: Tether and full tether management system

Our tether management protocol involves a specially trained employee handling the tether at all times to ensure it is kept in a proper state. Clear communication between the pilot and the tether manager is paramount for safety. We also implement a post-use maintenance routine for our tether to ensure its health.

Electronics Enclosure

To house our electronics, we use a 15.24 cm watertight enclosure made by Blue Robotics, which has been tried and tested in our previous products. Given that it is an off-the-shelf component, the number of pass-throughs is limited, which became a constraint during the design of the system. In order to put more than one cable through each pass-through, we carefully planned the placement of each cable, purchased penetrators with a larger diameter, and sealed them with epoxy. This is a waterproof solution that ultimately increases the cable capacity of our end caps.

We also purchased a pressure relief valve (PRV) from Blue Robotics to relieve excess pressure inside the tube. When the temperature of air increases, it expands. Given the static volume of the enclosure, this will result in higher pressure, which, if not relieved, could push on the O-Rings and cause the end caps to come loose, flooding the electronics.

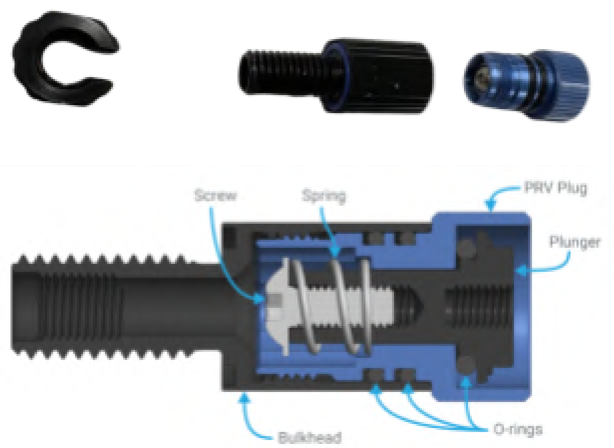


Figure 33: Pressure relief valve and cross-section from Blue Robotics[1]

PCB Design

Last year, one of the most glaring issues with our product was the wire management inside and outside of the enclosure. The close proximity of power wires to signal wires led to electrical noise that ultimately limited how much control we had over our robot. This year, a custom printed circuit board (PCB) was designed and implemented to allow the clean and professional integration of our electronic components. Now, instead of messy wires, we have seamless traces integrated into a board that is approximately half a centimeter thick.

The design process for the PCB was extensive and centered around our core values as a company: extensibility, serviceability, precision, and, of course, safety. After deciding which components were necessary to build our propulsion system and claw, we sourced two 48V-to-12V voltage converters capable of supplying over 67 amps each.

The space inside of the enclosure is limited, so we measured and planned the layout of the board and determined the footprint of each component. Due to size constraints, we determined we would need two boards. An acrylic mounting plate system was designed to fit inside of the tube and secure both boards. In an effort to reduce noise, one board was designed to manage power distribution and conversion, while the other managed signals.

To address extensibility needs, we aimed to find connectors that were easy to disconnect, allowed for many connections, and made it easy to add and remove wires from the connector itself. After extensive research, we selected WAGO lever nut connectors and chose to implement the twelve-pin board mount version of this model.

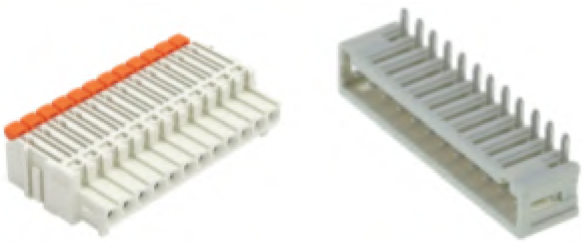


Figure 34: WAGO twelve-pin board mount lever nut connectors[2]

We utilized any extra pins we had on connectors to break out more signals, power, and ground in order to remain adaptable to the addition of future modules. The component footprints were placed so the ports for the Raspberry Pi, Arduino, and other components were accessible, ensuring serviceability. At this point, our company hosted a PCB design review, where we had multi subteam collaboration to refine our design choices in a global system view.

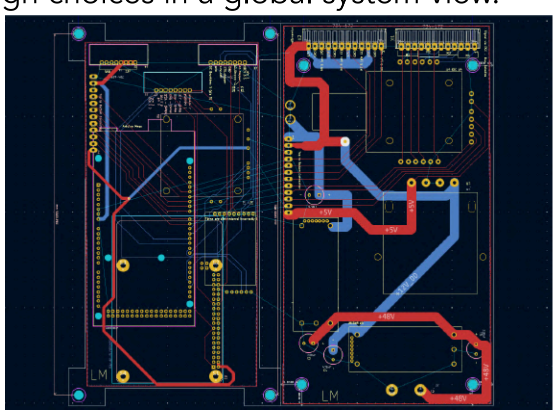


Figure 35: PCB layout - version 1

To minimize noise and maintain signal integrity, large ground planes were placed on both sides of each board. This can also help to dissipate heat, which was required due to internal enclosure power conversion.

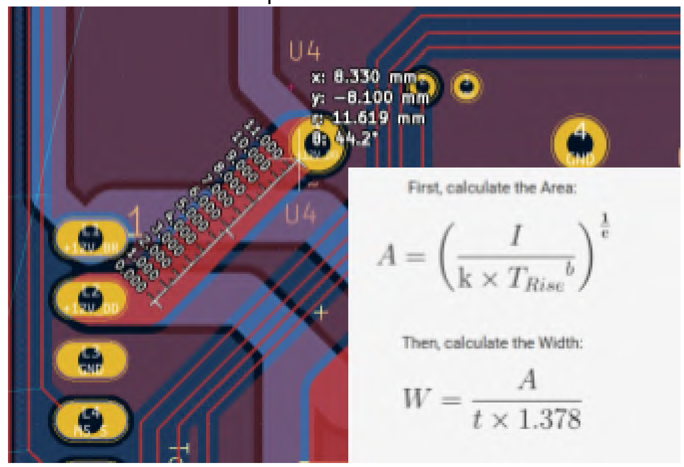


Figure 36: Measuring traces and formula to calculate trace widths based on IPC-2221 specifications[3]

During fabrication, parts were added in stages, and the PCB was powered and tested at each stage in order to protect the components and ensure board functionality before being integrated into the larger system.

Version 1 was imperfect, and while we were able to make it functional, our team continued the design process and compiled a list of improvements for Version 2. Components were added, like a linear actuator connected to a syringe for the lake acidification pH sampling task, and a servo motor to adjust the camera angle of our top camera for the photosphere portion of the shipwrecks task.

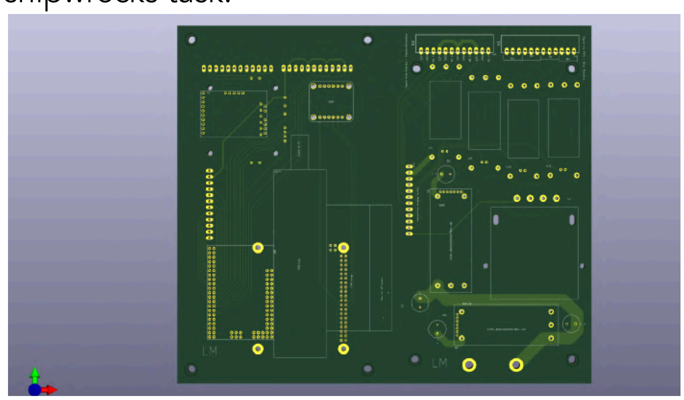


Figure 37: PCB 3D viewer - version 2

We gained extensive insight from version 1 that allowed us to improve our design and present a robust solution. This year's electrical system is the result of an intensive design process with the goals of clean wiring, building in development potential, and reduced noise, all while abiding by standards and physical space constraints.

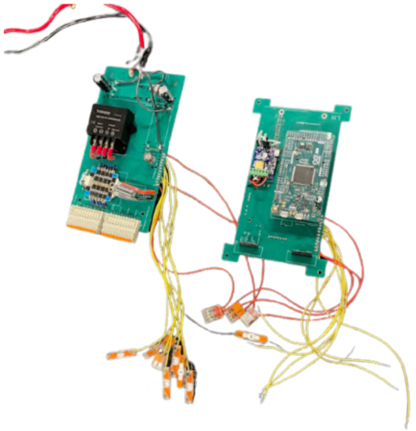


Figure 38: Fabricated PCB

Cameras

This year for cameras, we are reusing the ExploreHD 3.0 cameras from Deepwater Exploration. They are rated to 400 meters underwater and have preprocessing color correction for underwater environments onboard. At the price point, there was no cheaper way to replicate that level of quality manufacturing cameras in-house, but we still wanted to innovate with our camera system. To do this, we focused not on improving the cameras themselves, but on how they were utilized. The team had previously only mounted two cameras on last year's ROV, both in the center of the robot, with one looking down at the claw and one looking forward. While this was generally solid once the ROV reached a task, there were still issues finding and aligning with tasks from a distance.

To address this, we employed two new camera views, increasing our camera count to 4 total. The first new view was a 3rd person POV inspired by the perspective players usually get in video games.

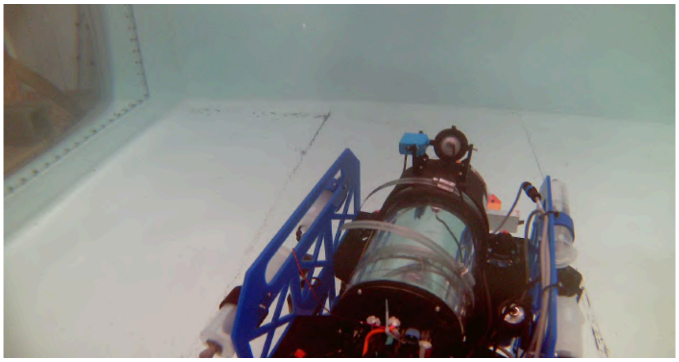


Figure 39: Third person camera view of the ROV

This was implemented by adding a mount to the ROV's tether and flotation to the back of the camera to make it float upwards. This allows us to see our whole ROV in view with the competition tasks. Additionally, we added an underside camera view that allows us to visualize the whole competition field as we fly down towards tasks, allowing us to position ourselves over areas accurately, like we needed to for landing for the photosphere generation task.

Figure 40: The front camera of the ROV on a servo (Left), and the third person camera on the tether (Right)

For the lakewater acidification sample collection task, operators found it difficult to track the extraction tool position on the side of the ROV. A camera pointing directly downwards in line with the camera made the task more manageable, but at a cost; we now could have both our claw and forward view from the previous year. To solve this, we mounted our front-view camera on a servo to give it 180 degrees of rotation (Figure 40).

This not only allowed operators to use both of the views from our previous ROVs, but it also gave the camera an even wider range of motion needed to capture the top of the pool for generating the photosphere. While this came with the trade-offs of added complexity and losing the ability to see multiple front-facing camera views at once, the decision was pretty clear as pilots almost always focus on a singular view at a time, and the team had already integrated servos into previous designs.

Safety

Our Philosophy

Safety is paramount here at NUWave. Our company always makes sure to take the time to complete tasks correctly, following proper protocols and wearing the right personal protective equipment, even if it takes longer or is more difficult. We understand that operating in this way reduces the risk of harm to our team, resulting in a more productive, comfortable, and happy environment.

Safety Features

There are numerous safety features implemented on NUWave's ROV to reduce the risk of harm, both to the vehicle itself and the people that surround it. All of our thrusters are properly shrouded to ensure that nothing can get caught in them and that they cannot be touched. There is also a 30A Littelfuse installed within 30 centimeters of our Anderson Powerpole connectors as an additional safety precaution.

Figure 41: A marked, shrouded thruster on the ROV

Special care is taken to ensure that all electronics within the ROV are fully waterproofed. All of our wire connections have at least two layers of waterproofing, including waterproof solder sleeves, marine epoxy, and duct seal. All electronics, connections, and the electronics tube are checked frequently to ensure that there is no leakage.

When working on certain tasks, especially ones that involve returning to the surface, we have planned out the safest way to complete that task. For example, when removing the damaged thermistor, the pilots and the team member working poolside will communicate to ensure that the pilots know when the poolside member is grabbing Scylla, reaching for the thermistor, removing the thermistor and when they are releasing the ROV. The pilots will communicate back to ensure the thrusters are turned off while the poolside member is holding it, as well as anytime they are moving the ROV, such as when they are opening the claw.

Safety Procedures

While there are physical features on Scylla to ensure safety, there are also many guidelines in place to ensure good practices during operation and testing, as well as in lab and pool environments.

Personal protective equipment (PPE) is vital, especially when working with any kind of harmful substance or tool, such as epoxy, power tools, or solder. All team members must wear gloves, masks, goggles, respirators, or any other necessary PPE when working with something that could be harmful. In addition to ensuring all members are educated on PPE and use it correctly, NUWave works to make certain that the risks present but harmful substances and tools are mitigated by taking actions such as only buying unleaded solder, teaching and overseeing the use of power tools, and utilizing fume hoods within our lab space.

Figure 42: Team member Nik wearing safety goggles, using a heat gun over unleaded solder and a fume hood (left) and team members showing off their gloves, goggles, and respirators (right)

In addition to our use of PPE, our company follows specific guidelines whenever new features are added, as well as before the ROV enters the water. When a new feature is added to the ROV, we work to test it in stages and go through multiple iterations as a team to find the safest and most effective way to implement that feature. We start by testing functionality dry, then power off the ROV and put it in water to make sure there is no leakage from the new component. After inspecting it for signs of water, we will test functionality out of the water one more time to make sure that nothing was missed, before powering the ROV in the water and testing it in the pool.

NUWave also maintains proper workspaces, such as making sure that the lab space where we build Scylla stays clean, with empty walkways in case of an emergency. When working with objects that could be harmful if dropped, such as nails, care is taken to observe anything that falls and promptly pick it up if needed. Furthermore, when working with any kind of tool, it is made sure that the area is completely clear before working, that other people in the space are aware of the tool use, and that everyone else is a safe distance away. When working poolside, team members wear proper footwear and move slowly, particularly if carrying something heavy, to reduce the risk of slippage. Moreover, all objects brought to the pool are placed a safe distance from the poolside to prevent tripping hazards near the pool's edge.

NUWave believes that communication is our most effective safety tool. All members make sure to announce aloud whenever they are using a tool, such as announcing a soldering iron or drill is about to be in use, that way everyone around them is aware and knows to be cautious of it. We also have implemented an Observation Program, so all team members know to speak to the safety officer if they feel uncomfortable or if they see something that they feel could be unsafe, so the safety officer can take the appropriate steps to address their concerns. In doing so, NUWave is able to proactively prevent incidents before they occur as well as identify areas of improvement. Please see appendix B for the safety checklists.

Critical Analysis

Testing

At NUWave, we believe testing is an integral step not just at the end of the design process, but throughout it. Design decisions influenced by verified data have fewer design oversights and yield better results. This year, one of our central decision points was our thrusters and we noticed that some of the specifications we were seeing online weren't lining up. To validate this observation, we built a thruster test stand.

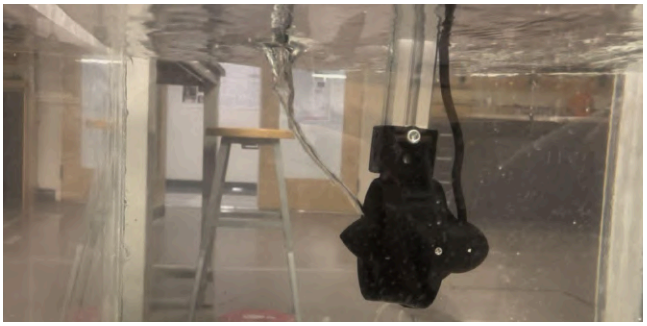


Figure 43: Vortices in the thruster test stand

The base of the thruster test stand was repurposed from an old dunk tank game that was a capstone project 5+ years ago. The mount was made from aluminum extrusion donated by Automation Direct and used a load cell on a lever arm to measure thrust. Amperage was tracked using our power supply to get the following data points seen below (Figure 45). From this data, it was determined that Diamond Dynamics thrusters were actually drawing more current than the spec sheet listed, at the same time, they were still over twice as efficient in thrust per amp than BlueRobotics thrusters at full speed. From this, we were able to inform our decisions about which thrusters to use where. We were also able to reuse the tank as an outreach tool at the Marine Science Center (MSC) High school symposium for demonstrations.

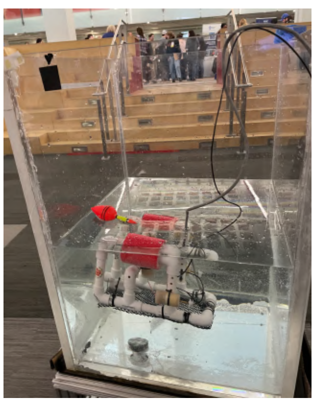


Figure 44: The thruster test stand being used for a demonstration at the MSC symposium

We applied this same level of rigor to all of our parts. From running a sample study on the porosity of different filaments and infills to determine the best option for our ROV, to putting 3D printed parts through stress tests to improve designs .

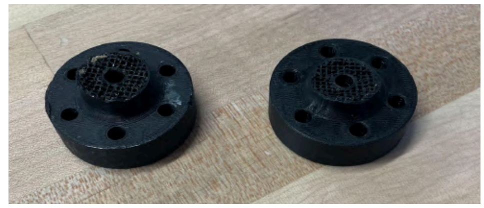


Figure 46: The broken second iteration of our claw mount after stress testing. This led to the final version

As for the actual testing of the ROV, employees follow a very strict policy to ensure that all facets of the ROV are watertight and operational before beginning a mission after any major systems change. First, we run all systems dry to ensure base functionality. Then the ROV is powered off and placed at the bottom of the pool for 15 minutes to ensure it is watertight. Once it is returned to the surface, all connectors and pass-throughs are thoroughly inspected for any signs of water. A second dry systems test is then performed to ensure that exposure to water didn't cause any damage not visible to employees. Finally, after all of those checks have passed, can a new configuration of Scylla begin attempting its missions for the day. This test is performed not just to protect our robot, but as a safety precaution for anyone in and around the pool.

Following any pool test, initial debriefs are held to discuss initial thoughts on what worked well, and what needs improvement. A deeper debrief is then held at the team's general meeting with a focus on discussing deeper questions about what the results of the test mean for the ROV and how the team should proceed given these results. From there, work is delegated from the COE to subteam leads, and then from subteam leads to individual members for further progress.

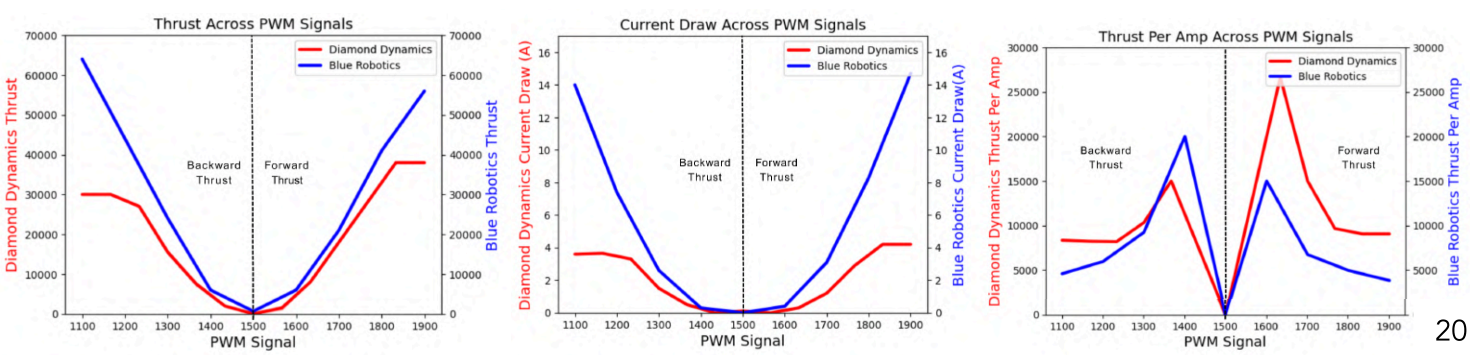


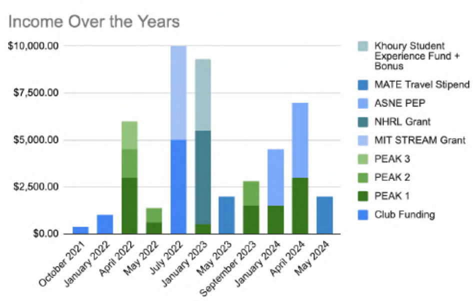
Figure 45: Measured data of the load PWM input mapped against load cell force (left), amperage (center), and thrust per amp (right)

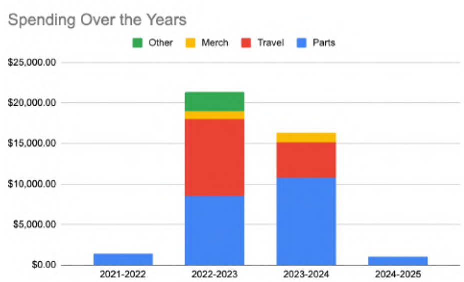
Troubleshooting

When troubleshooting, our team follows a philosophy of assess, isolate and solve. Whenever something isn't working as it should, we first take the time to very clearly assess what has gone wrong. From there team members will test different sub-components of the broken system to isolate the error. Once the error is isolated, we test viable solutions to the problem until we fix our whole system. This process was integral in our PCB testing as we were having issues with some of our thruster turning on at one point in the process. We then isolated different components to find that two of our ESCs were no longer working. For each ESC in isolation, we diagnosed a problem and solved it. One ESC needed to be entirely replaced as it had shorted from a chip overheating, while another had just had a solder job come loose. This measured process of controlling our variables allows for quick and easy repairs. Our ROV is also designed to be serviceable with our whole PCB being removable in under 5 minutes and our frame being entirely separable in 30 minutes. These design features accelerate our speed of servicing rapidly. Lastly, we have some common solutions we converge to, and teach new members to look out for. Our most common mechanical failure of 3D printed parts breaking is often fixed by optimizing the geometry with something like a chamfer or increasing the infill on a given part. We take care to include new members in the troubleshooting process to help them develop the instincts for this process moving forward

Accounting

At the end of the 2023 fiscal year, the NURobotics club that is home to the NUWave team had its budget cut almost completely. As such, NUwave receives almost no funding from the school. Instead, we get all of our funding for parts from research grants. While in the grand scheme of things this isn't necessarily a bad thing as it allows team members to develop skills in scientific writing, it does impose some constraints on our ability to fund our robot improvements as we have to frame them as research. This means we need a very good idea of exactly how much funding we need and what areas we need it in to make a plan for grants writing. At the start of the year we made the following breakdown of our spending over the years to allow for a data driven plan to be mad





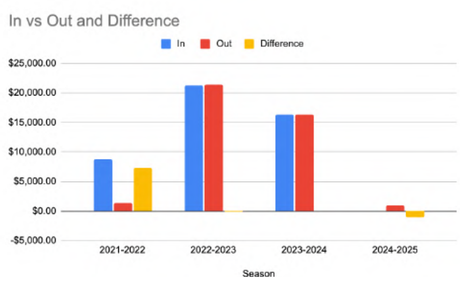


Figure 47 (left): Historical club income   Figure 48 (middle): Historical club spending   Figure 49 (right): Yearly spending

From these numbers, we were able to make distinctions about which grant targets had been most reliable, and estimate how much money we need to raise to both meet our yearly needs and end up in a budget surplus. From Figure 48, we learned that we were spending in the range of $16,000 to $21,000 in a competition year. With our $6,273 budget surplus from previous seasons, we had a mild cushion, but certainly not enough to get us through the year. To get a more accurate target, we made a breakdown of expected costs when compared to a series of grants, and to give a bit of a spoiler, we've listed their outcomes below:

Expense Category	Expected Spending	Actual Spending	Grant Candidates	Expected Funding		Recieved Funding
MATE Parts Funding	$8,000	$7,841.10	Club Funding	$200	Very Likely	$800
MATE Travel	$8,000	$7,303.60	PEP Funding	$5,000	Very Likely	$5,000
Team Onboarding	$500	$211.98	PEAK Grants Fall	$3,000	Likely	$0
			Other PEAK Grants	$3,000	Likely	$3,000
			Honors Propel Grant	$3,000	Optimistic	$2,000
			MIT STREAM Grant	$9,999	Optimistic	$6,700
			MATE Travel Stipend	$2,000	Optimistic	UNSURE
			Khoury Fund	$1,200	Medium	$0
			Ocean Exchange	$10,000	Low	DID NOT APPLY
Totals	$16,500	$15,356.68				$17,500

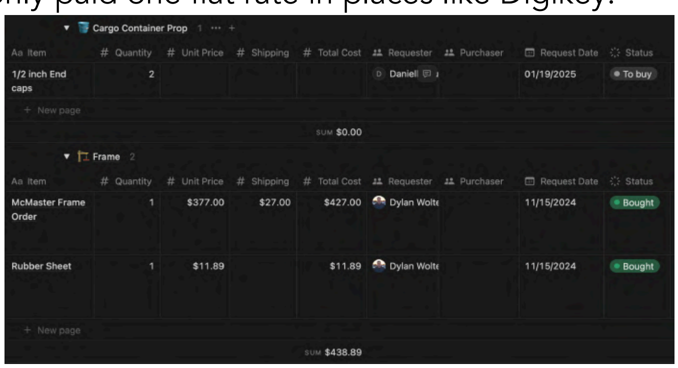
Figure 50: Funding overview including our grant application matrix

A more detailed accounting spreadsheet is provided in Appendices C and D. The spending numbers presented for the travel section are expected to be highly accurate as all of the flights, hotels, rental cars and other MATE related expenses have been booked. The only things estimated are gas reimbursements for the trip. Notably, we operated in a budget surplus this year of $2,143. While the biggest potential contributor to that was booking our travel early which saved us an estimated $6,819.40 (Figure 51).

Saving Table	Our Price	Price Available After Regionals	Money Saved
Hotels	$1,934.00	$3,980.00	$2,046.00
Flights	$4,719.60	$9,493.00	$4,773.40
Totals	$6,653.60	$13,473.00	$6,819.40

Figure 51: Savings estimate table for early travel booking

We also found other ways to improve our accounting system. We noticed that when requesting part orders, there was no central place to put needed items and track the progress of their order. To fix this, we developed a bill of materials (BOM) tracking system in Notion that allowed team members to request items whenever they needed them, and the status of the order would be trackable as the CFO went through the purchases. Further, this ended up saving money on shipping as conglomerated orders only paid one flat rate in places like Digikey.



Cargo Container Prop 1

Item	Quantity	Unit Price	Shipping	Total Cost	Requester	Purchaser	Request Date	Status
1/2 inch End caps	2				Daniell		01/19/2025	To buy
+ New page								
				SUM $0.00				

Frame 2

Item	Quantity	Unit Price	Shipping	Total Cost	Requester	Purchaser	Request Date	Status
McMaster Frame Order	1	$377.00	$27.00	$427.00	Dylan Wolte		11/15/2024	Bought
Rubber Sheet	1	$11.89		$11.89	Dylan Wolte		11/15/2024	Bought
+ New page								
				SUM $438.89				

Figure 52: Our BOM tracking system

We also heavily emphasize creative reuse of parts as mentioned in our design rationale to keep our spending as low as possible, and build connections with places like Igus and Automation Direct for parts sponsorships. We received a total of $660.74 in estimated fair market value of parts received this year, and regularly provide updates to all of our sponsors on progress. The American Society of Naval Engineers also provides cash support for our competition robotics endeavors.

Acknowledgements

Dr. Tom Consi (Mentor/Faculty Advisor): For meeting with our CEO every week and helping to guide the team towards success while letting us learn from our own mistakes.

Paul McGuinness: For inspiring the passion for underwater robotics that made this team possible.

Lauren Colby: For helping us get access to the pool and for being so accommodating.

Automation Direct (Chip McDaniel): For the donations of a range of items from wires to sensors to stepper motors, Automation Direct was the first to help, and Chip made everything easy.

Igus: For their donation of lead screws and lead screw nuts for the float.

NURobotics: For helping grow this team from two people into the project it is today.

Northeastern Undergraduate Research and Fellowship: For supporting our underwater research endeavors through their PEAK awards.

Jill Zande: For her incredible support whenever we had questions or hurdles to overcome, and for showing us so much kindness.

Matt Gardener: For his unbelievably fast answers to any of our rules questions.

Woods Hole Oceanographic Institution: For all of their help on our Thruster Test Stand journey.

American Society of Naval Engineers: For supporting our club's growth into new avenues.

MIT Sea Grant: For giving us the space to test and for the MIT STREAM Grant.

Dr. Andrew Bennett: For allowing us to test at MIT Sea Grant and for helping us out when we needed supplies for immediate repairs.

MATE: For hosting the competition and allowing us to compete.

References

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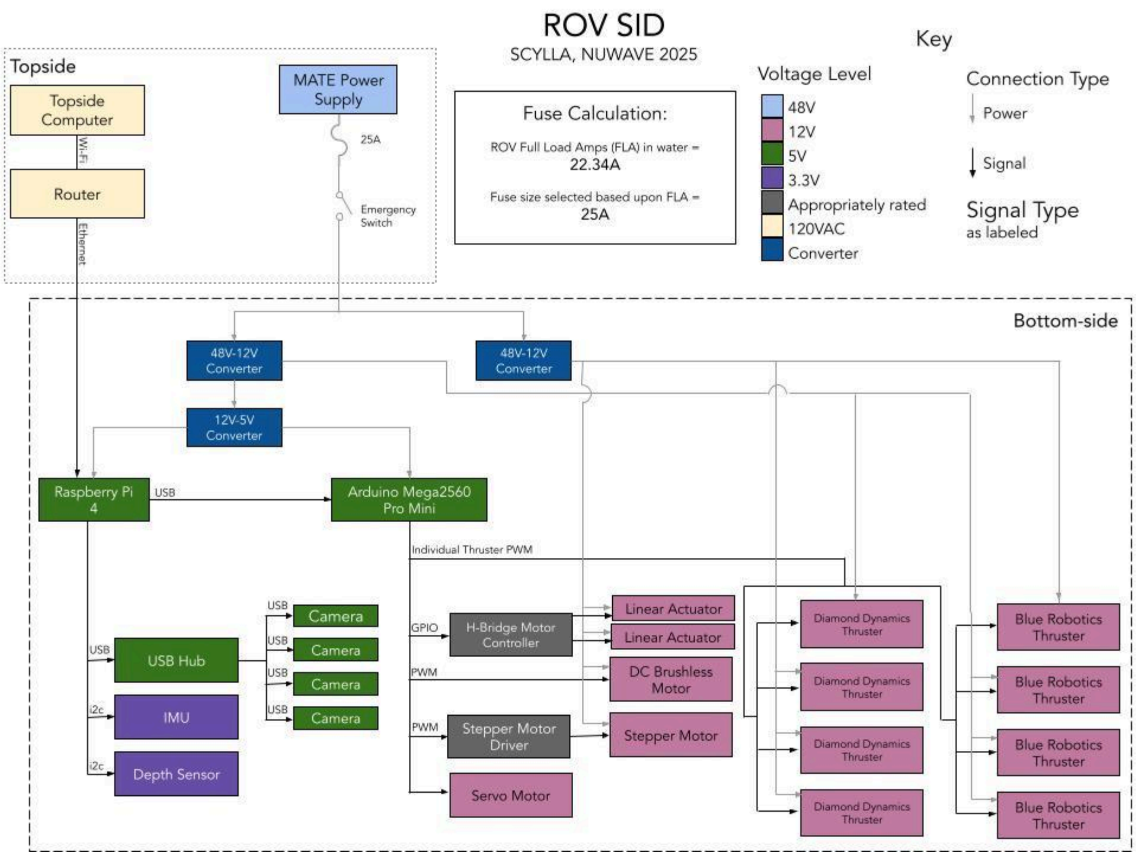
Appendix

A. ROV SID



B. Safety Checklists

Construction Checklist

- ☐ Get the proper personal protective equipment (PPE) for the construction task
- ☐ Ensure workspace is clear, with nothing nearby that could be damaged
- ☐ Inspect machinery and cords before use, and do not use if damaged
- ☐ Tell all people around you to be aware of any tools that are going to be in use
- ☐ Follow instructions and safe practice guidelines of all tools
- ☐ Make sure all electronical equipment is properly grounded
- ☐ Unplug any equipment when it is not in use
- ☐ Store all materials properly and securely when finished

Operational Checklist

- ☐ Clear testing area, including removing any personal items or unnecessary materials
- ☐ Verify power supply is OFF
- ☐ Check over ROV and tether to ensure their is no damage
- ☐ Ensure all cables are secured, tether support is in place, and the tube is fully closed with nothing interrupting the seal
- ☐ Check connectors and make sure all passthroughs are fully tightened
- ☐ Make sure all members are ready then announce as power is turned on
- ☐ Wait for ESC startup sequence to play and check for camera feed
- ☐ Place the ROV into the water, burp it, then check functionality of thrusters and claw
- ☐ Communicate during launch and retrieval

Emergency Checklist

Excessive Bubbles

- ☐ All poolside members should be on the lookout for large bubbles exiting the ROV, particularly from tube passthroughs or connectors
- ☐ If spotted, inform pilots to stop flying and immediately pull ROV in from the water
- ☐ Pilots announce as power is turned off
- ☐ Dry off ROV and identify source of leak to be fixed

Lost Communication

- ☐ Power cycle the ROV to see if it reinitializes
- ☐ If it succeeds, continue with the mission
- ☐ If it fails, then the ROV is pulled in while the pilots announce as power is turned off

C. Budget

Income	Type	Description		Amount
Rollover Funding	Grant	Grant funding from the previous year		$6,273.45
PEAK Grants	Grant	Research seed funding for 4 small projects		$3,000.00
Honors Propel Grant	Grant	A grant for our onboarding program		$2,000.00
MIT STREAM Grant	Grant	A grant for the remote deployment of our ROV		$6,700.00
Club Funding	Cash	Funding from our club		$800
ASNE PEP	Cash	Funding to support us in going to competitions		$5,000
			Total Income:	$23,773.45
Expenses	**Type**	**Description**	**Projected Cost**	**Amount**
Onboarding	Purchased	PVC, thruster materials and other WavePerch supplies	$500.00	$211.98
Mechanical	Purchased	New frame and thrusters along with tools for construction	$3,500.00	$3,230.22
	Reused	Arm and some thrusters		$1,867.00
	Donated		-	$103.74
Electrical	Purchased		$4,500.00	$4,398.90
	Reused		-	$1,188.00
	Donated		-	$557.00
Software	Reused	All topside and computers (re-used from last year)	-	$1,000.00
Travel	Purchased	Flights, hotels, car rentals and entry fees	$8,000.00	$7,303.60
		Spending Totals:		$15,144.70
			Total Income:	$23,773.45
			Total Expenses:	$15,144.70
			Total Reused:	$4,055.00
			Total Donated:	$660.74
			2025 Budget Rollover:	$8,628.75

D - Project Costing

NUWave Budget 2024-2025				Reporting Period		
School Name:	Northeastern University		Start Date	09/01/2024		
Mentor:	Dr. Tom Consi		End Date	06/30/2025		
Date	**Type**	**Category**	**Expense**	**Description**	**Amount**	**Running Balance**
9/2	Reused	Mechanical	Thrusters	2 Diamond Dynamics TD7 Thruster	$ (318.00)	$ (318.00)
9/2	Reused	Mechanical	Arm	Motors for the arm	$ (361.00)	$ (679.00)
9/2	Reused	Mechanical	Electronics Tube	6" BlueRobotics Electronics Enclosure	$ (329.14)	$ (1,008.14)
9/2	Reused	Electrical	Cameras	4 Deepwater Exploration ExploreHD Cameras	$ (1,188.00)	$ (2,196.14)
9/2	Reused	Software	Topside Setup	Monitors, Computer and Controllers	$ (1,000.00)	$ (3,196.14)
9/9	Purchased	Onboarding	Onboarding	PVC, thruster materials and more as a base kit for teams to start with	$ (211.98)	$ (3,408.12)
9/25	Purchased	Electrical	Sensors	Depth Sensor and IMUs	$ (133.18)	$ (3,541.30)
9/25	Purchased	Mechanical	Printer Filament	PLA and PETG Filament	$ (298.02)	$ (3,839.32)
10/13	Purchased	Electrical	Wire	Wire for connections and tether	$ (357.86)	$ (4,197.18)
10/17	Purchased	Mechanical	Float Mechanical	Motors, mounts and more	$ (636.25)	$ (4,833.43)
10/17	Purchased	Electrical	Dev Boards	3 * Raspberry Pi 4 8GB, 3 * Arduino Megas	$ (400.00)	$ (5,233.43)
11/2	Purchased	Mechanical	Thrusters	4 BlueRobotics and 2 Diamond Dynamics TD7 Thrusters with ESCs	$ (1,270.00)	$ (6,503.43)
11/2	Purchased	Mechanical	Frame Materials	Hardware and Acrylic	$ (611.92)	$ (7,115.35)
11/4	Purchased	Mechanical	Tools and Attachemnts	Syringes, zip ties, mesh, power tools and similar	$ (414.03)	$ (7,529.38)
11/24	Cash-Donated	Income	ASNE PEP	Cash Funding from the American Society of Naval Engineers	$ 5,000.00	$ (2,529.38)
2/10	Purchased	Electrical	Float Electrical	Boards, Supplies and Enclosures	$ (876.95)	$ (3,406.33)
2/10	Purchased	Electrical	PCB Supplies	Boards and supplies for PCB R&D	$ (2,630.91)	$ (6,037.24)
2/17	Parts-Donated	Electrical	Automation Direct Parts	Ethernet Cable and Stepper Motors	$ (557.00)	$ (6,594.24)
3/8	Parts-Donated	Mechanical	Igus Parts	Lead Screws and Nuts	$ (103.74)	$ (6,697.98)
3/12	Purchased	Travel	Registration Fee	MATE Fee (Considered a part of competition costs so travel)	$ (650.00)	$ (7,347.98)
4/4	Purchased	Travel	Hotels	Hotels	$ (1,934.00)	$ (9,281.98)
4/10	Purchased	Travel	Traversal	Flights + Car Rental	$ (4,719.60)	$ (14,001.58)
					Total Reused	$ (3,177.88)
					Donated Parts	$ (660.74)
					Donated Cash	$ 5,000.00
					Total Spent	$ (15,144.70)
					Final Balance	$ (14,001.58)