Engineering Report

Whirlpool Robotics

Hackley School, Tarrytown, NY, USA

Project Coordinator & Mentor:

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Team Members:

Name	*MATE Status*	*Company Role*	*Hours*	*Grade Level*
Travis Knaggs	Returning	Lead designer, Pilot, Hardware engineer, Writer	170	12th
Sam Nadol	Returning	Lead electrical engineer, Programming manager, CEO	225	12th
Cydnee Copeland	Returning	Project manager, mechanical engineer, Co-pilot	140	12th
Mateo Arencibia	New	Mechanical Engineer, CAD Specialist	100	10th
Ben Iaderosa	New	Marketing and Presentation Manager	25	10th
Jimmy Mulosmani	New	Assistant Designer	20	11th

Abstract

Our ROV is designed with four main principles in mind: (1) functionality, (2) modularity, (3) sustainability, (4) precision. *First*, we have ensured that our ROV can complete most tasks encountered in the marine underwater robotics setting. This includes high-powered thrusters, a strong gripper, and a 25-meter tether. The rectangular frame allows several places to attach motors to the ROV while remaining incredibly stable in the water. *Second,* the frame itself is easily replaced, consisting only of two acrylic sheets laser cut to size and the central extruded aluminum body. This simplicity allows for easy access to the internals of the robot, with the entire frame able to be disassembled or unassembled in under 5 minutes. This also allows us to easily bring extra pieces of acrylic already cut to size in case of any damage. *Third,* the ROV is designed to help maintain natural ecosystems and carry out construction tasks. For example, force sensors are used on the gripper to protect wildlife that it may handle. *Fourth,* The precision of the ROV is essential due to the delicate nature of its missions. This was ensured by pressure sensors on the gripper and the 360º movement alongside self-leveling capabilities. Ensuring that our robot's design adheres to these principles allowed us to build a useful, heavy-duty, and easy-to-use underwater robot.

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I. Team & Project

Company Profile

Whirlpool Robotics has been working on ROVs since 2016, and has attended MATE competitions every possible year. Over the years each member of the team has learned various skills and proficiencies in many different tools due to our small, but dedicated, number. This year we took on two new younger members to be the team's future. The members of each role of the team are described above:

Schedule

This ROV is a brand new design and our company's way of merging the ideologies behind our flat design with the ease of customization provided by a cube frame to get full 360 degrees of movement. Simultaneously we also moved much of our electronic system onto the ROV itself, with the remaining time spent refining and testing the ROV. In order to complete the ROV in time a schedule was created, though due to our small size, all team members helped with each aspect whenever possible.

.The tasks were divided into trimesters as follows:

1. Trimester One – Redesign and Testing (Sept. through Dec. 2022):
    a. Redesigning Frame—Travis Knaggs, Cydnee Copeland, Ben Iaderosa, Jimmy Mulosmani
    b. Redesigning Electronics — Sam Nadol, Mateo Arencibia
2. Trimester Two – Final Construction (Dec. through Feb. 2023):
    a. Laser Cutting and Assembly—Travis Knaggs, Cydnee Copeland, Mateo Arencibia, Ben Iaderosa
    b. Programming & Wiring New Electronics — Sam Nadol, Jimmy Mulosmani
3. Trimester Three – Testing (Feb. through April. 2023):
    a. Pool Testing & Pilot Practice — Travis Knaggs, Sam Nadol, Cydnee Copeland
    b. Testing & Upgrading Electronics — Sam Nadol, Mateo Arencibia, Jimmy Mulosmani
    c. Documentation — Travis Knaggs, Cydnee Copeland, Ben Iaderosa

II. Engineering Design Rationale

Engineering Design Rationale

The ROV was built to be robust, stable, and multipurpose. The flat acrylic sheets cap off the ROV’s rectangular shape, protecting the internal electronics while also making it more hydrodynamic. The ROV remains stable in all but the most extreme currents due to the eight T200 motors used which have an automatic stabilizing function to ensure the ROV remains flat. The dual camera system makes it ideal for work in environments where other robots fail, allowing the operator to control the ROV regardless of any silt kicked up in its environment. The eight motors and use of extruded aluminum do increase the weight and cost but the extra maneuverability provided was well worth the sacrifice to us. Our previous year’s ROV we felt was too wide so our new design minimized the width while also only increasing height by 8.5 cm.. The onboard electronics, though the threat of a water leak is always present, increase maneuverability and make future additions to the ROV easier. All of these decisions give our ROV the ability to set up complex sensors(Such as the Coastal Pioneer Array or our float), set up and repair undersea cables, and explore delicate ecosystems.

Brainstorming

Due to our team's long history of competing at MATE, when attending a competition, we are always looking for new ideas seen used in other teams' ROVs. Both our onboard electronic system and usage of a remapped console controller were inspired by seeing it executed well by other teams. As seniors competing since 2016 we have had many different ROV designs over the years and this design is an evolution of the 2023s six-motor system with full 360-degree movement. We tested several different ways to go about doing this by splitting the team into 3 groups of two with each pair looking at potential ways to reformat the motors, taking some ideas from the ROVs that the 2023 Senior team had seen at worlds. Different materials and structures were debated and tested between each of the three groups, with each preferring a different approach from 3D printing, laser cutting, and cutting extruded aluminum. The influences these three teams had on our ROV’s final design are clear in how each of the 3 mediums was implemented somewhere on the ROV.

Innovation

This ROV's design is a merger of last year's radical design and the cuboid shape we used in the years before. We previously used extruded aluminum to make a cuboid frame where each aspect of the ROV could be mounted and that is visible in the ROV's inner core. Last year's acrylic design and six-motor system can be seen in the acrylic end caps used to secure the onboard electronics. An 8-motor system would not have been possible on last year's design due to structural limitations so we went back to the drawing board in September. We also limited the use of acrylic for structural support due to weaknesses seen at last year's competition, preferring extruded aluminum for any key structures. To ensure cost was not dramatically increased we extensively reused acrylic from the 2023 ROV and fully repurposed the frame from the 2022 ROV.

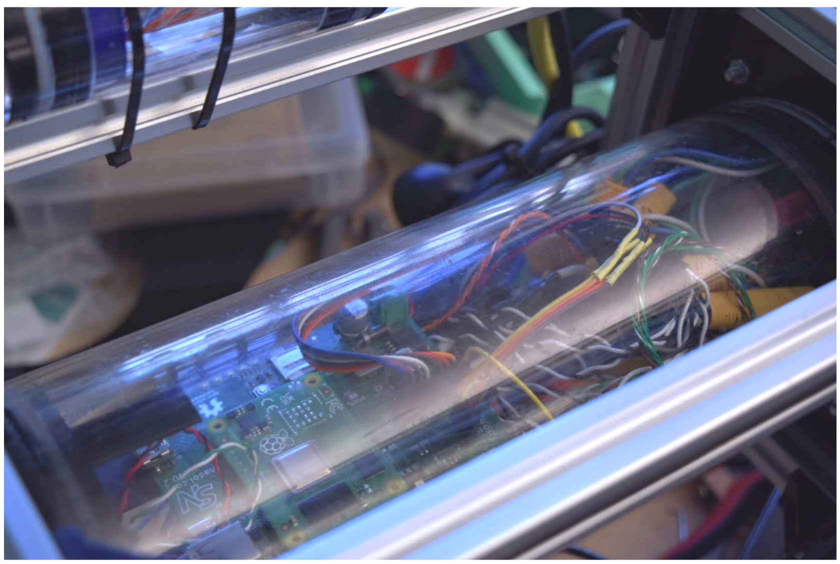


Fig 1 (close-up of onboard electronics)

Vehicle Structure and Systems

To reduce the width of the ROV compared to last year's design we centered the ROV around the onboard electronics tube. The extruded aluminum frame used in our 2022 ROV was repurposed and modified to be the inner core of our ROV, which provided numerous points of contact for attaching motors and other components. Though this did dramatically increase the weight of the ROV which would then lead to a decrease in speed, the addition of two more motors compared to last year 6 motor design alongside the 45 Degree angle each was oriented to gave the Starfish

ROV a significant increase in thrust on all axis compared to the 2023 ROV. In addition to an increase in thrust, the 8-Motor design also allows 360-degree movement on both axes which further mitigates any downsides of the increased weight.

While the ROV is much less hydrodynamic compared to last year's design when moving horizontally this was an unfortunate consequence of the new design but the forward movement retains the same hydrodynamics. The increased weight of the ROV also aided in stabilizing it in any currents in an offshore environment where it would be relocating coastal sensors like the Coastal Pioneer Array. The profile of the ROV simultaneously decreased due to the new design while mobility dramatically increased, allowing it to be more maneuverable in the delicate situations it would be facing operating in areas such as coral reefs, or the maintenance and installation of undersea cables.

The 8 Motor design also allows the ROV to self-level which further aids its precision in the aforementioned situations. Acrylic was once again used for the end caps of the ROV due to its ease of use and low price, though it is weaker than extruded aluminum it was not used in areas where high stress would be placed on the ROV. Any acrylic used on the frame was also repurposed from leftover materials purchased last year. The end caps are also easily replaceable if they were to break, only attached by twelve screws. We were able to purchase more equipment this year as we were able to repurpose last year's acrylic pipe holding our electronics. With that funding, we used a smaller tube of the same design to mount a second high-quality camera beyond the one inside the tube, which allowed us to look at the claw while driving the ROV.

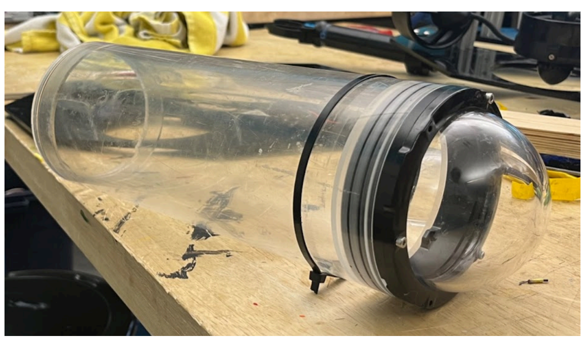


Fig 2 (Acrylic Tube)

Build vs Buy, New Vs. Used

As a team that has been competing in MATE competitions since 2016 and the program has been available at Hackley since 2014 we have a very large accumulation of spare parts and equipment. As a result, six of our eight T200s were bought in previous years allowing us to incorporate used equipment whenever possible. Our inner aluminum frame was entirely repurposed from our 2022 ROV, modified, and cut down to a smaller size. A large amount of the Acrylic used was also from leftover sheets not used last year. The ESCs and Tether were also reused from a previous ROV. These practices of reuse fall in line with the mission requirements in terms of incorporating sustainability in our model whenever possible. The motors, claw, and acrylic tube were all purchased however we have attempted to construct each of those parts ourselves several times in previous years only to have them catastrophically fail on competition day, as a result, we have slowly purchased replacements for each part. Due to the mission requirements and the delicacy of environments such as coral reefs, there can be no room for error in the core functionality of the ROV as it would then damage the ecosystem around it. Our decisions of what to build VS buy are further influenced by the mission requirements which are detailed further below.

Fig 4 (Sam Nadol Soldering Motor Electronics)

Propulsion

For the thrusters, we decided to use the Blue Robotics T200 thrusters. These thrusters provided the ultimate power to our ROV while maintaining a relatively affordable price point. That being said, they are the most expensive pieces of equipment on the ROV, however, our team decided that we should place the most resources into the thrusters as they are the most essential part of the vehicle. Six of these motors are reused from our previous ROV and were purchased after our repeated efforts to assemble our motors through parts bought separately failed. We purchased two more T200s so we could implement an eight-motor design, a natural evolution of our previous ROV's six-motors. Eight motors allow the driver to move the ROV omnidirectionally however each motor must give an identical amount of thrust for this to be achieved. In situations where accuracy is paramount, (the installation and repair of underwater cables, taking samples and conservation of fragile coral reefs, and installing coastal equipment) the omnidirectional movement is essential to make the minute adjustments needed for the self-leveling capabilities of our ROV. One of the several ways we ensured this was by purchasing identical motors as any construction by us may become subject to slight flaws. We believe that the benefits provided by the freedom of movement outweigh any cost of the T200s and will be utilized by our company for years to come. We decided to make the expensive purchase now rather than continuing to upgrade every year which would be more expensive in the long run and meet our company's ideals of sustainability and conservation.

Gripper

For manipulation, our ROV is equipped with the powerful Newton subsea gripper. It has 124 N of grip force and a sensor to detect when an object has been gripped, enabling it to modulate its force and ensure whatever is picked up remains unharmed. This enables it to traverse and take samples in delicate marine environments, while also being maneuverable enough to install and maintain essential undersea cables, both areas where any excess pressure could be catastrophic. The gripper is also strong enough to relocate and deploy various flotation devices in necessary areas as well as take any needed samples in waters all around the world. Though we felt using both a purchased gripper and motors was not preferable, the precision provided by the Newton Gripper, critical in the aforementioned situations where this ROV would be deployed, could not be replicated with the resources available to us. This gripper however has been in the possession of Hackley School for over four years now, purchased after our attempts to construct a homemade claw failed on competition day several years ago.

Camera

The ROV currently consists of two 1080p H264 cameras. One is placed at the front of the ROV facing forward, to allow the pilot to see where they're going, and the other is placed above and angled down. This allows the pilot an excellent view of the gripper, as anything being grabbed can typically be seen by two cameras, which is essential for the delicate work this ROV will be carrying out. The high quality also enables better obstacle observance and avoidance. 1080p cameras were chosen for their high resolution, and H264 was chosen as the video codec to allow any computer to decode them.

Pressure Sensor

Our Bar-02 pressure sensor can sense the current pressure and temperature of the water, as well as calculate the depth of the ROV based on these measurements. It is connected via I^2C to the main onboard computer, which then transmits the data through our integrated networking protocol to the surface control computer, where it can be displayed for analysis. The Bar-02 sensor assists the ROV in conducting offshore work as detecting the depth of the ROV aids it in locating mission targets when visibility is not clear.

Float

Our float's design and construction align with the main goals of our ROV. One main part of the enclosure's design is that it is designed to fit easily into the ROV's primary gripper. This allows the operators to deploy the float easily and with precision. The float's simple design is highly cost-effective, allowing many of them to be constructed and deployed if desired by the operator. Once deployed, it begins to relay information over a dedicated 2.4 GHz WiFi network, transmitting the current time (sourced from an onboard RTC), depth data (from an additional Bar-02), and other miscellaneous data to the main ROV seamlessly. While primitive in comparison to the Coastal Pioneer Array used in our oceans, this float begins to fill a similar function of monitoring data critical to the health of our oceans.

Buoyancy

Our ROV frame is naturally buoyant due to the size of the electronics enclosure, with some small additional ballasts added to ensure balance. The open frame design allows many spaces to add floats or weights, altering buoyancy on the fly to ensure that neutral buoyancy and balance are maintained regardless of payload or additional equipment added to the robot.

III. Electronics Design & Rationale

Electronics Design Rationale

In previous years, our electronics system was based on off-the-shelf parts, such as Raspberry Pi 3Bs and RS282 serial communication modules. Unfortunately, this design schema was unsustainable, as the form factor of the parts could not be controlled, and in the case of serial communication, this limited the maximum possible number of electronic components and sensors we could use on the robot. In summary, the serial communication was not scalable due to bandwidth limitations, and therefore not sustainable. To solve this challenge, in this year's robot, we decided to deploy a custom Ethernet network between the surface-level control electronics and the robot, which allows for an effectively unlimited amount of data (100 MB/s) to pass through our tether. Because of this improvement, we were able to improve the operation of individual components such as the two cameras, enabling a higher resolution and framerate, as well as improving the command protocol, increasing the reliability and efficacy of both the gripper, and more importantly, the motors. Finally, the use of Ethernet communication allows for a modular and expandable network, so, for example, our float can directly connect to the same network, using the same protocol, and communicate with the same computer used to control the robot, allowing for a smooth and concise user interface.

Control System

The control system (i.e. the electronics at the surface placed in the control box) consists of the following components (in the "chain" of control electronics from the tether to the control computer):

1. 12V POE Injector
2. Ethernet Switch
3. WiFi Router
4. Control Laptop

The Xbox controller used to manipulate the ROV is connected via USB to the Control Laptop. The Control Laptop, assigned an IP by the DHCP server on the WiFi Router, connects to the electronics on the ROV and sends commands from the Xbox controller, over the low-gauge tether, to be interpreted and executed by the ROV.

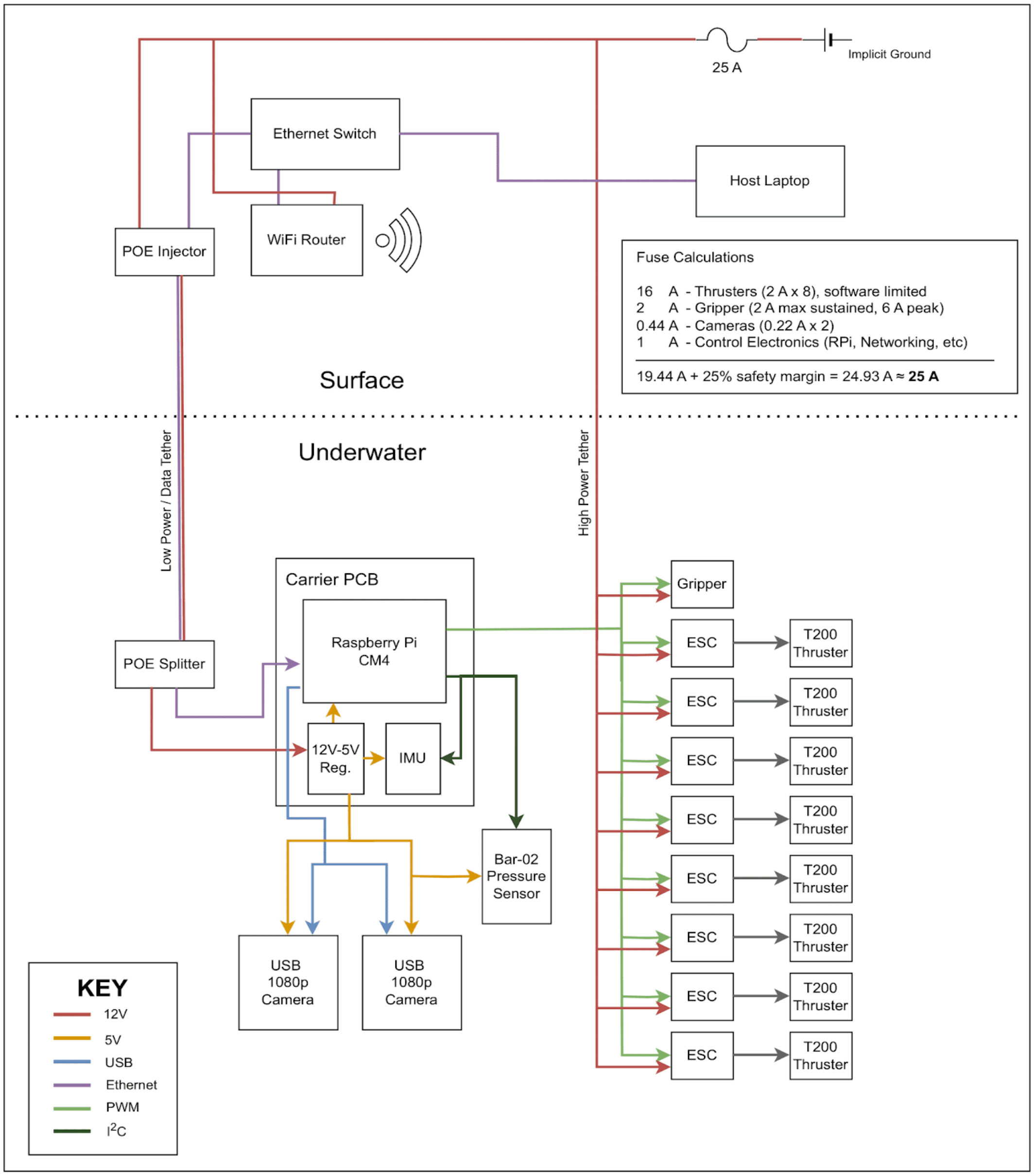
Subsurface Electronics

The electronics system below the surface consists of the following main components:

1. High- and Low- Gauge Tethers
2. POE Splitter
3. USB Ethernet Adapter
4. Custom PCB Control Computer
5. 8 ESCs & Gripper
6. 2 1080p Low-Light Cameras

The Low-Gauge (high-thickness) wire delivers 12V directly from the power supply to the ESCs and gripper, and the High-Gauge (thin) wire delivers the ethernet connection and POE power for the control electronics and cameras. The first portion of the system works analogously to the electronics on the surface: commands to be received from the control system will be sent through the tether, passed through the POE splitter, and are interpreted by a script on the on-board computer to pass on to the relevant component; motor commands get sent to the ESCs, which then are relayed to the proper T200 thruster. Commands for the claw go directly to the Newton Subsea Gripper. Finally, the information received by the cameras goes directly to the Raspberry Pi (on-board), which is then sent back through the communication system to the surface-level laptop.

System Integrations Diagram (SID)



Programming

All programming for the ROV was done in Python; the surface code is all either Python or C. The ROV has one large service that runs the ESCs, gripper, camera streams, communication, and self-leveling calculations. This was done in Python for ease of editing on the ROV's computer, which runs embedded Linux and as such has minimal tools that would make editing another language, such as C, much harder (due to the lack of a compiler such as GCC, for example). For the surface code, Python was used to interface with the ROV directly over a websocket, and C where websocket communication was not required, which was chosen due to its execution speed.

Tether & Cable Management

We used the Blue Robotics Fathom tether, bundled with their high-power wire, both 25m, to connect the ROV with the control system on the surface. Zip Ties are used to connect the two; these ensure both that the wires are easily accessible if they need to be swapped out, but also that they are firm and do not jostle around relative to each other. Alternative tethers were explored prior to the purchase of the Blue Robotics tether, such as sourcing our own wires as well as tethers from other companies, but overall, the purchased tether provided the best combination of guaranteed reliability, waterproof ecosystem (connections into the subsurface tube), and neutral buoyancy.

IV. Safety & Testing

Safety Features & Rationale

To ensure Safety while working on the ROV we ensured a qualified adult was supervising and the user was taught how to use each tool. Goggles and gloves were also worn whenever it was deemed necessary for the safety of the operator. Safety was also paramount when designing the ROV; this is evident both in the crafts design and our construction methods. Shrouds cover all 8 of the motors, which are also embedded in the frame to further prevent any injury to operators. This combined with the extensively tested watertight seal on the acrylic tubes helps mitigate any possibility of electronics shorting. Anderson Power poles provided a safe connection to the power source without the risk of exposed wire seen in Alligator clips. We also have force-sensitive thrust controls to ensure that a small user error on the surface does not result in significant damage to anything around the ROV through accidental contact.

Testing Summary

We spent much of the three months before the competition testing our ROV in the pool. During pool testing we focused on 1) navigation & ease of control, 2) the ability to complete the missions, and 3) the neutral buoyancy of the robot. Because of our design, neutral buoyancy was prioritized last since its density was already close to that of the water without any modification. To make slight adjustments, we attached weights and floats to the Robot. Before pool testing, we tested several different thicknesses of acrylic with scrap pieces left over from previous school projects to determine the optimal size. To practice for the competition we built PVC models of the tasks seen in the flythrough which was used extensively in the month leading up to the competition. Prototyping of designs was difficult to accomplish as we could not get access to a pool until April so we used a large plastic bin filled with water to test and prototype any pool systems.

Safety Checklist

We addressed the following safety concerns:

1. ROV — Physical Aspects
    a. All items attached to ROV are secure.
    b. Hazardous items are identified and protection provided
    c. All propellers are completely shrouded to IP-20 standards. Mesh size is less than 12.5 mm
    d. No sharp edges or elements of the ROV design could cause injury to personnel or damage the pool surface.
2. ROV — Electrical Aspects
    a. Tether has proper strain relief at the ROV.
    b. There are no exposed motors.
    c. There is no exposed copper or bare wire.
    d. All wiring is securely fastened and properly sealed.
    e. Any splices in tether are properly sealed.
    f. Single attachment point to the power source.
    g. Anderson powerpole attachment to power source.
3. Surface Controls — Electrical & Physical
    a. Properly sized inline fuse within 30 cm of power supply attachment point.
    b. All wires entering and leaving the surface control station have adequate strain relief and wire abrasion protection as the wires pass through the enclosure.
    c. The surface control station is built in a neat and workmanship-like manner. No loose components or unsecured wires. All electrical components are covered inside an enclosure.
    d. All connectors utilized are properly rated for their application

V. Budget & Cost Management

Main Engineering Budget

Below is a list of components purchased, or if they were reused, their estimated value. After our funding was secured, we set aside certain dollar amounts for expected large future purchases, such as travel expenses, the two motors we were missing, and the control electronics. Remaining funds were reserved until they were required for incidental parts during the build process, where any purchases required were first evaluated for cost efficacy and if there were any cheaper alternatives. If no better feasible option was found, the item was then purchased to be integrated into the robot.

Purchased

Item Description	Cost	Source
Raspberry Pi CM4	$35	DigiKey
2 T200s and ESCs	$472	Blue Robotics
Custom PCB	$60	JLCPCB & LCSC
2” Dia. Camera Tube	$46	Blue Robotics
Foam Poster Board	$125	Staples Custom Foam Posters
M3 Screws	$40	*(various sources used)*
Wires	$50	*(various sources used)*
Competition Transportation cost	$50	N/A
Fathom X Tether Interface	$240	Blue Robotics
Plastic Panel Acrylic	$20	Amazon
Total Value	***$1138***	–

Reused or Donated Parts

Item Description	Cost	Original Source
6 T200s & ESCs	$1180	Blue Robotics
2 USB Low-light Camera	$99	Blue Robotics
4” Dia. Electronics Tube	$212	Blue Robotics
Fathom ROV Tether	$150	Blue Robotics
Xbox One Controller	$60	Team Donation
25m Feet of Tether	$200	Blue Robotics
Netgear Router	$200	Recycling
WetLink Penetrator: Motors	$100	Blue Robotics
WetLink Penetrator: Claw	$12	Blue Robotics
WetLink Penetrator: Data Cable	$12	Blue Robotics
Electrical Tape	$15	Home Depot
Zip Ties	$15	Home Depot
Newton Subsea Gripper	$250	Blue Robotics
Bar-02 Sensor	$30	Blue Robotics
Total Value	***$2535***	–

V. Acknowledgements & Funding

Acknowledgments.

We would like to thank our project coordinator Ms. Melissa “The Boxer” Boviero for all of her help and advice in designing, building, and testing our robot, as well as for her support over the last eight years. We would like to thank Hackley School for its continued and future support for our underwater robotics program. Lastly, we would like to thank our friends and family for their encouragement and continued support over the years, both at home and whilst competing.

Funding

We would like to thank the Hackley Upper School for funding our project throughout the last five years, as well as our family for providing additional financial support on occasion.

VI. Gallery

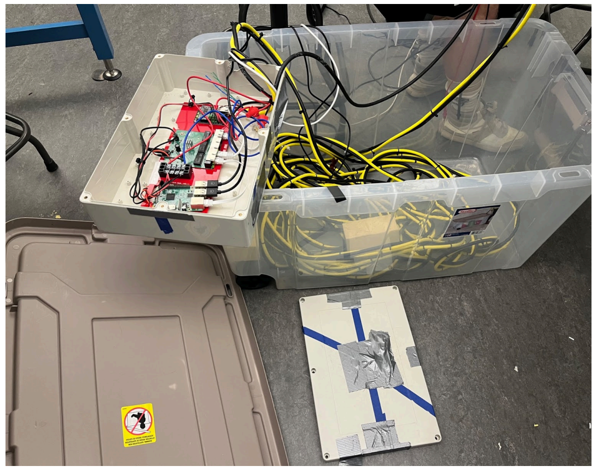


Fig (5) Tether

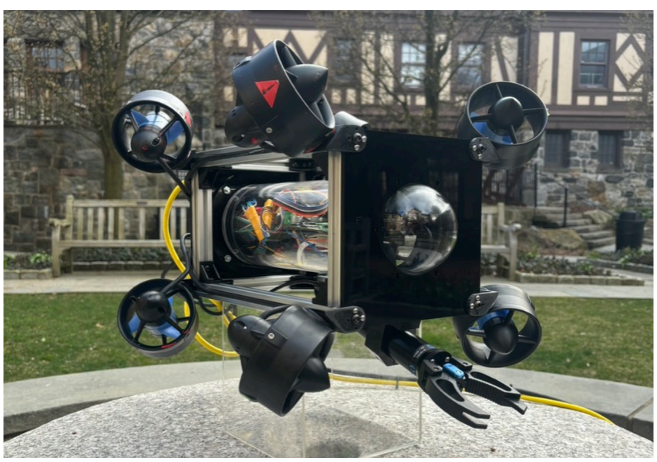


Fig (6) Finished ROV

Fig (7) Side View of finished ROV

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