WUROV

Wentworth Underwater Remotely Operated Vehicle

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MATE ROV COMPETITION

Wentworth
INSTITUTE OF TECHNOLOGY

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Introduction

Abstract

Wentworth Underwater Remotely Operated Vehicle (WUROV) is a multidisciplinary collaborative company built upon students aiming to learn further into the process of design, manufacturing, and robotic applications. WUROV's newest Remotely Operated Vehicle (ROV), Yellow-Crab, was designed to identify shipwrecks and their cargo, as well as capture images of the surrounding environment using photosphere technology. It assists in replacing damaged thermistors and installing a pCO2 sensor on the subsurface smart buoy. Additionally, the ROV can collect water data to further analyze the pH levels and environmental DNA (eDNA) of invasive carp.

Yellow-Crab has been designed, developed, and tested in less than one year by a group of 13 students. Throughout the process, quality, and safety standards set by the industry have been of high priority to ensure the ROV is capable of solving multiple challenges. The system is designed with versatile mechanisms and expendable electronics to allow modularity.

This technical report outlines the engineering process that the WUROV company has followed in the past year to provide other groups of students in the future with information of a successful and innovative approach to finding solutions to challenging problems in underwater research.

Figure 1. WUROV Deck Crew

Teamwork

Company

WUROV is a university team from Wentworth Institute of Technology aimed at building ROVs for underwater research to address environmental concerns including impact on various marine life ecosystems and climate change. Throughout this journey, the company has had an influx of new and old members joining to contribute to this mission. The company is composed of Chief Executive Officer (CEO) who focuses on networking with the community and finding sponsors, Chief Technical Officer (CTO) who is in charge of the final design decisions within each three teams: Electrical, Mechanical, and Software, each led by a team lead, who is responsible for managing all company tasks assigned to that team and reporting back to the CTO. Team leads assign tasks and share important information amongst the team members to ensure equal contributions from everyone. Each section is tailored to the interests, goals, and skills of the students to ensure continuous learning and growth amongst them.

Figure 2: Teamwork throughout pool testing

WUROV places a high priority on the learning process and encourages cross collaboration between teams and team members. The company uses a task board management website called Trello, where students can check what tasks need to be done, who is doing that task, and which tasks are completed. Using software such as Discord and Zoom to have virtual meetings when necessary or to easily communicate among team members to ensure correct information on Yellow-Crab development and team meeting times. Google Drive is the main storage website used by WUROV, where students can edit any designs needed, and have access to previous meeting notes if needed to catch up. Returning members of the company organize various workshops and lectures that enable students to get familiar with the main systems of the ROV. The mentoring with a hands-on approach has been a critical part of WUROV's success in the past and the team continues to maintain this structure.

Schedule

The company organizes the project into five main stages (see Figure 3). The "learning stage" is where the company receives their scores from the previous competition and examines what points were earned. The team members also share mistakes seen at the competition and discuss ways to improve the design of the ROV, documentation, engineering presentation, and setting goals for the next year. The "recruitment stage" is the period after the competition where the company introduces new members to the project and begins researching for the new ROV, Yellow-Crab. Next is the "designing stage" which consists of the planning, prototyping, and manufacturing processes of assembling Yellow-Crab. The planning process is where team leads meet with their team and look at previous ROV designs and understand the mistakes made, discuss how to improve the design and model the new ROV components on either KiCAD or SolidWorks. This stage is when the team also begins looking for sponsorships and ways to help the local robotics community with nearby high schools or public events. The team would showcase their last year's ROV and educate the audience on how it operates, what materials and software are used to create it, and why developing and operating a ROV is important. The "testing stage" follows with mechanical, electrical, and software tests to ensure proper operation in the pool. The mechanical team ensures the ROV passes the buoyancy and waterproof testing. The software team tests the vectors and controls of the ROV and adjusts values if needed. Electrical ensures their printed circuit boards (PCBs) operate as expected and sees if any necessary modification is needed. Lastly, the "competition stage" follows with the completion of the ROV by documenting all aspects of the design process, creating the safety and qualifying ROV videos, and sharing the work with others in various competitions and presentations. As well as where purchases such as travel and registration are made for the MATE ROV Competition. Where the CEO signs the students up to participate in the World Championship and goes through the travel process at Wentworth Institute of Technology (WIT), drivers who are 21+ are required to go through a driver course to ensure safe traveling during the trip.

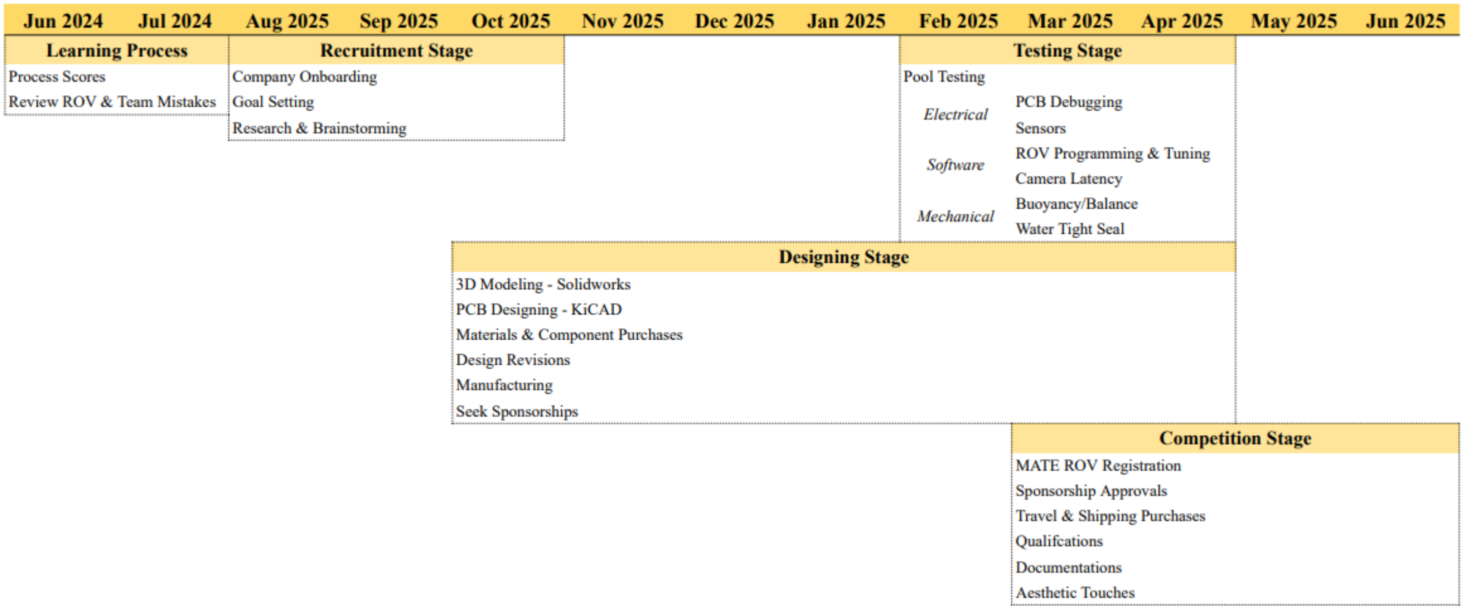


Figure 3: Project Schedule

Resources and Procedures

Mission objectives and solving day-to-day operational problems were managed through resources, procedures, and protocols. WUROV's decision-making process is structured and effective. It begins with the team directly informing the team lead, who then engages with the CTO. The CTO presents the necessary information to the CEO, ensuring that final decisions are made with authority and insight. The Wentworth Institute of Technology provided the majority of resources. The ROV's mechanical manufacturing process took place at the Accelerate and Machine Manufacturing lab, where students have access to CNC machines, and experienced student workers supervise them to ensure safety protocol and achieve desired designs. WUROV is under the WIT IEEE Student Branch, where the company has access to a workspace which provides 3D printers such as the BambuLabs and Prusa to print necessary pieces, such as the ROV's arm and frame of the float, and tools such as soldering stations, hand tools, and much more. Students were educated by WIT IEEE members on how to operate the printers, find where tools are stored, and were instructed on safety protocols that need to be maintained to continue usage of the space. In the workspace, the WUROV team has a designated storage location and has access to old components from previous ROVs. New components are organized via Google Sheets, where when the team

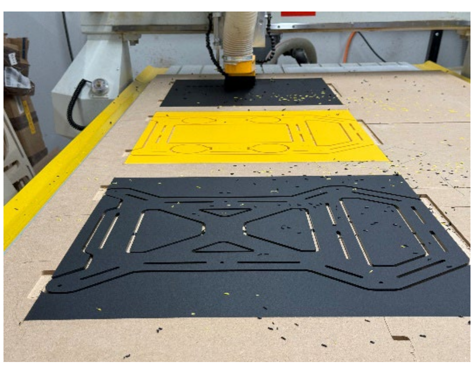


Figure 4: High-Density Polyethylene sheets getting cut

orders new materials, they can see where the materials are ordered from and their delivery status. When components for PCBs arrive, they are required to be in the same space as the boards and with their order sheet, so that they can be easily organized. For ROV testing, WUROV uses Simmons University's pool, where availability is only for four hours every weekend with the company's safety officer present to avoid any violations of the Safety Checklist (refer to the Appendix for the Safety Checklist). The company proceeds to maintain a good relationship with all resources by following safety and travel protocols to ensure no future problems that could delay the project schedule mentioned in Figure 3.

Design Rationale

Overview

WUROV's previous ROV designs act as an example of strengths and weaknesses that provide a great deal of insight leading into the designing of new vehicles. The 2024 MATE ROV Competition was WUROV's most successful competition to date, in which we scored 381.0 total points and place 21/29. The most successful implementations from last year's design were the modular electronics that allowed for quick troubleshooting and swapping of sensors/modules, the strong modular frame, and the power over ethernet (POE) camera modules. However, the team did not find the electronics housing, the performance of the power systems, the latency of the cameras, and the overall size of the ROV to be effective. This year, the team took those into account and focused on including higher latency cameras, a smaller frame, better heat dispersion, and better sectioned power distribution for the 2025 ROV design.

Figure 5: WUROV 2025 Full Assembly

Problem Solving

Decisions based on design were made during both team meetings and all-hands meetings. Team meetings are meetings between members working on the same system, either electrical, mechanical, or software. Each team would find a separate time and place to meet weekly without overlap to ensure members could attend multiple meetings throughout the week. The objective of these meetings was to make decisions and split tasks pertaining to each respective system. All-hands meetings are meetings including all members of the company. These were also arranged weekly to ensure all teams updated each other on their progress. Progress reports were given by each team, and overarching design and company decisions were made democratically throughout these meetings. In any sight of different approaches, team members would breakdown each approach on the board, showcasing what each solution is most effective in and defective in. For example, the company assessed how much a solution would cost, how easy something could be designed, could a tool be designed for multiple tasks. This follows the philosophy of something like a decision matrix but without the arbitrary assigning of values to each

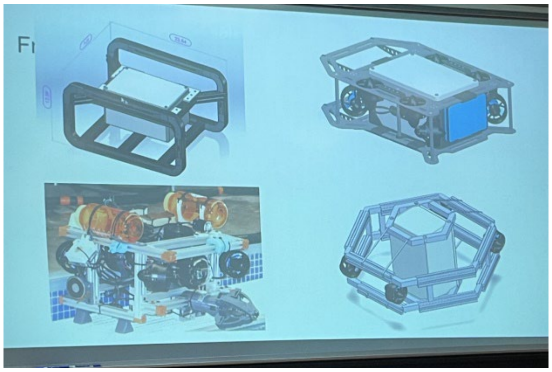


Figure 6. Decision and planning meeting

category. This allowed our team to become better communicators and learn to perceive their solutions in multiple lights. Finally, the team would decide on the best solution by voting at the end of each meeting. All solutions were considered, in hopes to keep all members engaged and involved. Sometimes one discussion was enough, but there were times when needed to revisit decisions after seeing glaring errors in our solutions such as design issues with the 3DOF arms and the number of cameras the team wanted. These mistakes serve as important lessons to always think ahead, keep modularity in mind, and remember Murphy's law. Ultimately, some decisions cannot be revisited and must be solidified early in the designing process for the sake of staying on track with the project timeline, it is up to the CTO to make those rulings. In these cases, such as the inconveniences accompanied by a cramped enclosure, members must learn to adapt, overcome obstacles, and keep these challenges in mind for next year when they can be solved.

Systems Approach

Team leaders frequently collaborated with each other to establish a balanced system approach. The addition of various tools/sensors to the design, including the camera modules, ph-sensor, and robotic arms, required the mechanical, electrical and software teams to maintain constant communication to design the mechanical mounting, supporting electronics, and algorithms. Throughout the designing stage, the designers on the mechanical and electrical teams convened with the software team to make sure the physical systems were in line with the software teams' vision for completing tasks. One main example is WUROV's new system control board, in which it was crucial for the electrical team to constantly check with the software team, so the Orange Pi was connected correctly and was designed to make troubleshooting software easy. This communication occurred at All-hands meetings but even more prevalently on the company's discord channels.

Build vs. Buy

WUROV places a large emphasis on members designing as much of the ROV as they can. Not only is it engaging for the members of the company to build an ROV from scratch, but it also allows members to learn from mistakes in design, leaving the company better equipped for the next year. Our members also gain valuable skills through building. 3D CAD, PCB design, machining, 3D printing, soldering, all these skills are crucial for our members future careers. Decisions of building versus buying items mostly come down to budget and complexity. Unfortunately, some components or systems can be extremely difficult to replicate from nothing. In these cases, simply purchasing and retrofitting to current needs is far more viable. For example, our sensors and other electronic modules. These devices take a lot of time to research and develop, involving hours of calculations, designing, and testing. However, this does not mean that the company does not plan on developing some of these circuits and devices in the future. For building, WUROV focuses first on redesigning what the team has designed in the past. Every year, the company finds issues with the mechanical, electrical, and software systems for its ROVs. The company focuses on solving these issues before focusing on more complex design challenges. Some components that have been consistently redesigned in the past few years are the frame, electronics housing, power distribution systems, motor controllers, processing unit, cameras, robotic arms, and the operating systems. Starting broad with the building to get the main systems working as desired then moving inward to specific components/circuits is the company's goal in the coming years. One example of this progress towards designing our own systems after a purchase is our tools. Last year, WUROV purchased a Blue Robotics gripper because it was reliable and saved the time of designing a waterproof robotic arm. This year we began designing our own robotic gripper, but we benefit from having a reliable back-up in case we are unsuccessful. Additionally, designing our own robotic arm is much cheaper than buying another Blue Robotics gripper.

New vs. Reused

The decisions for what should and should not be reused comes down to improvisation, budget, and obsolescence. When things go wrong, WUROV is lucky enough to have an assortment of different materials, tools, and components in inventory that can be implemented. This goes for issues with budget as well. For example, the company had issues finding the correct connectors to match our tether, so the team decided to extract the same connectors from its 2024 ROV. Another example is the propulsion for this year's ROV, a new set of T200 thrusters did not fit into our budget so we took those from the 2024 ROV as well. Certain items are better to replace, like penetrators because they can get damaged over time and the seals can wear. Then there is the case of upgrading components. The software team opted for a new IMU because it was a direct upgrade to the one used previously.

ROV Design

Mechanical Design

Structure

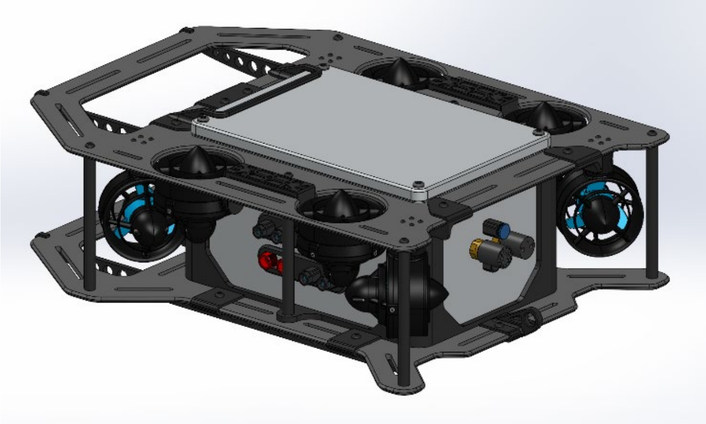


Figure 7: 3D Model of Yellow-Crab

In the development of this year's ROV, the team strategically mitigated for cost, size, and weight to meet the competition requirements and optimize mission performance. When selecting materials for the frame, weight was the most significant factor taken into consideration regarding material properties, and prioritizing maintaining the weight of the ROV at or below 18 kg. HDPE (High-Density Polyethylene) is the most suitable selection for this application due to its lightweight characteristics and high strength-to-density ratio. The material's relatively low density of 0.926 g/cm³ significantly contributes to the overall lightweight nature of the ROV. Further, HDPE demonstrates an impressive strength-to-density ratio, featuring a yield stress of 33 MPa, a modulus of elasticity of 1250 MPa, a stress at break of 60 MPa, and a strain at break of 400% (Awad, 2019). Moving from last year's ROV weighing 24kg to this year's ROV weighing 18.15kg demonstrates a 27.8% decrease in overall weight. Although there is no maximum vehicle size, the team considered that during the demonstration, the ROVs must be able to pass through a 1-meter x 1-meter opening. Additionally, there was a need to design a more compact and smaller ROV for improved maneuverability and task capabilities. Reducing the overall dimensions of the ROV from 0.63 x 0.68 x 0.31m to 0.61 x 0.46 x 0.23m. At the same time, the design of the ROV and the different structural components were evaluated based on the cost and manufacturability. For instance, the team assessed trade-offs on material strength and the cost of metal 3D printing the components for the arm. As a result, material stiffness and yield strength were optimized utilizing composite materials of FDM filament and carbon fibers. In contrast, the team was also able to mitigate costs by using materials such as HDPE and 6061-T6 Aluminum stock, resulting in cost savings in shipping, handling, and manufacturing. Ultimately, these decisions reflect the strategic and thoughtful design approach that optimizes performance within defined cost, size, and weight constraints, allowing us to make informed trade-offs.

Frame

In designing the frame, careful selection of materials and components was essential to achieve mission objectives driven by the need for structural integrity, adaptability, and cost-effectiveness. The frame is constructed using two HDPE plates that enclose the boundaries of the electronic housing. These plates are supported by six 6061-T6 Aluminum bars and reinforced with two HDPE ribs attached to the bottom of each plate to prevent warping at the front overhangs. This arrangement and shape of ROV were selected to be the most ideal of three different derivatives with different shapes and materials because of its low profile and open structure that effectively reduces drag and improves maneuverability in water currents. The HDPE and 6061-T6 Aluminum materials were chosen for their lightweight properties, corrosion resistance, and ease of manufacturing. The HDPE plates, each with a thickness of 0.25 inches, were cut using a CNC router and chamfered as part of the post-processing. Simultaneously, the aluminum rods were cut, turned, faced, and threaded using a lathe machine. On the other hand, the freedom of design and customization was improved through the use of additive manufacturing to produce add-ons, including fixtures, mounts, brackets, clamps, and cable management rails. These components were printed in Polyethylene Terephthalate Glycol (PETG) with high resolution at a layer height of 0.06 inches (0.001524 m) to enhance their strength and reduce water absorption. PETG is a material that has high impact resistance and was selected to be the most suitable because it offers a high ratio of elasticity and rigidity, as the parts are printed with 80% infill with a gyroid infill pattern.

Electronics Housing

The main requirement for the design of the electronic housing was to improve aluminum head dispersion, reliability, and increased surface area. The change in electronic housing in last year's ROV plays a significant role in the enhanced operation of the ROV. The material was changed from an acrylic tube to an aluminum case because of its high thermal conductivity, lightweight properties, and corrosion resistance. Further, an acrylic tube is more prone to cracking or shattering under stress; based on last year's design, the team learned that using acrylic is unsuitable for waterproofing, and the portability of the ROV as a small crack can spear quickly. An enclosure with a verified IP68 rating also ensures that ROV electronics remain fully operational in high-pressure, saltwater environments. This greatly improves reliability and significantly reduces the risk of mission failure. Additionally, the expanded surface area in contact with the surrounding water serves as an efficient cooling medium. These characteristics facilitate better heat dissipation, preventing overheating and allowing for enhanced layout options and modularity of the electronics.

Figure 8. Electronic Housing

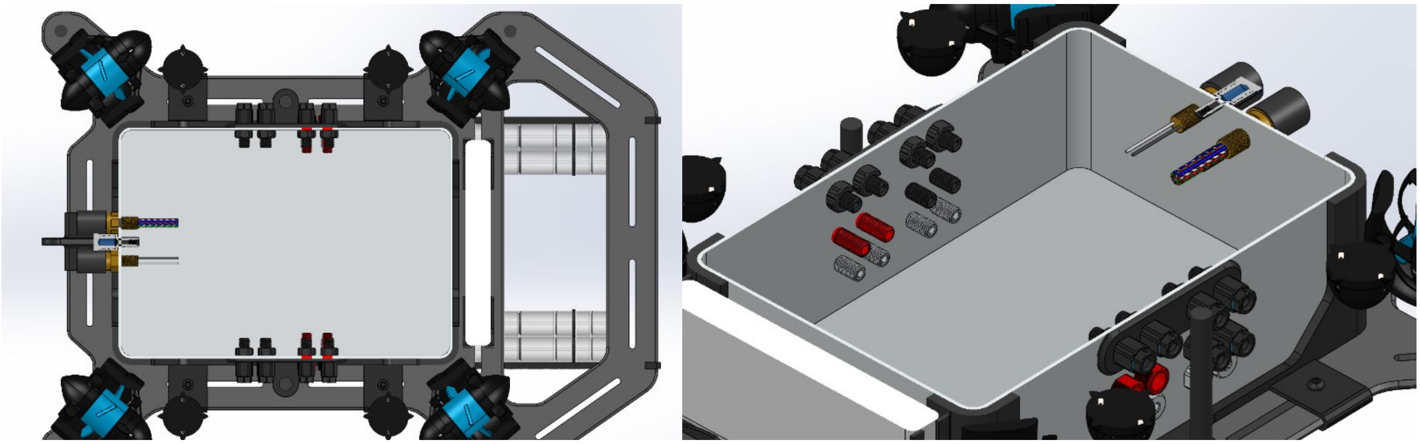
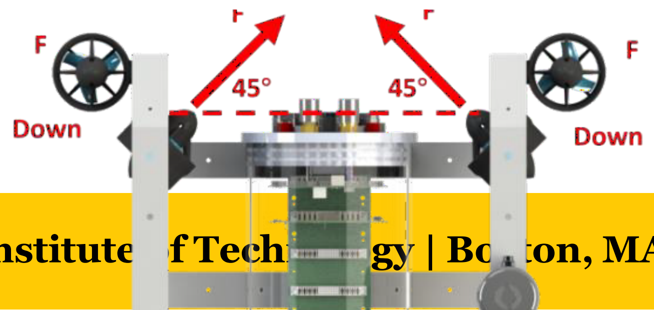


Figure 8: Electronic Housing of Yellow-Crab

Propulsion

The propulsion system is made up of eight T200 Blue Robotics thrusters allowing for a full 9 degrees of freedom (DOF). In the mission



challenges, this was particularly useful towards the maneuvering of the hydrophone as it gave the ROV better stability and allowed our pilot to precisely place it within the designated zone. Having complete autonomy over all axes also aided us in completed the photosphere tasks as well.

The configuration of the side thrusters for colossus titan continues to be in 45-degree angles as in previous years as well as the vertical thrusters pointing downward toward the robot base (Figure X). The configuration of the propellers symmetrical allowing for the same maximum thrust to be applied in any opposite direction. The consistency of the thruster mounts has slightly reduced the costs of 3D printing compartments.

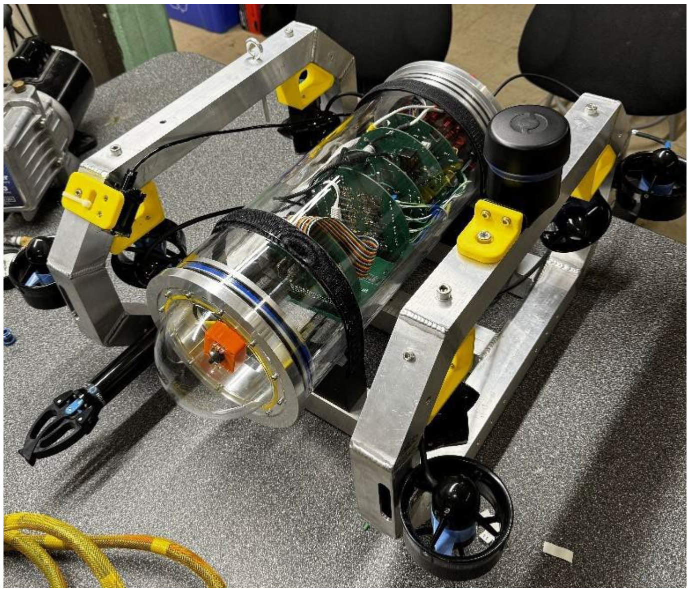


Figure 10: ROV Propeller Configuration

Buoyancy

Using Archimedes' principle and density calculations through SolidWorks, the team discovered that the ROV was positively buoyant on its own and displaced a lot more water than it weighed on its own. WUROV accurately calculated the additional mass needed to reach neutral buoyancy for the Colossus Titan using the Tables below. The tables were script calculations written in Excel to figure out the exact volume and weight ratios for reaching the neutrally buoyant state. The additional mass was added to the ROV in the form of tools, sensors, and weights. The main principle WUROV followed was shifting the additional weight towards the vehicle parts which rose above the surface. Through multiple tests in the pool and adjustments of weight, the weights were added in the correct positions to achieve a balanced and neutrally buoyant ROV, decreasing the load on our propulsion system.

	Mass	Volume	Density	Density of H_2O	Buoyancy	Weight of Object	State
	g	mm^3	kg/m^3	kg/m^3	N	N	
Frame	13035	14320800	910.214513	1000	140.487048	127.87335	Partially Submerged

Table 1: Buoyancy Calculations

	Density of Polyurethane Foam	Volume of Polyurethane Foam	∑ Volume	Mass	∑ Mass	Density	Buoyancy	State
	kg/m^3	mm^3	mm^3	g	g	kg/m^3	N	
Frame	192	-1285800	13035000	1285.8	14320.8	1000	127.87335	Neutrally Buoyant

Table 2: Increase in amount of Mass or Volume to be Neutrally Buoyant

Payload and Tools

The cameras part of the ROV each have their own separate housing. Power and communication is facilitated by a PoE cable. PoE injector cables are used to inject 48VDC into the camera module's PoE stack. The camera housing contains a Raspberry Pi Zero 2W attached to a PoE HAT to serve as the camera server host. Connected to the Raspberry Pi is a wide-angle IMX519 which communicates to the PI though the CSI-2 connector. There is a front facing camera that is used for aligning tools to props, another camera faces downwards to carefully place props in their destinations such as the sacrificial anode and cargo cover.

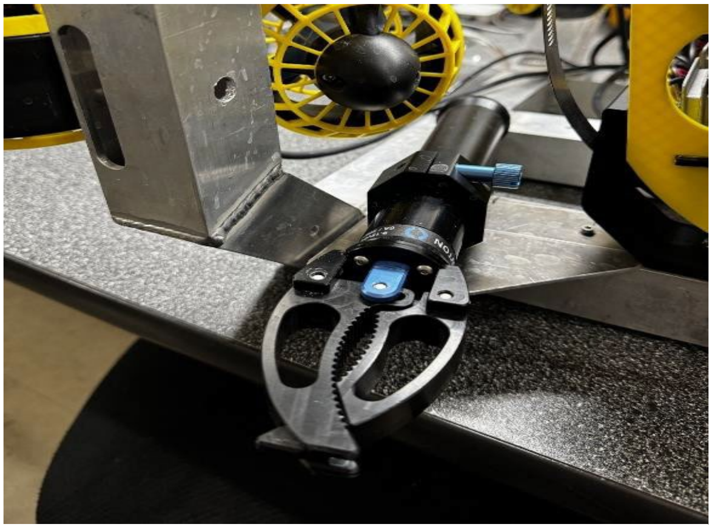


Figure 11: Blue Robotics Gripper

Based off the mission tasks, WUROV purchased the Blue Robotics Newton Subsea Gripper, a reliable tool for lifting heavy props and one that is great at handling various PVC pipe thicknesses and small, tiny hooks like the hydrophone metal pins. The team did not prefer using pneumatics only for the gripper module, so this purchase was justified. A PH0-14 pH sensor was selected to measure the pH of the Lake Acidification water sample. A Blue Robotics Bar02 depth sensor is used to automate ROV depth control.

Electrical System

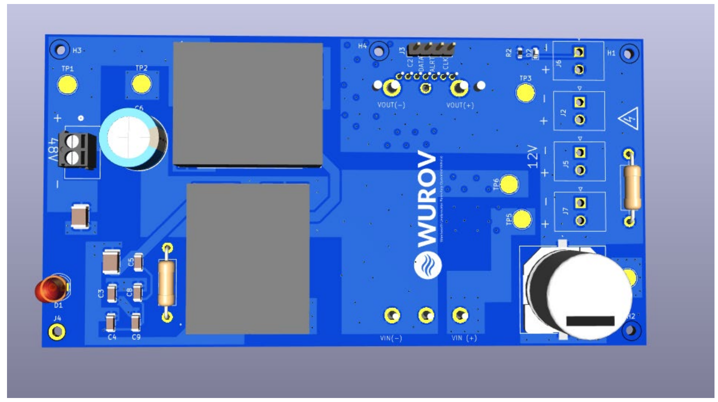
Modular Printed Circuit Boards (PCBs)

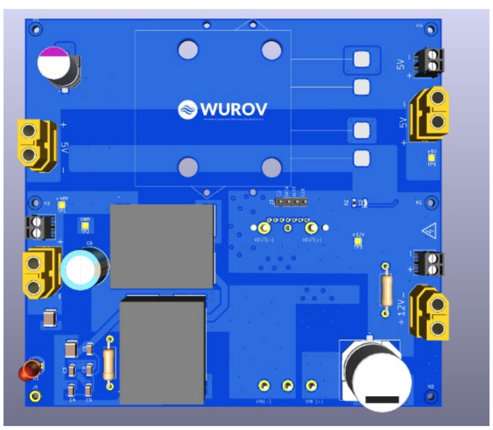
This year WUROV abandoned its backplane PCB design in exchange for a system strictly composed of wire harnesses. This abroach allowed the team to troubleshoot each board without having to rely on the operation of another. The tradeoff to this decision was less organized electronics housing which made troubleshooting during each pool test cumbersome.

The electrical team worked to design each board as an individual module that could be easily removed without jeopardizing the functionality of the ROV. Each modular PCB was designed with auxiliary components that allow users to configure the boards into non-ROV systems and possibly use alternative power sources than what is provided at the MATE ROV Competition. To reduce the surface area of the electrical system, each board is designed to mount onto the others using standoffs, allowing the team to organize the electronics housing into multiple different configurations, mounting and unmounting boards as needed. The use of wire harnesses greatly benefitted this versatility because the neatly organized groups of wires could be twisted and bent to suit each configuration. Some additional ways that the electrical team was able to organize the housing was with the use of cable ties, mounts, and command strips using each wall of the enclosure. Each PCB utilizes the same types of connectors to keep assembly simple and to categorize each connection. For sensors and tools, Molex MiniFit-JR was used. For power delivery, XT60, Molex KK, and screw-in terminals were used. These connectors were specifically chosen because of their high current capacity, the screw-in terminals were chosen to add versatility and to make troubleshooting easier. One connector that was only used for the Thruster Control Boards (TCBs) was a spring-lock terminal used for delivering Pulse Width Modulated (PWM) signals to the Electronic Speed Controller (ESC). The decisions to utilize screw-in terminals and spring-lock terminals on the TCBs were based on the need from the programming team to swap wires and thrusters to calibrate the control systems, something learned from years past.

Power Distribution

The power distribution system for Yellow-Crab consists of 3 separate PCBs: two Power Distribution Boards for supplying power to the thrusters and one Instrument Power Distribution Board (IPDB) for supplying power to the sensors, tools, and main computer of the ROV. The electrical engineers at WUROV redesigned this system for Yellow-Crab due to brown-out issues experienced at 2024 World Championships. WUROV was able to identify that the cause for these brown-outs or resets to the onboard computer were due to fluctuations in power because of the thrusters overdrawing current. When all the voltage buses were connected, as WUROV had configured its system to be, the load of the thrusters could essentially "steal" current from the 5-volt bus, which caused the on-board computer to turn off during missions. To solve these issues, WUROV designed Yellow-Crab's thrusters to have isolated power delivery buses, one PDB per 4 thrusters. Each PDB consists of an EMI filter to cancel out any noise from the source, a 48V to 12V 600W buck converter (q54sg12050nrfg), a smoothing capacitor for the 12V output, indicator LEDs for input/output, test points for troubleshooting, and 4 Molex KK connectors capable of delivering a total of 44 A. The q54sg12050nrfg 600W power converters from Delta Electronics were picked by the electrical team because WUROV already possessed 4 modules. By reusing these devices, the electrical team was able to save approximately $1200. To avoid thermal issues and ensure the maximum amount of current could be supplied by each module, the PDB board contains 4 layers of 2oz copper and a heatsink for the power converters. The IPDB is very similar to the PDBs except it includes a 12V-5V 50W buck converter (Tobsun EA50-5V) to provide both 5V output and 12V output to the different tools/sensors and other devices inside of Yellow-Crab. Due to this board being designed subsequently to the PDBs, it contains XT60 connectors which were discovered by the team later in the design process. These connectors were chosen because they had much higher current capacity and provided more reliable contact for the connections. In addition to the features listed on the PDB, the IPDB has smaller test points, two XT60 connectors for 5V output, one XT60 connector for 12V output, a screw terminal for each bus (48V,12V, and 5V), and the capacity to add an additional 12V-5V 50W buck converter.





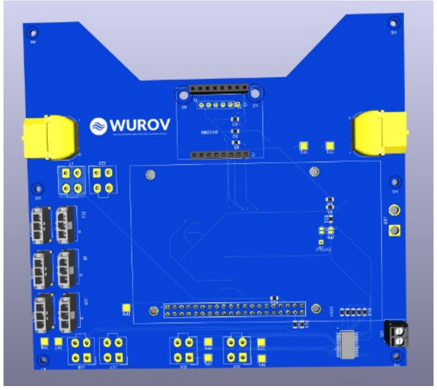
Thruster Control Board and ESCs

Yellow-Crab is equipped with 8 Blue Robotics T200 thrusters that were taken off WUROV's 2024 competition ROV. To control these 8 thrusters in tandem, the electrical system incorporates a device called an electric speed controller or ESC. ESCs are intelligent analog devices that take PWM signals and translate them to 3-phase pulsed DC outputs that can be used to rotate a brushless motor like the T200 thrusters. The PWM signals that Yellow-Crab's ESCs receive are produced by a PWM driver IC called the PCA9685. Yellow-Crabs thruster control board consists of a single 4in1 ESC called the Lumineer Mini Razor Pro (BLHeli). The team decided to use two of these 4in1 ESCs for the thruster control system instead of continuing to use Blue Robotics ESCs due to the compact package, similar pricing, and similar performance. The max current rating for these

ESCs is 45 A, thus a max current of 11.25 A per thruster. Since the WUROV PDBs are only designed to output 44A, the TCB is protected from a catastrophic error. The max throttle of each T200 thrusters at 12V is 17A, and our system can produce 11A, meaning the Yellow-Crab TCB can run each thruster at 64% max throttle all at once. If we take into consideration the maximum force of each thruster, Yellow-Crab can hypothetically produce 2.37kg f of forward thrust and 1.86kg f of reverse thrust per thruster.

Systems Control Board

This year the software team decided on moving on from the jetson nano development board that served as WUROV's onboard computer during the 2024 World Championship. WUROV's reasoning for using the jetson nano was to utilize its graphical processing power for rendering camera views, but discovered it was not needed. For Yellow-Crab, WUROV has chosen an Orange Pi 5 Max, which has higher processing power than the Jetson. This allows Yellow-Crab to boot and carry out operations much quicker, helping to the team to complete mission tasks at a faster rate. To accommodate this new device, the electrical design team created an expansion board that delivers power to the Orange Pi 5, maintains a connection to all the necessary tools and sensors as well as the TCBs.



Tether

WUROV's tether consists of 25 ft of Blue Robotics subsea ethernet cable and a 48V power line (a 12-gauge wire) taped together for security. WUROV doesn't utilize strengthening components to reduce the weight and increase the flexibility of its tether. Using a heavier tether would cause the ROV to have a difficulty surfacing. The tether consists of dual connectors on both ends, for one end to connect to the surface station and the other to the ROV. On the ROV end of the tether are two Macartney Subconn circular connectors that deliver the power and data from the surface station to matching connectors on the ROV. These connectors have been joined to the tether cables through soldering. Subsequently these joints were wrapped in electrical tape and encased in epoxy to prevent corrosion. On the topside, the tether is connected to a 30A fuse which is 10cm away from the SBS50 Anderson Powerpole which connects to the surface station which provides the 48V. Due to our fuse calculation, in the figure below, our current for the whole ROV is at 28.007A which will not activate our fuse. Carabiners are attached on both ends of the tether as strain relief, clipping onto designated and secured locations.

WUROV's Tether Management Protocol was developed to prioritize efficiency. Tether management is very important to the team as keeping the tether accessible and organized will lead to faster set-up and clean-up progress. While operating the ROV and the tether is out on the pool deck, one member must be managing the tether. That member will either be feeding or pulling on the tether to ensure the pilot can navigate freely. Additionally, it is up to the tether manager to alert other members of the deck crew of the tether to avoid any possible injuries. When the tether is no longer in use, it is stored onto a tether stool for easier transportation, to reduce damage to tether, and to keep it neatly wound.

Component	Voltage Volts	Usage Current Amps	Max power Watts	Quantity	Total Max Power Watts	Total Max Current 48V Amps
PDB 1	48 V	12.5 A	600 W	1	600W	12.5 A
PDB 2	48 V	12.5 A	600 W	1	600W	12.5A

Orange Pi 5 Max	5 V	3.6A	18W	1	18W	0.375A
Arm 1	5 V	2.7A	13.5W	1	13.5W	0.281 A
Arm 2	5 V	2.7 A	13.5W	1	13.5W	0.281 A
Subsea Newton Gripper	12 V	6.0 A	72W	1	72.0 W	1.500 A
Network Switch	5 V	1 A	5W	1	5W	0.1 A
Cameras	5 V	1.5 A	7.5 W	3	22.5W	0.47 A
Total Calculations					**1344.5 W**	**28.007 A**

Table 3: Fuse Calculation

Software

Computer System

The main computer used in the ROV is the Orange Pi 5 Max. This SBC comes with a NVME M.2 SSD slot that we use to lower our boot time and remove bottlenecks associated with filesystem usage. Ubuntu Server 24.04 is the operating system used for the Orange Pi. This distribution Linux allows for easy compatibility with ROS2, that is used for all controls and communication between the surface station operators and the ROV. This platform allows for devices to function independently from each other and communicate through a publisher-subscriber interface.

In the surface station there is a router that allows for communication through an IP network. Ethernet cables and a 5-port switch inside the ROV allow for speeds of up to 1 Gigabit per second, which is extremely useful in implementing real-time camera systems for the ROV.

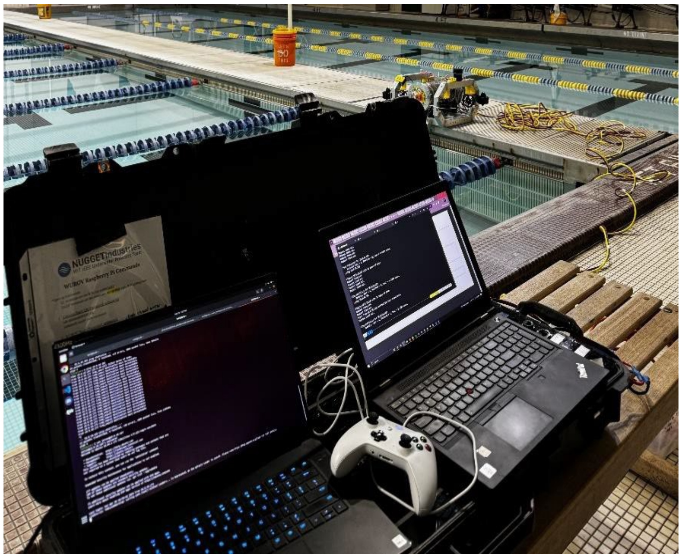


Figure 12: Programming station multiple devices

Onboard camera modules are connected to the main electrical housing through a single PoE cable. The PoE cable powers a Raspberry Pi Zero 2W. Connected to the Pi Zero is an IMX519 wide-angle camera. This year we wrote a custom application stream that makes use of the Pi Zero's GPU to hardware-accelerate H.264 encoding 640x480 images at 30fps. With a custom stream viewing application to pair with the server, we have achieved very low latency video streaming.

All SPI and I2C device drivers are written by the software team. The high clock speed of the Orange Pi keeps loop times and communication consistent of the ROV with the surface station compared to last year following the ROS master update as the surface.

Thrust Allocation

The 8 thrusters of the ROV require careful calculations to translate a desired thrust vector into 8 thrust outputs. These are solved by first setting up the equation $\boldsymbol{\tau} = \boldsymbol{T}(\boldsymbol{a})\boldsymbol{f}$ where $\boldsymbol{\tau}$ is a vector of net thrust output, $\boldsymbol{T}$ is a matrix of weights that tie each individual thruster output to the linear or angular axes that they affect, and $\boldsymbol{f}$ is a vector of individual thrust outputs. We can solve for the thruster outputs $\boldsymbol{f}$ by calculating the complete orthogonal decomposition of $\boldsymbol{T}$. In our case the calculation is done for both horizontal and vertical sets of thrusters and results with 2 vectors of 4 individual thruster outputs in kgf to form the desired net thrust vector. After solving for each thrust output, the values then need to be translated to a PWM period. Because of the asymmetrical thrust curve for forward and reverse thrust, 2 quadratic regressions are fitted to the forward and reverse segments of the T200 PWM to thrust data. This allows us to get the same individual thrust output whether the thruster is to run in reverse or not. The corresponding PWM periods are then mapped to a 12-bit control register value and written to the PCA9685 to move the ROV in the desired 3D translation and rotation.

Control System

To precisely control the ROV, the data from the Inertial Measurement Unit (IMU) sensor is utilized. Quaternion PID is used to control the orientation of the ROV and normal PID is used to control ROV depth. Quaternion PID avoids gimbal-lock issues that may be caused when using Euler angles in 3D space. We use PID control to hold the ROV at the orientation the pilot was at when they stopped giving rotational input. This is used to stop the ROV from drifting when the rotation stick is released. Depth control is also done this way, where when the pilot isn't commanding a depth change, the ROV should hold its current depth. Another control system feature is angular velocity control. Rather than giving a net thrust moment input to the system, the pilot controller controls the angular rate of the ROV's axes allowing for more consistent rotation. The last main control system feature we have is a scheme where pilot translational inputs can only change movement along the global XY axes no matter the rotation. If the ROV is holding a downwards pitch and then a forward movement is inputted, the ROV will not move down, only parallel to the surface of water. Xbox controllers are used to control the ROV. These control system features make the ROV much easier to operate due to not having to constantly stop the ROV from drifting along its axes.

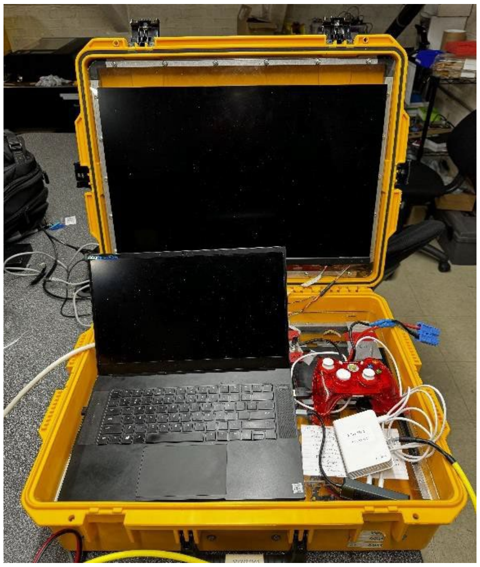


Figure 13: Surface Station for joystick controls

Safety

Safety is WUROV's top priority, ensuring the well-being of all members and those around them. To minimize the risk of injury, WUROV has implemented comprehensive safety features and procedures for building, operating, and transporting the ROV. WUROV additionally follows safety protocols from the WIT IEEE Student Branch, Accelerate, and Machine Manufacturing Lab. These measures foster a safe and welcoming environment for everyone involved.

Safety Feature

Recognizing the potential hazards of improper tool and equipment use, WUROV mandates strict adherence to safety protocols. Every member is required to follow the company's safety checklist (refer to the Appendix for the Safety Checklist), utilize personal protective equipment (PPE), and conduct job safety and environment analysis (JSEA). Before operating any tools or equipment, members must complete a mandatory safety training session. This training covers the essentials of PPE, JSEA, and the safety checklist procedures, including preparation for ROV operations on the pool deck and emergency response protocols. Less experienced members must work under the supervision of senior members to learn proper tool handling techniques. On top of these requirements, when using a workspace, members are required to clean their workspace so that other members can use the space and find all materials in their designated spot. During pool tests, the safety officer is required to attend with the safety checklist to ensure protocols are followed and required to be lifeguard certified.

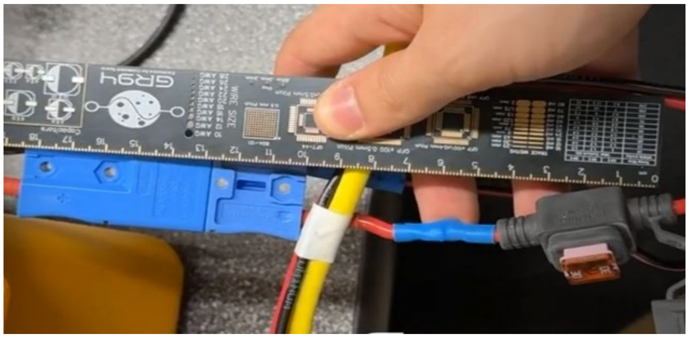


Figure 15: 30A fuse placed roughly 10cm away.

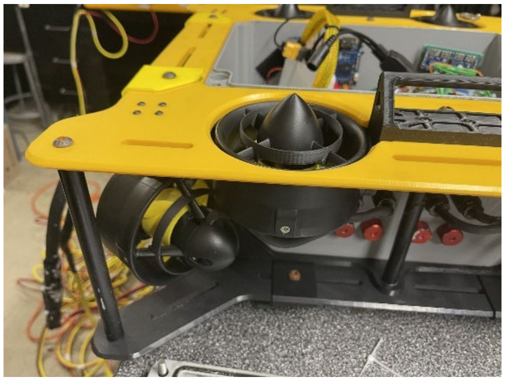


Figure 16: The two types of 3D printed propeller guards mounted on both sides of the thruster.

For the ROV, safety features were implemented. Such as having strain relief on the topside and bottom side of the tether, shown in Figure 13. A thimble is used on the bottom side of the tether which is mounted on the bottom of the HDPE frame. A strain relief cable grip with a carabiner is used on the top side of the tether which is connected to our control station. The reasoning for this strain relief was to prevent any straining to the wiring to the surface station and straining to the tether connection to the ROV.

To enhance safety and prevent any contact with the T200 thrusters, thruster guards adhering to IP-20 standards have been installed, shown in Figure 21. Additionally, to protect personnel from potential current spikes, a 30A fuse has been integrated into the design. This fuse is strategically placed 10 cm from the Anderson Powerpole connector on the tether, shown in Figure 20. By integrating these safety measures, WUROV not only prioritizes the protection of its members and nearby spectators but also ensures a structured and secure working atmosphere.

Testing and Analysis

Testing

WUROV's design process prioritizes the testing phase in the designing stage of the project schedule. Recognizing that this is where many errors occur. Drawing from accumulated experience over previous years, the team has developed a process to ensure all designed, selected, and manufactured products meet design requirements.

Each team at WUROV follows a structured process that includes designing, simulating, manufacturing, testing, and iterating. Students create models using software such as KiCAD or SolidWorks, where they simulate the models to evaluate their functionality. If a model is found to be inefficient, modifications are made before proceeding to manufacturing. For example, in Figure 20, the left side displays an earlier iteration of the gripper used in the ROV's design. Due to inefficiencies and unnecessary design choices, this version was not manufactured; instead, it was modified into the final design shown on the right side.

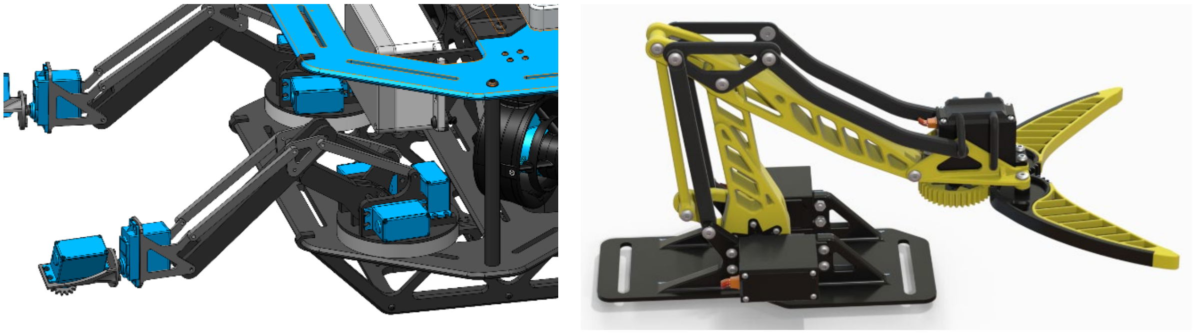


Figure 17: Arm iteration

There are instances when designs proceed to the manufacturing and testing phases but do not perform as expected or contain unnecessary features. This is illustrated in Figure 21, which compares the first version of the power board, represented by the green PCB, with the final version, shown as the blue PCB. Adjustments were made to optimize the size and ensure the board operates as intended, effectively minimizing wasted space.

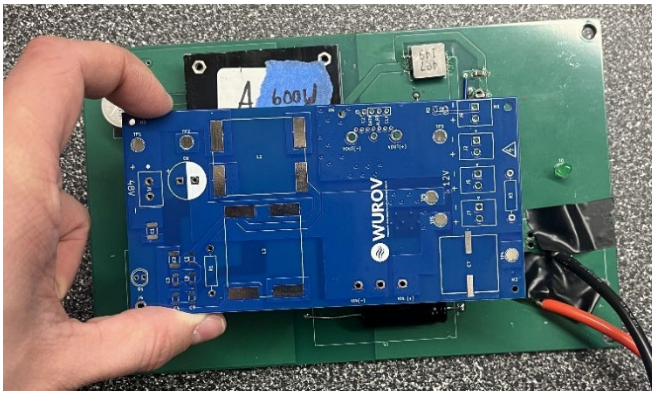


Figure 18:Comparing the new power board above the old power board design

The prototyping phase encourages students to generate innovative ideas that can provide better solutions to various challenges. Prototypes are often 3D printed using inexpensive materials or manufactured using wood or acrylic sheets. Most errors typically involve tolerance issues, which are tested through a dry fit assembly. This process involves gathering all assembly components and putting everything together to identify improvements. Tolerances are then iterated using the same inexpensive materials until a successful design is assembled and approved by the entire team.

As an underwater vehicle, the ROV must undergo waterproof testing. To start, students test the electronic housing for waterproofness by placing it in a pool to check for any water leaks. If water is detected, they identify the source of the leak and determine how to seal it. This process is repeated until the housing is completely waterproof. This testing ensures that the electrical components inside the housing remain safe from water exposure.

Troubleshooting

Troubleshooting is also an important process that WUROV has aimed to improve. One method of troubleshooting follows a software and electrical approach called unit testing. Due to the large number of sensors and modules in the ROV, the team follows a procedure where each component is tested separately before being used in an assembly of components. All sensors are individually tested, and all PCBs designed have subcomponents that are tested similarly. When two or more components of the same assembly are successfully tested, they are combined, and a system test is performed. This ensures that any small failure is captured and identified to prevent extra costs in damage and speed up the assembly process in case of a failure.

WUROV conducts extensive testing with various electrical equipment such as oscilloscopes and multimeters. The team used oscilloscopes to ensure PCBs were working as expected. As shown in Figure 20, this data shows what the voltage looks like with noise (top) and then with a capacitor to smooth the result when powering up (middle) and when powering off (bottom). This approach allows the team to double-check their work effectively.

Buoyancy tests are conducted to ensure that the ROV achieves neutral buoyancy. This allows the Yellow-Crab to ascend and descend easily without needing to exert maximum power on the thrusters. If the ROV is positively buoyant, the team adds weights near the center of gravity of the frame. Conversely, if the ROV is negatively buoyant, the team removes weights to achieve neutral buoyancy.

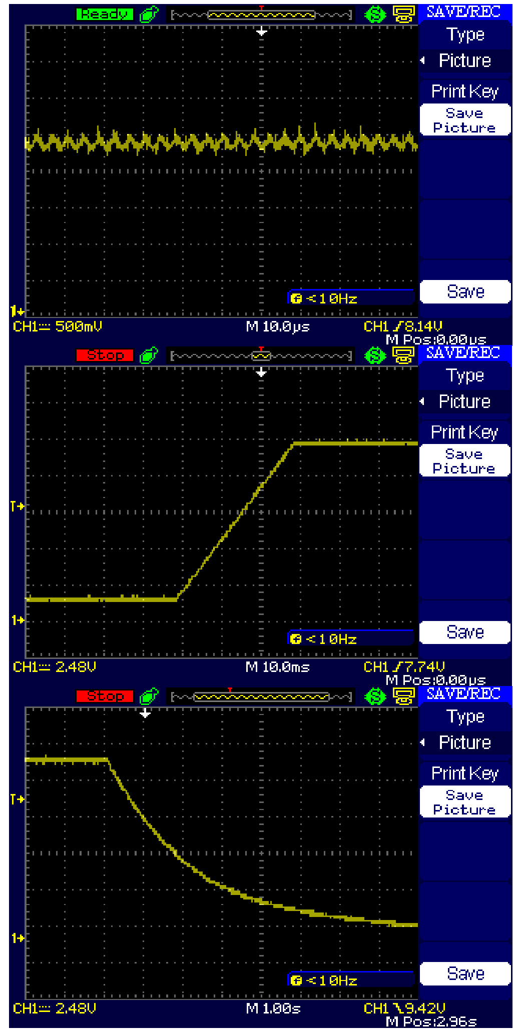


Figure 19: Oscilloscope results with

Accounting

WUROV creates a budget at the start of the fall semester, which includes the amount of money required to build the ROV and the amount needed for travel. These numbers consider many factors, such as what items the team plans to reuse from the previous year and what large purchases need to be made. This year, some of these items included reusing a surface station from previous years, but the team needed to purchase a new set of thrusters, which was a significant expense.

A CEO considers all the expenses required by the three sub-teams and periodically calculates the remaining amounts for items. Also calculates the travel expenses once the competition locations are revealed. These expenses include lodging, flights, rental cars, luggage, and other related costs. See below for more details on how these looked like over the last year for the WUROV team.

2024-2025 WUROV Gross Income			
Company	**Item Description**		**Amount**
Wentworth Funding	IEEE Student Branch	Fundraising Account	*$2,557.05*
		Conference Allocations	*$2,550.00*
		Project Budget	*$4,500.00*
		TOTAL :	**$9,607.05**
	Student Government		$2,853.50
Room Alert	Sponsorship		$1,000.00
TOTAL INCOME:			**$13,460.55**

Table 4: WUROV's starting budget

2024-2025 WUROV Expenses				
ROV Materials				
Item Purchased	**Company**	**Item Description**	**Purchase Status**	**Amount**
Thrusters	BlueRobotics	8 T200	Re-used	$1,760.00
Penetrators	BlueRobotics	8 wetlinks, 8 potted, vacuum test port, etc.	Purchased & Re-Used	$134.00
PCBs	JLC PCB	Power distribution boards, motor control boards	Purchased	$765.41
Tether Connectors	McArtney		Purchased & Re-Used	$348.60
Surface Station	Pelican	Pelican Case, XBox Controller	Re-used	$275.00
Housing	Raychem	IP68 Box enclosure	Purchased	$422.05
ESCs	GetFPV	Lumineer mini razor pro 4in1 ESCs	Purchased	$120.00
MISC		HDPE, screws, filament, etc.	Purchased & Re-Used	$515.93
TOTAL ROV EXPENSES:				**$4,340.99**
Float Materials				
Item Purchased	**Company**	**Item Description**	**Purchase Status**	**Amount**
PCBS	JLC PCB		Purchased	$14.00
Housing & Buoyancy		Polycarbonate tube	Re-used	$0.00
TOTAL FLOAT EXPENSES:				**$14.00**
Operating Expenses				
Item Purchased		**Item Description**	**Purchase Status**	**Amount**
Hotels		2 Student Rooms, 1 Mentor Room	Purchased	$4,363.67
Airplane Tickets		6 Student Tickets, 1 Mentor Ticket, Checked Bags	Purchased	$1,910.79
Rental Cars		1 Midsize SUV, 1 Fullsize SUV	Purchased	$1,627.33
Food		2 Meals ea. 8 Days	Purchased	$2,240.00
Mission Props		PVC Pipes	Purchased & Re-Used	*$0.00*
MATE Registration		MATE ROV World Championship	Purchased	$650.00
ROV Shipping		Delta Overweight Check bags	Purchased	$200.00
Poster Printing			Purchased	*$0.00*
TOTAL OPERATING EXPENSES:				**$10,991.79**
			TOTAL WUROV EXPENSES:	**$15,346.78**

Table 5: WUROV Total Expenses

Appendix

Safety Checklist

Workstation Maintenance

- ☐ Area clear, organized, and safe.
- ☐ Verify all tools and cables are neatly stored and there are no tripping hazards.
- ☐ Verify the power source is off before modifying the electronics.
- ☐ Keep track of all items coming out of the ROV and making sure every item is put back in the ROV in their correct location.
- ☐ Create a shopping list if anything is needed to repair the ROV.

Pool Deck Pre-Power Procedure

- ☐ Area is clear, safe and organized (no tripping hazards).
- ☐ Verify the power is off before being in contact with ROV.
- ☐ Tether is connected and secure to the ROV.
- ☐ The Anderson powerpole is connected to the surface station.
- ☐ Ensure the power strip is connected to the wall outlet.
- ☐ Laptop is connected and secured on the surface station.
- ☐ Xbox controller accounted for and connected to the laptop.
- ☐ Strain relief between tether and ROV is connected and secured.
- ☐ Strain relief between tether and surface station is connected and secured.
- ☐ Ensure electrical PCBs are all accounted for, connected and secured on backplane board.
- ☐ Inspect all electrical wiring is organized, secured and not damaged.
- ☐ Pressurize electrical housing to 10 mmHg and maintain pressure for 2 minutes before proceeding.
- ☐ Ensure the pressure port is securely capped.
- ☐ Ensure all screws are fully fastened and secured.
- ☐ Thruster guards on and secured.

Pool Deck Power Up Procedure

- ☐ Notify pool crew, "Powering up."
- ☐ Flip the power on to the surface station and ROV.
- ☐ Connect laptop to router.
- ☐ Ensure communication between ROV and surface station.
- ☐ Notify pool crew, "Testing controls."
- ☐ Perform controller test (ensure the thrusters are working properly, joystick movements correspond with the thruster activity and gripper responding to the joystick.)
- ☐ Ensure video feed on monitor and proper camera position.
- ☐ Launch Time
- ☐ Ensure no members are operating the thrusters while members are handling ROV.
- ☐ Place ROV in the pool.
- ☐ Visually check if any bubbles from the electrical housing.
- ☐ If there are bubbles from the electrical housing, remove ROV from the pool immediately and call out "leak detected!"
- ☐ Processed with Leakage Detection Procedure
- ☐ Pilot calls out, "ROV ready to go!
- ☐ Deck crew members handling the ROV call out "ROV safe to go!"
- ☐ Co-pilot calls out "Thrusters Engaged." and the pilot begins the mission.
- ☐ ROV Retrieval
- ☐ Pilot calls, "ROV coming up!"
- ☐ Deck crew calls out, "ROV surfaced. Power off!"
- ☐ Co-pilot flips off the power switch and calls out, "ROV off!"
- ☐ Deck crew removes the ROV from the water and calls out "ROV received."

EMERGENCY

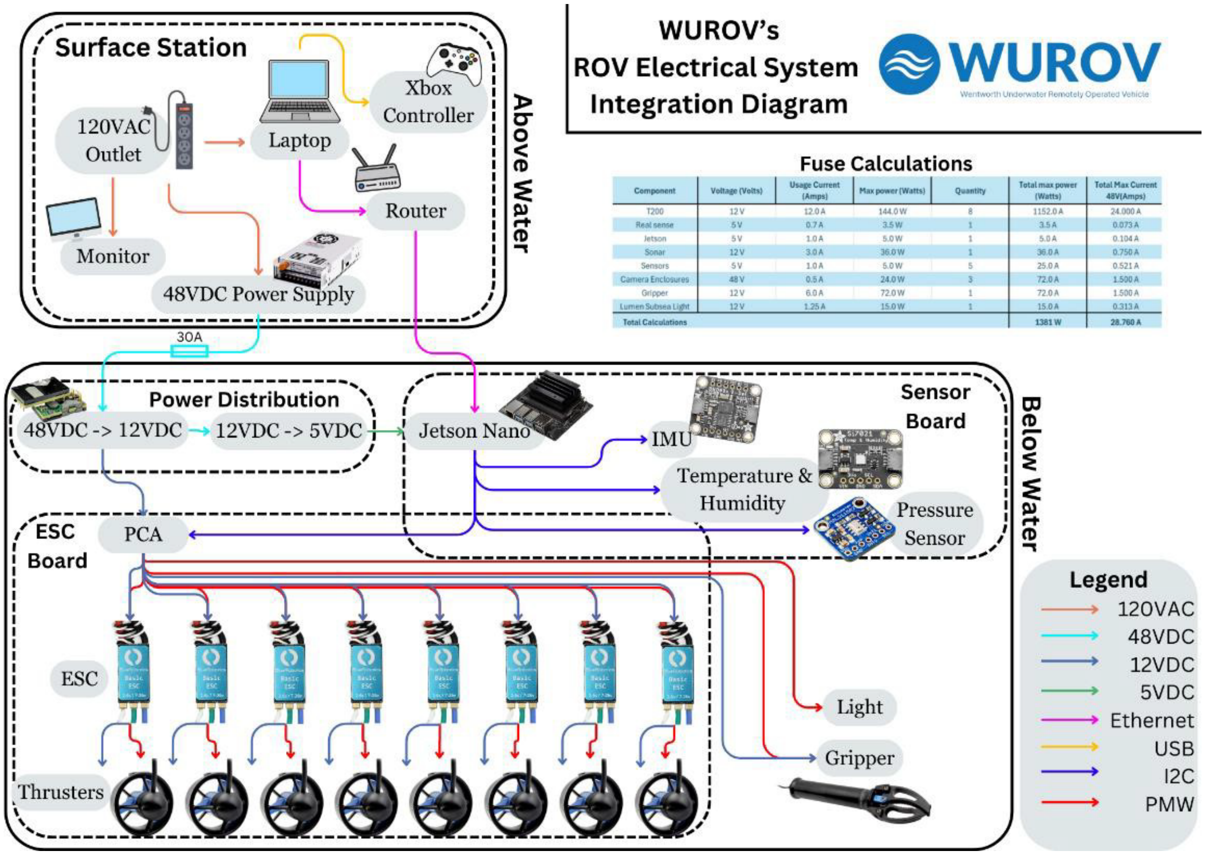
Leakage Detections Procedure

- ☐ Co-pilot flips off the power switch and calls out "ROV off!"
- ☐ Deck members recover ROV by pulling the ROV to the surface using the tether. Then removing the ROV from the water.
- ☐ Visually inspect the source of the leak. Do not disassemble the ROV until the location of the leak is detected.
- ☐ Document incident, cause of leak for future redesign or repairs.
- ☐ Check all systems for damage and proper operations.

Loss of Communication Procedure

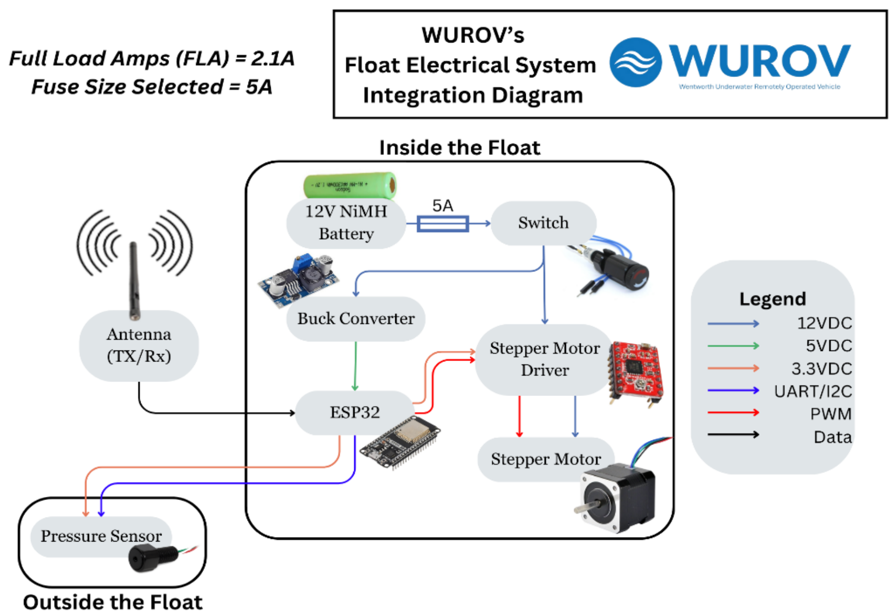
- ☐ If there is no communication between the ROV and surface station, the pilot calls out "ROV not respond!"
- ☐ Co-pilot flips off the power of the ROV and calls out "ROV off!"
- ☐ Deck members pull the tether to recover the ROV and once the ROV is out of water, members will call out "ROV received!"
- ☐ Power cycle the ROV and see if communication is restored.
- ☐ If communication is not restored, begin troubleshooting the issue.
- ☐ If communication is restored, ensure ROV is safe and ready to go. Then proceed with the mission.
- ☐ Document incident, cause of loss of communication for future redesign or repairs.

System Integration Diagram (SID)



Component	Voltage (Volts)	Usage Current (Amps)	Max power (Watts)	Quantity	Total max power (Watts)	Total Max Current 48V(Amps)
T200	12 V	12.0 A	144.0 W	8	1152.0 A	24.000 A
Real sense	5 V	0.7 A	3.5 W	1	3.5 A	0.073 A
Jetson	5 V	1.0 A	5.0 W	1	5.0 A	0.104 A
Sonar	12 V	3.0 A	36.0 W	1	36.0 A	0.750 A
Sensors	5 V	1.0 A	5.0 W	5	25.0 A	0.521 A
Camera Enclosures	48 V	0.5 A	24.0 W	3	72.0 A	1.500 A
Gripper	12 V	6.0 A	72.0 W	1	72.0 A	1.500 A
Lumen Subsea Light	12 V	1.25 A	15.0 W	1	15.0 A	0.313 A
Total Calculations					1381 W	28.760 A

Appendix 1: WUROV's ROV SID



Appendix 2: WUROV's Float SID

Acknowledgments

WUROV would like to acknowledge the following companies and individuals for their respective help:

- Room Alert and CEO Rick Grundy for providing us with $1000 to travel to the World Championship
- Springfield Central High School for allowing us to present to their students
- Chris Thierauf for keeping us in contact with WUROV alumni and providing advice
- Professor James McCusker for ordering our Orange Pi 5 Max and prototyping materials
- Tedi Qafko for reviewing PCBs and assisting with troubleshooting
- Wentworth Student Organization Council for ordering all our project materials/components
- Wentworth Center for Student Life for providing us with our project budget of $4,500
- Wentworth Student Government for providing us with the $2,853.50 to travel to the World Championship
- Wentworth School of Engineering for providing us with our own workspace
- Wentworth Accelerate for allowing us to use their manufacturing tools
- Wentworth Police for giving the team access to the university facilities after close
- Mass Robotics for allowing us to showcase our ROV at various public events
- Simmons University for allowing us to use their pool facilities to test our ROV
- MATE ROV for organizing this competition and volunteering time to develop our careers
- The Gravel's for allowing us to use their pool for testing and completing our video demonstration

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