



WITROV

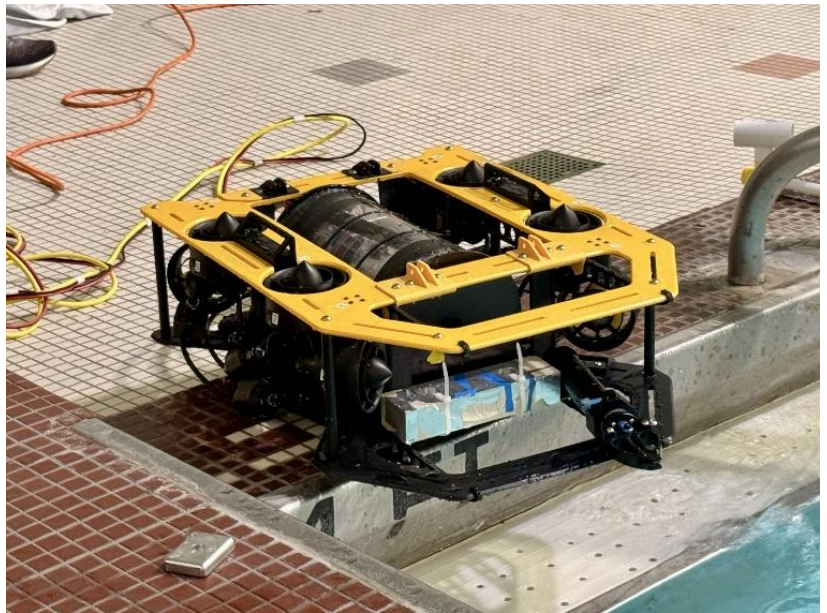
**Wentworth Institute of Technology
Boston, Massachusetts, United States
Explorer 0430A**

Team Members:

- Noah DeGrazia (CEO)
- Lulya Tesfamicael (Mechanical Lead)
- Ryan Staley (Mechanical)
- Garrett Vieira (Safety Officer)
- Joleen Zhu (Control, Float)
- William Zhou (Control)
- Ben Oosting (Float)
- Omar Elhashash (Float)
- Matthew Zubricki (Business)

Mentors:

- Prof. Saurav Basnet
- PhD Christopher Thierauf
- Victor Lomba



"If I have seen further than others, it is only because I was standing on the shoulders of giants" – Sir Isaac Newton



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Abstract

Wentworth Institute of Technology Remote Operated Vehicle (WITROV) is a multidisciplinary collaborative company built upon students aiming to learn further into the process of design, manufacturing, and robotic applications. WITROV's newest Remote Operated Vehicle (ROV), Yellow-Crab 2.0, was designed to identify the danger levels of large icebergs, identify invasive species of European Green Crab, and endure the various extremes of the polar circle.

Yellow-Crab 2.0 has been designed, developed, and tested in less than one year by a group of 9 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 WITROV 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.

Teamwork Project Management

WITROV is a university team from Wentworth Institute of Technology aimed at building ROVs for underwater research to address environmental concerns, including the 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 is in charge of the final design decisions within each three teams: Mechanical, Control, and Business Operations each led by a team lead, who is responsible for managing all company tasks assigned to that

team and reporting back to the CEO. 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.

WITROV 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 Click-Up, 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 2.0's development and team meeting times. Google Drive is the main storage website used by WITROV, 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 WITROV's success in the past, and the team continues to maintain this structure.

Schedule

The company organizes the project into five main stages. 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 2.0. Next is the "designing stage" which consists of the planning, prototyping, and manufacturing processes of assembling Yellow-Crab 2.0. 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 control team tests the vectors and controls of the ROV and adjusts values if needed, as well as 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.

Resources and Protocols

Mission objectives and solving day-to-day operational problems were managed through resources, procedures, and protocols. WITROV'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. WITROV 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 WITROV 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 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, WITROV 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

Yellow-Crab 2.0 is a compact, open-frame Explorer-class ROV designed to inspect iceberg keels, identify invasive European green crab populations, and operate reliably in the extreme conditions of the polar circle. The vehicle is built around two HDPE plates that enclose a cylindrical acrylic electronics housing, supported by 6061-T6 aluminum bars and driven by



eight Blue Robotics T200 thrusters for full multi-axis control. Its payload includes two complementary manipulators, an articulated Blue Robotics Subsea Gripper and a rigid pneumatic gripper, along with a paired-laser measurement system and a vision system capable of automated crab detection. Each subsystem was selected and sized to keep the ROV below 18 kg and within the 1 m × 1 m demonstration envelope, prioritizing low drag, maneuverability, and modularity so that components can be serviced or expanded with minimal disruption.

Planning and Design Process

The team follows a structured, iterative process that moves each subsystem through designing, simulating, manufacturing, testing, and iterating. Planning begins with a review of the previous ROV: team leads examine prior designs, identify the mechanical, electrical, and software issues that arose, and prioritize resolving those known problems before pursuing new features. Concepts are modeled in SolidWorks or KiCAD and evaluated against cost, manufacturability, weight, and mission requirements before committing to fabrication. Design decisions reflect deliberate, balanced trade-offs: HDPE and 6061-T6 aluminum were chosen for their light weight, corrosion resistance, and ease of in-house machining; the pneumatic gripper layout was selected over a more compact alternative because it offered a wider grasping range for a given cylinder stroke; and the bulky prior electronics enclosure was replaced with a smaller acrylic-tube design that is easier to waterproof and allows visual inspection of the internal electronics. Low-cost prototypes in 3D-printed PETG, wood, or acrylic are dry-fit and refined until tolerances are correct, minimizing wasted material and cost.

System Approach

WITROV treats Yellow-Crab 2.0 as a single integrated system rather than a collection of independent parts, and team leaders collaborated frequently to keep the mechanical, electrical, and software teams aligned. Adding tools and sensors to

the design, including the USB camera modules, the BNO085 IMU, the pressure and leak sensors, and the two manipulators, required constant communication across teams to jointly develop the mechanical mounting, the supporting electronics, and the control algorithms. Throughout the design stage, the mechanical and electrical designers convened with the software team to ensure the physical systems matched the software team's vision for completing mission tasks. A clear example is the new Orange Pi carrier board: the electrical team checked continuously with the software team, so the Orange Pi 5 Max was wired correctly and laid out to make software troubleshooting straightforward. This same integration runs throughout the vehicle. IMU feedback drives the PID heading control, the vision system uses the tether's existing Ethernet link for real-time crab detection, and the two grippers are mounted on separate planes so the Subsea Gripper's articulation can support arm-to-arm tasks such as the eDNA sensor handoff. Coordination took place at all-hands meetings, sub-team meetings, and, even more frequently, on the company's Discord channels.

Vehicle Structure

In developing this year's ROV, the team strategically mitigated for cost, size, and weight to meet competition requirements and optimize mission performance. When selecting materials for the frame, weight was the most significant factor considered, with the goal of maintaining the ROV's weight 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 contributes significantly to the ROV's overall lightweight nature. 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). 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 smaller, more compact ROV for improved maneuverability and task capabilities. The design of the ROV and its structural components were evaluated based on cost and manufacturability. For instance, the team assessed trade-offs between material strength and the cost of 3D-printing the arm components in metal. As a result, material stiffness and yield strength were optimized using a composite of FDM filament and carbon fibers. In contrast, the team also mitigated costs by using materials such as HDPE and 6061-T6 Aluminum stock, resulting in savings in shipping, handling, and manufacturing. Ultimately, these decisions reflect a strategic, thoughtful design approach that optimizes performance within defined cost, size, and weight constraints, enabling us to make informed trade-offs.

Material Selection

To make material decisions objectively rather than by intuition, the team evaluated candidate materials using a weighted design matrix that scored each option against four primary criteria: weight, cost, manufacturability, and corrosion resistance. Weight carried the greatest priority, reflecting the goal of keeping the vehicle at or below 18 kg, while corrosion resistance was essential given the ROV's continuous operation in fresh and salt water. Cost and manufacturability were weighted to favor materials the team could source affordably and fabricate in-house using its available CNC, lathe, and additive-manufacturing capabilities. Applying this matrix, HDPE was selected for the frame plates for its low density (0.926 g/cm^3), high strength-to-density ratio, corrosion resistance, and ease of CNC machining; 6061-T6 aluminum was chosen for the structural support bars and machined endcaps for its strength, light weight, and machinability on a lathe; and PETG was selected for 3D-printed add-ons such as mounts, brackets, and cable-management rails because of its high impact resistance, low water absorption, and favorable elasticity-to-rigidity ratio. Scoring the alternatives in a common framework allowed the team to compare trade-offs side by side and confirm that each material was the best balance

of performance and cost for its specific role rather than the strongest or cheapest option in isolation.

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 from two HDPE plates that enclose 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 the ROV were selected as the most ideal among three derivatives with different shapes and materials because of its low profile and open structure, which effectively reduce drag and improve 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 0.25 inches thick, were cut using a CNC router and chamfered as part of post-processing. Simultaneously, the aluminum rods were cut, turned, faced, and threaded on a lathe. On the other hand, the freedom of design and customization was enhanced through additive manufacturing to produce add-ons, including fixtures, mounts, brackets, clamps, and cable management rails. These components were printed in Polyethylene Terephthalate Glycol (PETG) at high resolution, with a layer height of 0.06 inches (0.001524 m), to enhance their strength and reduce water absorption. PETG is a material with high impact resistance and was selected as the most suitable because it offers a high ratio of elasticity to rigidity, as the parts are printed with 80% infill and a gyroid pattern.

Watertight Enclosure

Although the placement of the watertight electronics enclosure within the ROV frame has not changed significantly since the previous year, the enclosure itself has been replaced with an older model. Last year's enclosure, while convenient in its rectangular



construction and accessible lid, was bulky and unreliable. This enclosure's size limited the available mounting area and scope for tooling. These drawbacks, along with a failure of the main O-ring for the enclosure lid, led our team to replace it with a new, or rather, an old, enclosure. Despite its smaller size and less convenient shape, this enclosure, built from an acrylic tube and machined aluminum endcaps, is easier to waterproof and allows for visibility of the electronics held inside. With an approximate depth rating of 40 meters, this enclosure is more than up to the task.

Buoyancy and Ballasts

The ROV's buoyancy calculation is based on Archimedes' principle, which states that any submerged object experiences an upward buoyant force equal to the weight of the fluid it displaces. For a fully submerged vehicle, this force is fixed by the volume of water displaced: $F_b = \rho_{water} \cdot V \cdot g$, where ρ_{water} is the density of the surrounding water, V is the displaced volume, and g is gravitational acceleration. The vehicle's behavior in the water is governed by the ratio of this buoyant force to its weight, $W = m \cdot g$. When the vehicle's average density is below that of water, it rises and is considered practically submerged; when above, it sinks and is fully submerged; and when the two are equal, the forces cancel, and the ROV holds depth.

The objective is to be neutrally buoyant, producing a vehicle that is effectively weightless underwater. To minimize the load on the propulsion system, conserve power, improve fine depth control and hovering stability, and free the vertical thrusters to contribute to maneuvering rather than fighting buoyancy.

Buoyancy was evaluated based on four main components: the frame, the Blue Robotics manipulator arm, the pneumatic manipulator arm, and the acrylic electronics housing. We measured each component's mass and extracted its displaced

volume from the SolidWorks, then entered both values into an Excel model that automatically applies the buoyancy and density relationships. Building the analysis as a live spreadsheet to allowed us to update a single input and immediately see its effect on the entire vehicle, making design iteration fast and repeatable.

The model evaluates each component and the assembled system against fresh water with a density of 1000 kg/m^3 . For every component, computed density, buoyant force, and weight, and flags the body as fully submerged, partially submerged, or neutrally buoyant. The results showed that the assembled has a mass of 20.095 kg while displacing 22.66 L of water, equivalent to 22.66 kg of fresh water. Since the displaced water weighs more than the vehicle, the ROV is positively buoyant on its own, producing a net upward force of 25.88 N (a system density of 884 kg/m^3 , below the 1000 kg/m^3 of water). The two arms are individually dense and sink on their own, which partially offsets the strongly buoyant frame and the air-filled electronics housing, but the assembly of the total system floats.

To reach neutral buoyancy, the vehicle must be made denser to match the surrounding water. In Table 2, the exact correction for the total system is calculated. Holding the displaced volume constant, the assembled ROV requires an additional 2,638.6 g of ballast mass, corresponding to the 25.88 N of net buoyant force that must be canceled. We satisfied most of the mass requirement with functional mass, tools, sensors, cameras, and the manipulator hardware, and trimmed the remainder with discrete ballast weights.



COMPONENT BUOYANCY ANALYSIS

Component	Mass	Volume	Density	Density H ₂ O	Buoyancy	Weight	State	Correction	δ Density	δ Force
	g	mm ³	kg/m ³	kg/m ³	N	N			kg/m ³	N
Frame	13035	14,320,800	910.21	1,000	140.49	127.87	Partially Submerged	Increase Mass	89.79	12.61
Blue Robotics Arm	1044	574,059	1818.63	1,000	5.63	10.24	Fully Submerged	Increase Volume	818.63	4.61
Pneumatic Arm	743	365,163	2034.71	1,000	3.58	7.29	Fully Submerged	Increase Volume	1034.71	3.71
Electronics Housing	5273	7,064,517	746.41	1,000	69.30	51.73	Partially Submerged	Increase Mass	253.59	17.57
TOTAL SYSTEM	20095.01	22,324,539	900.13	1,000	219.00	197.13	Partially Submerged	Increase Mass	99.87	21.87

Table 1: ROV Buoyancy Analysis

NEUTRAL BUOYANCY CORRECTION

CURRENT 2026 SYSTEM		
Total mass	20095.01	g
Total volume	22,324,539	mm ³
System density	900.13	kg/m ³
Water density	1,000	kg/m ³
Buoyancy force	219.00	N
Weight	197.13	N
Net force (Buoy - Weight)	21.87	N
State	Partially Submerged	

Mass to ADD for Neutral	2229.53	g
Volume to REMOVE for Neutral	2,229,529	mm ³
Equivalent Ballast Force	21.87	N

Table 2: Neutral Buoyancy Correction

Control Systems

The main goal for the team's control systems involving hardware, firmware, and software was to redesign and develop our previous systems to be more user-friendly. For the electronics; we streamlined our connector types to 2 main connector families (XT-60 and Molex micro fit), we added current sensing to the power distribution and incorporated a better cable management system. For the firmware, we created tutorials for development and added launch files/ scripts to make testing easier. Lastly, to lower the complexity of piloting, we developed our company's first user interface, complete with fixed camera views and interactive buttons.

To accomplish this goal, each member of the control team was assigned a section of the control system via the "ClickUp" control team task board. Members were provided with access to previous work from

previous years, and an overview of what was expected. Control team meetings were then used to gauge progress and to ask for assistance. From there, members conducted research independently and worked diligently to adapt the control systems as the specific needs changed over the year.

Electronics

WITROV is proud of its hardware systems which include 5 fully custom PCBs designed entirely by its members in the open source KiCAD software. Each board that is described below is manufactured by JLCPCB and shipped to Massachusetts for the team to assemble. The excellent workmanship displayed in the assemblies is the direct result of the countless soldering workshops taught by WITROV.

Power Distribution

To create a user-friendly power distribution system for Yellow-Crab 2.0, the team needed to identify the power constraints and develop a comprehensive power budget. Table 3 below identifies the losses of power along the tether as well as the current(I) constraints of the electronic speed controllers (ESCs) that drive each thruster.



ROV POWER CONSTRAINTS	
Supplied Voltage(V):	48
Supplied Current (A):	30
Supplied Power (W):	1440
Tether Resistance (Ohm):	0.03
Actual ROV Supplied Voltage (V):	47.1
Actual ROV Supplied Power (W):	1413
Thruster Voltage (W):	12
Max ESC Current x1 (W):	45
Max Power TCB x1 (W):	540
Max Power Total Thruster Power (W):	1080

Table 3: ROV Power Specifications

With the absolute maximum power for the thrusters identified, the team then analyzed if the remaining power was enough for the rest of the sensors and tools.

Remaining Power (W):			333
Components:	Voltage (V)	Max Current (A)	Power (W)
Orange Pi 5 MAX	5	5	25
BN008 (3.3V)	5	0.066	0.33
2x High Torq Servo	5	4.08	20.4
1x High Speed Servo	5	3.24	16.2
Depth Sensor	5	0.00125	0.00625
3x Pi Zero W (1.5W)	5	0.9	4.5
BitBlox Switch	5	0.14	0.7
Solenoid Valve	12	0.33	4
BlueRobotics Gripper	12	6	72
Total Power Cost			143.13625

Table 4: Remaining Power Budget

5V Bus Power Total	67.13625
12V Bus Power Total	76
Remaining Power:	189.86375

Table 5: Control Power Bus Identification

With all the constraints and loads identified, the team selected specific converters to handle the needs of the control system.

The thruster power bus consists of two identical printed circuit boards that convert 48V from the surface station into a usable 12V for the escs and thrusters. The thruster power distribution board consists of a 48V to 12V DC-DC switching regulator and supporting circuits such as current sensing, electromagnetic interference filtering, and indicator LEDs. The power converter that was chosen was the **PKM4613NHPIHS**, which was selected for its availability, meaning that stock is currently held and

manufacturing is still ongoing, as well as it meeting the power requirements. Thought the escs can only take 540 W each, each of these converters can supply 600 W. To ensure the safety of the escs, firmware limitations needed to be developed.

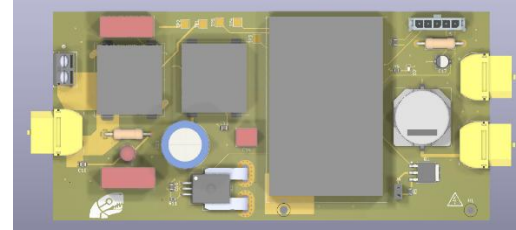


Figure 2: Thruster Power Board (TPB)

To supply power to the remaining buses a singular utility power board was designed. This board incorporates the same circuit as the thruster power board for the 12V rail but adds a 12V-5V switching regulator in series to produce the desired 5Vs. The buck converter chose for this was the **UWE-5/15-Q12P-C** which was chosen for its 75W power output, which is enough for the 67 W maximum 5V load. This board also includes an N-type mosfet at one of the connectors for controlling the pneumatic solenoid used in Yellow-Crab 2.0's fluid power.

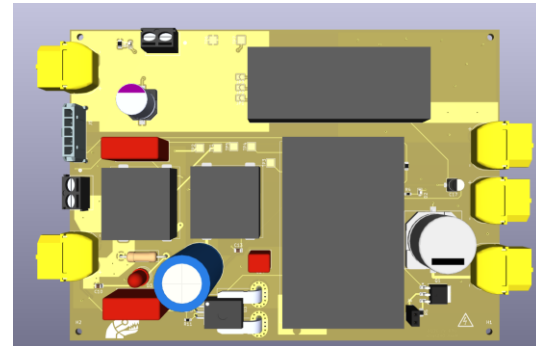


Figure 1: Utility Power Board (UPB)

Thruster Control

Yellow-Crab 2.0 is equipped with 8 Blue Robotics T200 thrusters taken from the company's 2025 build. 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 pulse-width modulated signals (PWM) 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 2.0's ESCs receive are produced by a PWM driver IC called the PCA9685. Yellow-Crab 2.0s 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 the typical 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. Through firmware limits, the TCB is protected from a catastrophic error. The max throttle of each T200 thruster at 12V is 17A, and our system is limited to 11A, meaning the Yellow-Crab 2.0 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 2.0 can hypothetically produce 2.37 kgf of forward thrust and 1.86 kgf of reverse thrust per thruster.

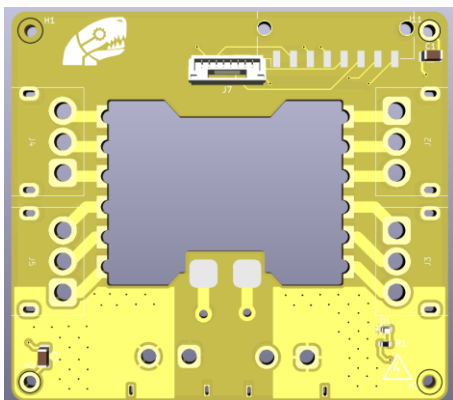


Figure 4: Thruster Control Board (TCB)

Hardware Control and Sensing

For Yellow Crab, WITROV has chosen an Orange Pi 5 Max, for its high processing power and speed. This allows Yellow-Crab 2.0 to boot and carry out operations quick, helping the team to complete mission tasks within a 15-minute period. To accommodate this new device, the control systems team created an expansion board that delivers power to the Orange Pi 5, connects sensors such as; IMU(BNO085), pressure sensor (Bar30), leak sensors (custom), PWM driver (PCA9685), ethernet switch (Switchblox), and the Analog to digital converter for the current sensors.

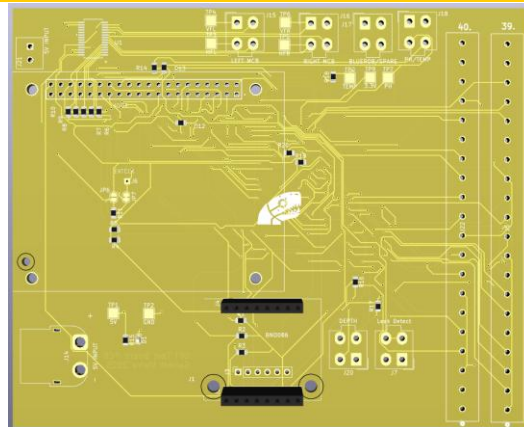


Figure 5: OPi Carrier Board (OPi Hat)

Electronics Assembly

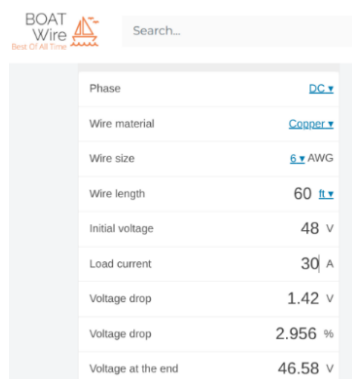
The Yellow-Crab 2.0 electronics are mounted into the watertight enclosure using a 3D mount that has been evolving with ongoing changes. The biggest issue with this part of the control systems has been the size of the PCBs, but the efficient use of volume has been a key part of the development.

Tether

This competition season, the tether had to be completely redesigned for the following reasons: to supply more voltage to our on-board electrical components; include the new pneumatic hose; and allow our ROV to operate in the newer, larger pools. Now, there are 1889.76 cm of 6/2 AWG duplex wire that will theoretically supply almost 47 volts at our desired current load of 30 amps, according to hand calculations using the physical properties of copper wire and an online calculator from the vendor we bought the wire from. To allow data and real-time Ethernet connection between the surface laptop and the ROV, another longer Blue Robotics 4-pair twisted Ethernet cable was purchased. Lastly, there is 1889.76 cm of pneumatic tubing to supply the new Blue Robotics pneumatic gripper arm. All of this is wrapped in a 1.9 cm PET braided sleeve to keep all the cables and hoses bundled together in an organized fashion, and to prevent any possible tear or rip damage to any tether element. For the new strain relief module, a less traditional wire support strain relief was selected. This decision mostly stemmed from the ease of inclusion with our new cylinder electronics housing, as it can be very easily attached by simply adding hooks or latches to



the cylinder. In addition, a traditional Kellems-style strain relief would not be compatible with our current tether penetrator.



BOAT Wire Online Calculator	
Phase	DC
Wire material	Copper
Wire size	6 AWG
Wire length	60 ft
Initial voltage	48 V
Load current	30 A
Voltage drop	1.42 V
Voltage drop	2.956 %
Voltage at the end	46.58 V

Figure 6: Online Calculator

```
Resistance of Tether:
.03 * 48 V = 1.44 V lost by desired 3% tolerance
1.44 V / 30 A = resistance of .048 Ω for round trip
.048 Ω / 2 = .024 Ω resistance per duplex side

"Face" Area of Wire:
R=ρ(L/a)
*Assume copper resistivity for rho and 18 m*
.024 = (1.72E-8)(18/a)
a = 1.72E-8(18)/.024
a = 1.29e-6 m^2 = 1.29e-5 mm^2

Wire Gauge:
12.9mm corresponds most accurately to 6 AWG, with ampacity bump up as well
```

Figure 7: Screenshot of Calculations

Surface Station

The surface station setup for this year remains largely unchanged, except for the integration of one of our old Lenovo ThinkPads to be the dedicated surface station laptop. This computer runs Ubuntu 24.04 LTS for easy terminal access and direct support for ROS2 Jazzy. All of the WITROV ROS2 code was downloaded, setup, and built to replicate that of our previous laptop.

This transition simplifies booting up the ROV computer systems and solidifies our existing, working system. Ubuntu and Linux gives us better compatibility with our OrangePi and Raspberry Pis. Previously, a PC dual-booting Ubuntu and Windows was used, which in itself is insecure, creating a risk of losing all of our data.

Software

The main computer used in Yellow-Crab 2.0 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 of Linux allows for easy compatibility with ROS2, which is used for all controls and communication between the surface station operators and Yellow-Crab 2.0. 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.

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. With our 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, following the ROS master update as the surface.

ROS2 Node Structure

The software architecture is divided into multiple ROS2 nodes, each responsible for a dedicated subsystem. This modular design simplifies debugging, improves reliability, and allows components to continue operating independently if another subsystem fails.

The thruster control node is responsible for motor output and vehicle movement. It subscribes to movement commands from the surface station and converts desired translational and rotational motion into PWM signals for the ESCs controlling the thrusters. The node also implements safety features



such as output clamping and emergency stop handling to prevent hardware damage.

The BNO085 IMU node communicates with the onboard orientation sensor through the I2C bus. This node continuously publishes orientation, angular velocity, and acceleration data to ROS2 topics. The data from the IMU is used by the control system for vehicle stabilization and closed loop heading control. To provide telemetry visualization and debugging tools, a ROS bridge node is implemented for communication with Foxglove Studio. This node converts ROS2 messages into WebSocket-compatible data streams, allowing real-time monitoring of sensor data, thruster outputs, and system diagnostics from the surface station. Foxglove is also used during development for data logging and troubleshooting.

The communication structure of the ROS2 system allows all nodes to exchange information asynchronously while maintaining deterministic control performance. This architecture also makes future expansion easier, including the addition of autonomous navigation, computer vision, and advanced sensor fusion systems.

PID Control System

Yellow-Crab 2.0 uses PID (Proportional-Integral-Derivative) control algorithms to stabilize vehicle motion and maintain precise maneuverability underwater. PID control is primarily applied to heading stabilization and rotational control of the ROV.

The proportional term provides immediate corrective output based on current error, allowing the system to react quickly to disturbances. The integral term compensates for accumulated steady-state error caused by underwater currents or thruster imbalance. The derivative term predicts future errors by measuring the rate of change, reducing overshoot and improving system stability.

Sensor feedback from the BNO085 IMU is continuously processed by the control node to determine the ROV's current orientation. The PID controller compares the measured orientation to the desired target heading and computes correction values that are distributed to the thruster control node.

This closed-loop system enables stable and responsive control during operation.

PID parameters are tuned experimentally in water-testing environments to achieve smooth motion while minimizing oscillation and overshoot. The modular ROS2 architecture allows PID constants and control logic to be adjusted dynamically during testing without modifying the entire software stack.

Propulsion

The propulsion system is made up of eight T200 Blue Robotics thrusters allowing for a full 9 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 completing the photosphere tasks as well. 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 $\tau = T(a)f$ where τ is a vector of net thrust output, T is a matrix of weights that tie each thruster output to the linear or angular axes that they affect, and f is a vector of individual thrust outputs. We can solve for the thruster outputs f by calculating the complete orthogonal decomposition of 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.

Payload and Tools

Cameras

The placement of cameras and the methodology behind it remains largely the same as for the previous



year, with the priority being visibility of the gripper(s), the floor, and obstacles around the ROV. This is achieved via a pair of cameras: one mounted at the front of the ROV, just below the top frame plate and angled slightly downwards toward the arms, and another mounted beneath the ROV, pointing directly downwards for maximum field of view. The biggest changes from the previous year's camera array are the camera type, the camera housing, and where computation occurs. While the previous year's cameras were mounted directly to PCB stacks for ethernet connection and required bulky housings, this year's cameras are small USB cameras, requiring much smaller housings and allowing computation to be completed inside the main enclosure.

Pivoting from the mechanical side of the cameras to the software side, one of the Pi Zero cameras is now equipped to automatically detect the crab images in accordance with Task 2.1. This is achieved by first capitalizing on the existing ethernet connection between the WITROV and the surface station PC by creating a socket server connection. The existing custom low latency C++ executable file on the Pi Zero streams video frames as JPEG images through the socket server. A new C++ executable file on the surface station PC is linked with that Pi Zero file and takes the video frames and runs them through a custom ONNX image detection model for real-time crab detection, with a simple counting function with terminal output. This model was trained on over 1200 images of the three crabs provided by MATE from a Raspberry Pi 4B to ensure accuracy, as well as about sixty images of each after the internet.

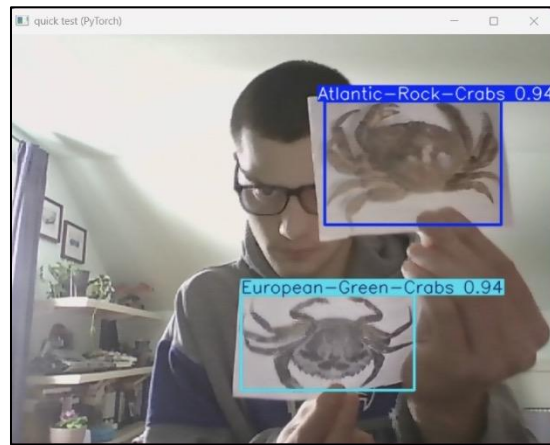


Figure 8: Live Crab Detection Proof of Concept

Manipulators

WITROV's primary goals for the manipulators were to expand on prior functionality, offboard fine motion control from thrusters, and perform the broadest array of tasks without dedicated tooling. With the success of pneumatic grippers utilized by other MATE ROV companies, two basic layouts were considered for a new pneumatic gripper, based on the Blue Robotics Newton Subsea Gripper (Layout 1) and Case Western's 2025 grippers (Layout 2).

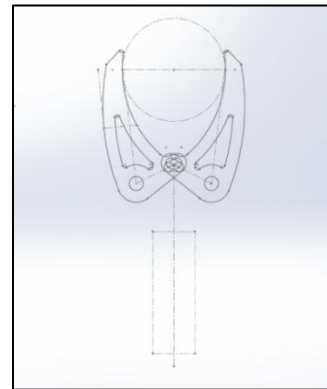


Figure 9: Pneumatic Gripper Layout 1

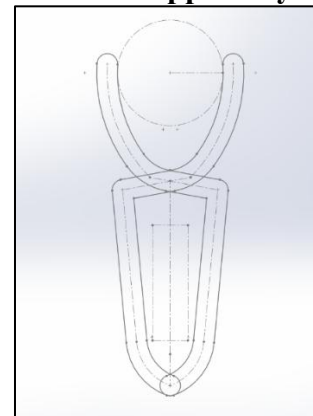


Figure 10: Pneumatic Gripper Layout 2



Although Layout 1 would have made for a more compact gripper, Layout 2 was chosen for its wider range of gripping sizes for a given cylinder stroke.

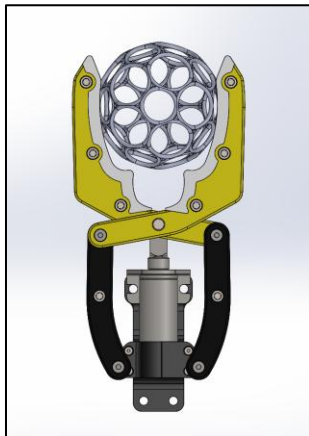


Figure 12: Final Pneumatic Gripper Assembly

The final pneumatic gripper is comprised of flat links, cut from the same HDPE sheeting used for the frame, shoulder bolts for pins, and a single-acting pneumatic cylinder as the driving actuator. The gripper profile is the result of an iterative design process which maximized the resulting grip forces imposed on PVC pipes of various sizes while ensuring the gripper was capable of grasping anything from ½” to 3” nominal PVC pipe, especially useful for collecting coral species and basket stars. The inside profiles of the gripper are coated in silicone rubber to maximize friction with PVC pipes. Although an articulated form of this arm was considered, the pneumatic gripper benefits from a rigid support structure and can be used as a basic “quick-grab” gripper, while the Blue Robotics Newton Subsea Gripper can be articulated for tasks requiring finer control.

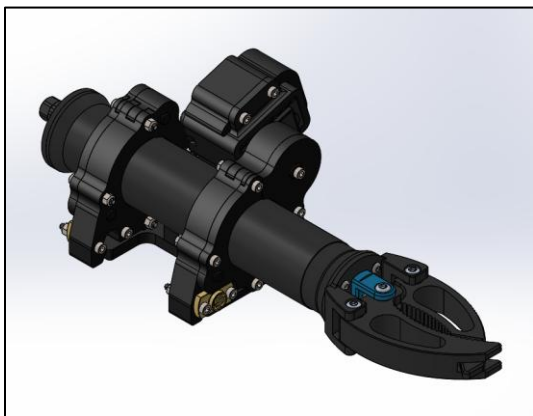


Figure 11: BR Gripper Wrist Rotation Assembly

Building off the previous year’s wrist-rotation system for the Subsea Gripper, two more degrees of freedom were prioritized: extension/retraction and elbow rotation, with each degree of freedom forming a layer of the final assembly. These degrees of freedom allow the arm to move the gripper to any location within a large arc and reduce the need to utilize thrusters for fine adjustment. The wrist rotation system for 2026 was designed to be compact while maintaining maintenance capabilities and expanding rotation to 3 full rotations for removal of biofouling from the observatory camera. This is achieved via a 5-turn servo engaging with a ring gear directly attached to the gripper and a series of planetary gears to stabilize the rotation.

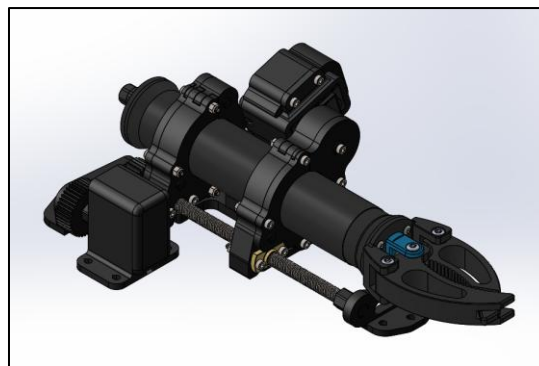


Figure 13: BR Gripper Linear Motion Assembly

The second layer of the system is the linear motion system, driven by a pair of lead screws: one driven by another 5-turn servo and engaging with the wrist rotation assembly, and the other acting as a guide rail to maintain stability. This system provides over 50mm of travel, allowing for fine positional control and payload manipulation.

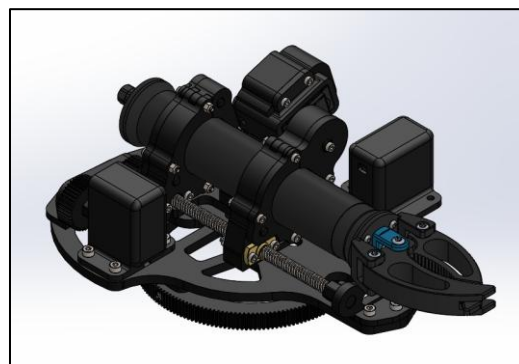


Figure 14: BR Gripper “Turntable” Assembly



The final layer of the Blue Robotics gripper articulation system is the elbow rotation, referred to as the “turntable” due to its resemblance to a record player or lazy-Susan. This layer acts as a mounting plate for the previous layers, fixes the entire assembly to the frame, and allows for rotation across the majority of the front of the ROV with an angular range of 55 degrees.

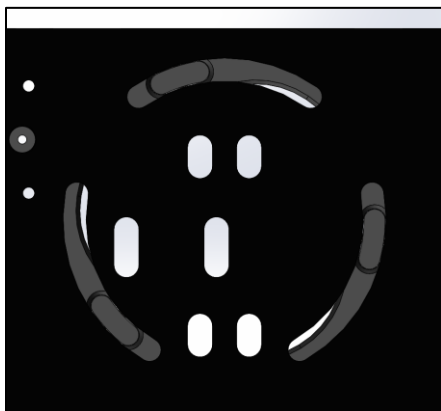


Figure 15: BR Gripper “Turntable” Slots

To reduce assembly bulk and weight, rotation is achieved by incorporating tabs into the turntable plate and slots into the frame itself, thus eliminating the need for a bearing or axle.

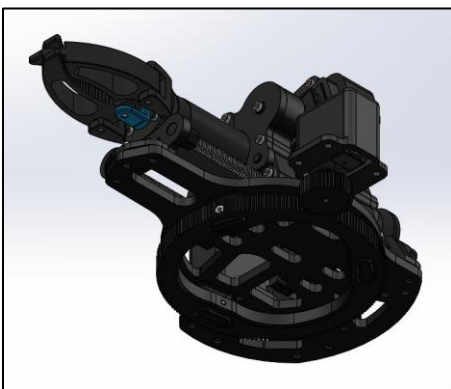


Figure 16: BR Gripper “Turntable” Gearing

By mounting a ring gear to the opposite side of the frame, the entire system is captured by the same mechanism which allows for the rotation. This large ring gear is driven by a much smaller gear, delivering maximum end-effector force (~30 N) with a relatively small servo.

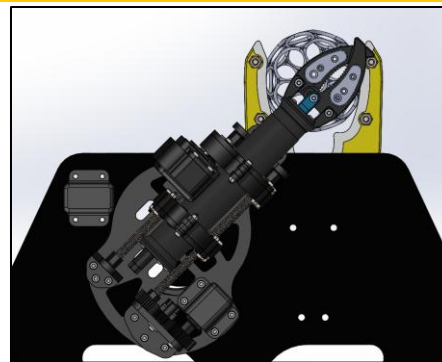


Figure 17: Arm Placement and Interaction

These two grippers are mounted on different planes so that the elbow rotation of the Subsea Gripper can be used for arm-arm interactions, including payload handoffs or delivery tasks, such as connecting the new eDNA sensor to the observatory.

Laser systems

To take accurate measurements in an underwater environment at various scales, Yellow-Crab 2.0 is equipped with a pair of scuba lasers mounted directly to the frame and directed parallel to the main camera view. These lasers are arranged in a parallel formation at a fixed distance from each other to create a reference scale in the camera view. To measure an object, Yellow-Crab 2.0 can rotate to direct the lasers so that they terminate on the object. Using the position of the laser dots in the camera view, accurate measurements of the object in question can be autonomously calculated using the pixel to mm ratio. The lasers utilized by Yellow Crab are class IIIa red lasers with a wavelength of 635 nm, an output power less than 5 mW, and a depth rating of 100 meters. To ensure the lasers terminate at a safe distance above water, a trapdoor-like plate hangs just in front of the lasers. When entering the water, buoyancy foam provides the force necessary to raise the trapdoor until it is parallel with the frame, where it is secured in place by a small magnet.

Task specifications

The laser systems were developed to measure the keel of the iceberg; the crab identification model was developed to identify populations of European green crab.



Build vs Buy, New vs Reused

WITROV 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, WITROV 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.

Safety

Personal Safety

Safety is WITROV's top priority, ensuring the well-being of all members and those around them. To minimize the risk of injury, WITROV has implemented comprehensive safety features and procedures for building, operating, and transporting the ROV. WITOV 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.

Recognizing the potential hazards of improper tool and equipment use, WITROV 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.

Equipment Safety

The primary safety device in place on the WITROV is the new wire support strain relief. This keeps everything on the ROV safe, as it prevents the tether from bending and contorting in such a way that the wires may tear. A shortened power tether would damage the ROV inconceivably and endanger everyone around.

To enhance safety and prevent any contact with the T200 thrusters, thruster guards adhering to IP-20 standards have been installed. 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. By integrating these safety measures, WITROV not only prioritizes the protection of its members and nearby spectators



but also ensures a structured and secure working atmosphere.

Operational Safety

To keep everyone safe while the ROV is deployed, all members of the WITROV crew have been briefed on all our JSEA procedures. Everyone is fully aware of the risks that are incurred by participating in the operation of the ROV.

Testing & Analysis

WITROV'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 sub team at WITROV 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.

There are instances when designs proceed to the manufacturing and testing phases but do not perform as expected or contain unnecessary features. For example, the teams, first batch of PCBs did not fit properly in the watertight enclosure. Adjustments were then made to optimize the size and ensure the board operates as intended, effectively minimizing wasted space.

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 test ensures that the electrical components inside the housing remain safe from water exposure.

Troubleshooting

Troubleshooting is also an important process that WITROV 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. WITROV 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 18, 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 2.0 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.



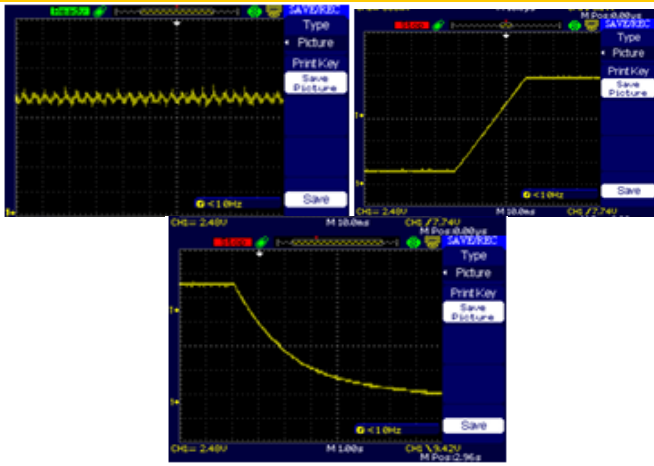


Figure 18: Oscilloscope results with and without a smoothing capacitor

Accounting

WITROV 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. The 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 Appendix B for details.

Acknowledgements

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- Springfield Central High School for allowing us to present to their students
- Chris Thierauf for keeping us in contact with WITROV alumni and providing advice
- Professor James McCusker for purchasing 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 \$3,500
- 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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Appendix A: 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.

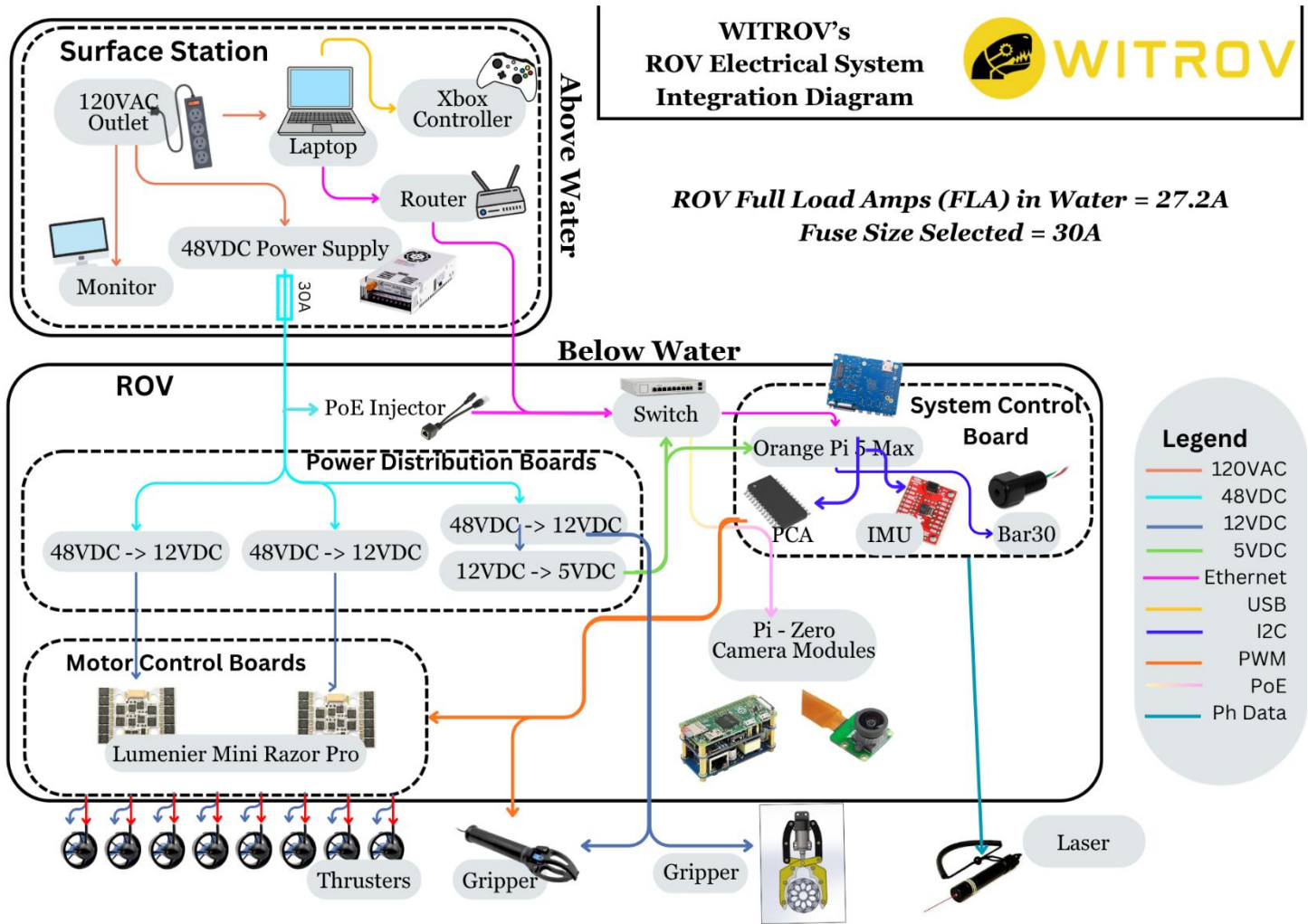


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Cost Total	\$3,314.49
Budget Left	-\$814.49

21

Appendix C: ROV SID



Appendix D: Pneumatics SID



Pneumatic SID

Operating Pressure: 40 psi

Required Pressure Rating: 100 psi

