WUROV
Wentworth Underwater Remotely Operated Vehicle

Wentworth Institute of Technology
Boston, Massachusetts, United States

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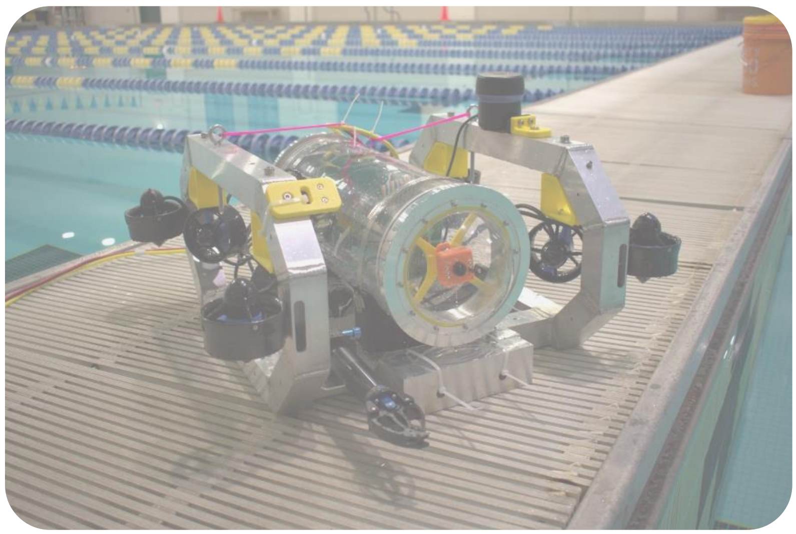

MATE ROV COMPETITION

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. Colossus Titan is WUROV's newest Remotely Operated Vehicle (ROV) built to collect and deliver data, assist in the deployment of coastal arrays, assist in the deployment of Science Monitoring And Reliable Telecommunications (SMART) Cables to collect and transmit temperature, pressure, and seismic acceleration data, and also, assist in healing diseased coral and promote healthy coral ecosystems using probiotic injection devices and underwater photogrammetry algorithms to assist in the study of coral reefs and their effects in their environments.

Colossus Titan has been designed, developed, and tested in less than one year by a group of twenty-one students. Throughout the process, quality and safety standards set by the industry have been of high priority to ensure a ROV capable of solving a multitude of challenges. The system is designed with versatile mechanisms and expendable electronics to allow modularity to the platform such that the ROV can resist environments for even further research purposes in salt water.

This technical report outlines the engineering process that the WUROV team 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 Team Members

Teamwork

Company

WUROV is a university team at 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 team has had a flux of new and old members joining to contribute to the mission. The company is composed of three teams: Electrical, Mechanical, and Software, each led by a team lead responsible for managing all tasks within that team. 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 the students.

Figure 2. Teamwork throughout pool testing.

WUROV places a high priority in the learning process and encourages collaboration between cross teams and team members. Returning students of the team 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 team organizes the project in four main stages as in Figure 2. The recruitment stage is the time period after the competition where the team reflects on previous design choices, design strengths and weaknesses and brainstorms ideas to further research into new innovative approaches for the main body of the new ROV. The next stage follows with the designing stage that consists of the planning prototyping and manufacturing process where the ROV is assembled. The testing stage follows with mechanical, electrical, and software tests to ensure proper operation in the pool. Lastly, the competition stage follows with the completion of the ROV by documenting all aspects of the design process and sharing the work with others in various competitions and presentations.

Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Recruitment Stage						**Testing Stage**					
Company Onboarding Goal Setting Research Brainstorming						Electronic boards Programming Water tight seal Pool testing Buoyancy/balance					
		Designing Stage							**Competition Stage**		
		3D Modeling/KiCAD Material/component decisions Revision of design Ordering Materials Manufacturing							Qualification Documentation Aesthetic Touches Additional tools and sensors Ship ROV		

Figure 2. Project Schedule

Resources and Procedures

Mission objectives are met by creating a schedule of building an ROV much earlier than when the mission objectives are posted. These objectives are met by beginning a design of an ROV with the idea of modularity of various sensors and modules that can attach to the frame of the body and ensuring enough open slots of modularity in electronics so that design changes can be easy to implement. In order to do this, an ROV is initially designed to be able to successfully implement waterproofing of electronics, drive capability, and one or more camera sensors. The design is then later edited with the priority of mission objectives. Resources are split into two main purchases of the ROV drive system consisting of a body frame and cameras and a second purchase consisting of pool props for emulating real tasks, and various manipulators, motors, and sensors that can be added to the design. This approach allows the team to operate as planned through the project schedule in the Figure above.

Design Rationale

Overview

WUROV's previous ROV designs act as an example of strengths and weaknesses that can provide a great deal of information leading in the new vehicle. Last 2023 MATE ROV Competition was the first competition of the new WUROV team building an ROV. The most successful implementations from last year's design were the modular electronics that allowed for easier changeability of sensors and modules as well as easier time of troubleshooting problems. However, the team did not find the main body frame a successive approach as the drag created by two side panels did not allow for great maneuverability in the controls. This year the Colossus Titan took those into account and also included better vision, better control algorithms and ROV stability, quicker maneuverability, more efficient power distribution, and a new frame design whose large size led to the name of the ROV.

Figure 3. The Colossus Titan Assembly for 2024.

Decisions on Design

The approach taken this year was one where the team could implement a main body frame that could reduce the water drag created by the plastic sheets in the previous ROV. A main body frame with open water flow from all sides was an approach that greatly assisted in the calculations implemented through the PID algorithms for stability and maneuverability. The reduction of water drag made these implementations much more accurate. The success in the electronics from the previous year led the electrical team to decide on a similar approach to follow the modularity of sensors from last year. Due to reduction of speeds due to USB protocol the team also decided to upgrade the main controller from a Raspberry pi to a Jetson nano that allows for much higher data transfer speeds for the camera feed. To allow for higher functionality, a real sense camera was also added in the front of the ROV to create a strong set of sensors with minimal failure points and great functionality.

Figure 4. Photos of team prototypping new frame ideas for the 2024 season.

Problem Solving

Decisions based on design were made during both team meetings and company 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. Company meetings are meetings between 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 in a democratic nature throughout these meetings. In any sight of different approaches, team members would breakdown each approach on the board and decide on the best option by voting at the end of each meeting. All ideas were taken into account to evaluate alternatives appropriately to ensure a great result on the specific goal.

Figure 5. Decision and planning meeting

Systems Approach

Team leaders consulted with one another often to create a balanced system approach. Due to various sensors added into the new system such as the real sense, jetson nano, pressure sensors, blue robotics gripper, the electrical team and software team had to be in constant communication with one another to test various electronic circuits and algorithms. The mechanical team consulted with the software team also to ensure proper location of sensors, camera angles, and thruster configurations in order to appropriately create a working system.

ROV Design

Mechanical Design

Structure

The size of the ROV was determined in a new approach this year by creating an electronic assembly first and approaching the overall structure of the frame to support the size of those electronics. Due to the change of the main control unit from a Rasp Pi to a Jetson Nano, the electronics increased the main size of the acrylic round tube housing to 20.3 cm. The team decided to test this approach for this year’s competition and during the testing phase, it was found that the buoyancy forces and weight of the ROV would both greatly increase as a result. By trading off more room for the electronics, the size, and the weight of the ROV increased also. Later, the large acrylic tube has allowed us to be even more modular than before having allowed for various electronic prototypes to control the ROV until a final conclusion stack of electronic was created. As a new team, a larger ROV allows for greater room for error and easier modifications compared to a smaller design that can be hard to change.

Frame

One of the issues of last year's ROV was the instability of the frame when moving in the pool. The team chose to replace the HDPE frame with a stronger material such as Aluminum 6061. The frame for Colossal Titan is made entirely of 6061 Aluminum box tubes. This material was chosen for its low density, resistance to corrosion, strength, ease of manufacturing, and weldability. Using our university's manufacturing lab, members of the mechanical team were able to drill the needed mounting holes and cut bends for welding the side walls. All the aluminum tubes seen on the frame were expertly tig welded together by WUROV. The frame supports all components of the ROV, including the electronics housing, propellers, sonar, and the gripper via 316 stainless steel hardware. Stainless steel was the best possible material due to its resistance to corrosion in water.

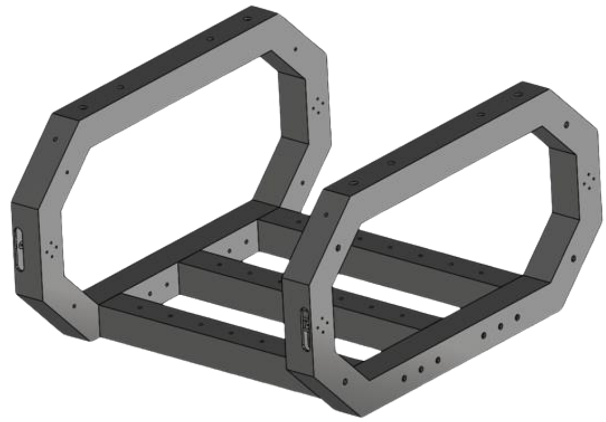


Figure 6: Perspective View of Aluminum

Electronics Housing

The design used to house the electronics of the ROV consists of a 20.3 cm. outer diameter and 19.1 cm. inner diameter, 45.7 cm long acrylic cylinder enclosed by two 6061 aluminum end caps, and either an acrylic dome or flat acrylic disk depending on programming preferences. The two end caps used for the housing were shaped individually on a lathe from a round stock of aluminum, including the glands for the 5 O-ring seals. Subsequently, a drill press was used for the penetrator holes and bolt holes for mounting supports, cameras, and the dome/disk. In the past, WUROV epoxied one of the endcaps directly to the acrylic. Now, both end caps are designed to be removable from the housing to make it easier to input cameras / other modules to the electronics and to allow the team to reuse the acrylic tube. On the inside of what is known as the "dome cap" are bolt holes for mounting a camera that can see directly out of the housing. This was incredibly useful as it minimized the number of cameras that needed waterproof cases. The other end cap is known as the "tether cap". The tether cap is dedicated to mounting the electronic supports and for all incoming wires including the tether connections. In total, there are 26 holes in the back of the tether cap, one being the vacuum test port, 2 for ethernet and power, and the rest are for any cameras or tools used on the ROV. The cylinder is secured to the frame of the ROV with two stainless steel straps and two PLA mounts that keep the housing horizontally and vertically centered, keeping the center of mass near the center of the ROV.

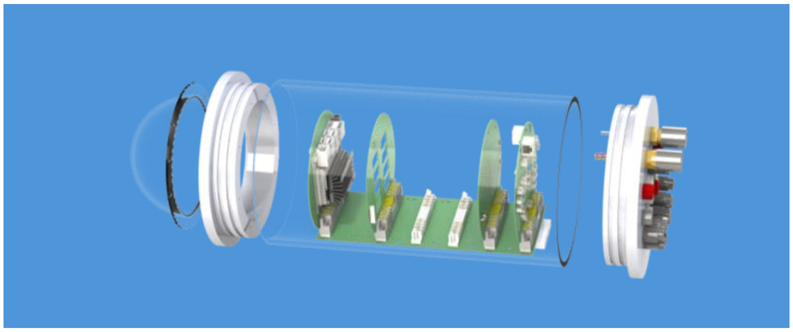


Figure 7. Blown-up View of the Electronics Housing

Propeller Configuration

Eight T200 Blue Robotics propellers make up the ROV's propulsion system design to allow for smooth and effortless movement. All propellers have been mounted to the 6061 Aluminum frame. The propellers mounted in 45-degree angles from the horizontal of the frame are utilized for cartesian xy-movements and yaw rotation. The propellers pointing downwards are utilized for z-axis movement along with roll and pitch rotations. The configuration of the propellers is symmetric, allowing for more prompt calculations of force and velocity vectors on the PID control loop. All eight of the thrusters are controlled by an Xbox controller at the control station.

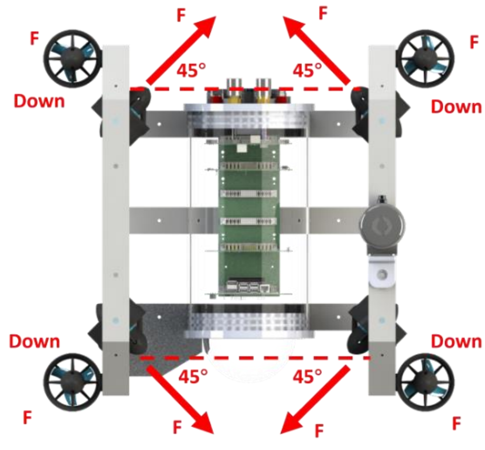


Figure 8: Propeller Configuration Diagram

Buoyancy

Using Archimedes' principle and density calculations using SolidWorks, the team accurately predicted the buoyancy and center of mass of the ROV before it was put into the water for testing. Using these calculations, the team discovered that the ROV was positively buoyant on its own. This saved money as buoyancy foam was not needed. All that was necessary to reach neutral buoyancy was to add mass to the ROV in the form of tools/sensors or weights. Through multiple tests in the pool, we were eventually able to add weight in the correct positions to achieve a balanced and neutrally buoyant ROV, limiting the load on our propulsion system.

	Mass g	Volume mm^3	Density kg/m^3	Desity of H_2O kg/m^3	Buoyancy N	Weight of Object N	State
Frame	5623.14	2082643.54	2700.001	1000	20.431	55.163	Fully Submerged
Tube (Acrlic)	1704.45	16737916.14	101.832	1000	164.199	16.721	Partially Submerged
Total System	21188.33333	18944842.68	1118.422	1000	185.849	207.858	Fully 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	3540496.46	5623140			1000	55.163	Neutrally Buoyant
Tube (Acrlic)	192			15033.46614	16737.91614	1000	16.721	Neutrally Buoyant
Total System	193	2243490.65	21188333.33			1000	207.858	Neutrally Buoyant

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

Payload/gripper

WUROV's gripper tool in last year's competition was a major weakness that the team set out on improving with this ROV. To do so, the team opted to purchase the Blue Robotics Newton Subsea Gripper and focus our efforts on perfecting our maneuverability, returning to the issue in the future. Having such a reliable tool at our disposal has been beyond helpful. Instead of having to focus effort on fully waterproofing our motors and reinforcing the arm to be able to lift the props, we have been able to avoid these issues and can accomplish most of the tasks with this gripper. Additionally, we plan on adding a secondary tool for tasks involving smart cables and for turning the valve on the irrigation tank.

Figure 9. Blue Robotics Gripper

Electrical System

Modular Printed Circuit Boards (PCBs)

The main connection between all the electronics is the backplane. The backplane of the ROV is a long-printed circuit board (PCB) with multiple female ports to allow for the modular installation of multiple PCBs. Each board has its own functionality. The ingenuity of this design allows for "plug and play" of different modules for mission adaptability and eases troubleshooting procedures. The anatomy of a backplane connector consists of three ground buses, three 12V buses, one 5V bus, and a General-Purpose Input Output (GPIO) pinout for the use of up to 40 different GPIO signals. With a capacity of up to six PCB modules, these connectors provide our systems with a modular, stable, and secure connection to the modules, while simultaneously providing power and data.

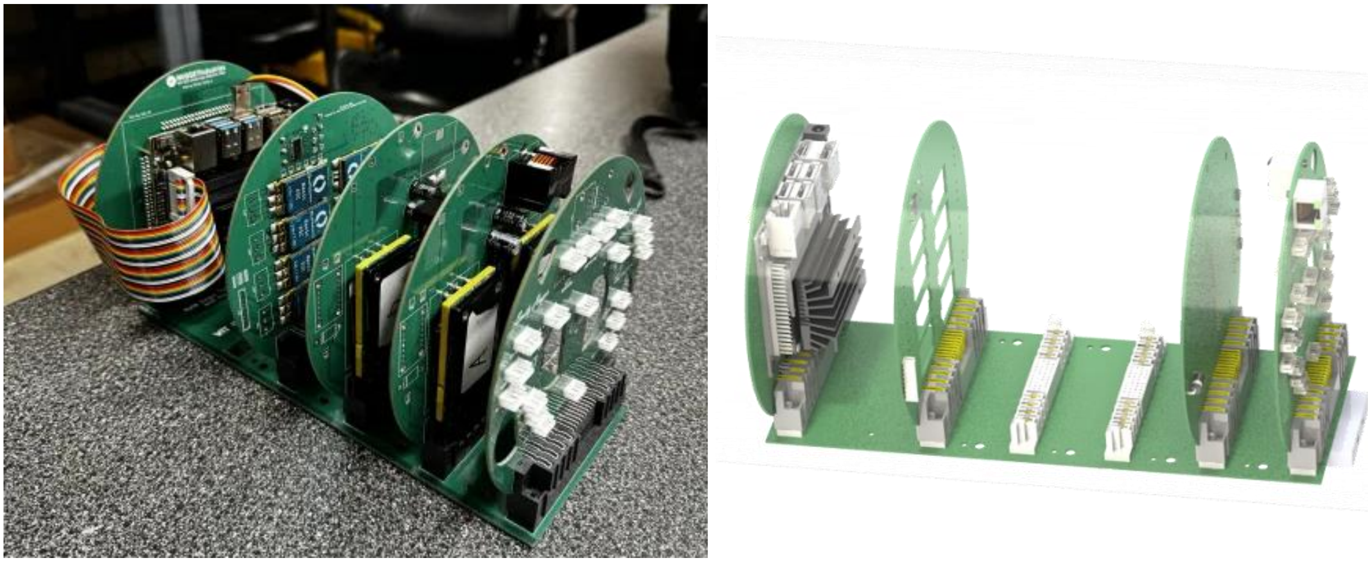


Figure 10. Assembly of printed circuit boards on the backplane.

Sensing

Attaining readings of the vehicle's conditions as well as analyzing the environmental surroundings is crucial in order to operate in a safe and efficient manner. The vessel hosts a board that houses all of the system sensors that read data from the exterior from the enclosure, as well as the Jetson Nano (Figure #), a microcontroller that serves multiple functions such as receiving and sending data from the sensors to the surface station for collection, sending inputs to the PCA modules for navigation, sending video outputs back to the surface station in real time in order to maintain clear visuals while operating under the water. Sensors that are assembled on this board include a Barometer (Pressure), a Temperature & Humidity sensor, and two Inertial Measurement Units (IMUs). The purpose of using an internal Barometer is to ensure that the acrylic enclosure maintains a vacuum during the mission. The internal temperature & humidity units ensure that the inside of the enclosure doesn't overheat or begins to accumulate water due to condensation, signaling a presence of water in the enclosure. Finally, the purpose of the 9DOF IMUs is for navigation and attitude purposes. IMUs read the orientation of the vehicle as roll, pitch, and yaw as well as providing an accelerometer reading to the operator. Loss of pressure or increasing levels of temperature or humidity within the enclosure will indicate to the operator that the vehicle must be surfaced for an inspection.

Power Distribution

The power management board operates with 3 voltage buses. A 48V bus, 12V bus, and 5V bus. The allocation of all on board voltage conversions into one PCB, as far away from the microcontroller as possible, is a precaution taken against noise. This allocation allows a thermal advantage, as this board generates a large amount of heat that could potentially disturb our microcontroller if placed too close. The 48V to 12V conversion is done with an isolated power converter. Because the voltage converter implements transformers, the ground planes are isolated, allowing for the 48V ground which has noise from tether, surface station, and the outside world to be isolated from a much cleaner, 12V ground. The implementation of an EMI filter on the 48V input allows for the noisy signal on the 48V bus to be cleaned up before undergoing a conversion, enhancing converter efficiency. The 12V to 5V conversion is non isolated, meaning that both grounds are the same net. The 12V rail is rated for roughly 100A under maximum load conditions. The 5V rail is rated for 7A under maximum load conditions.

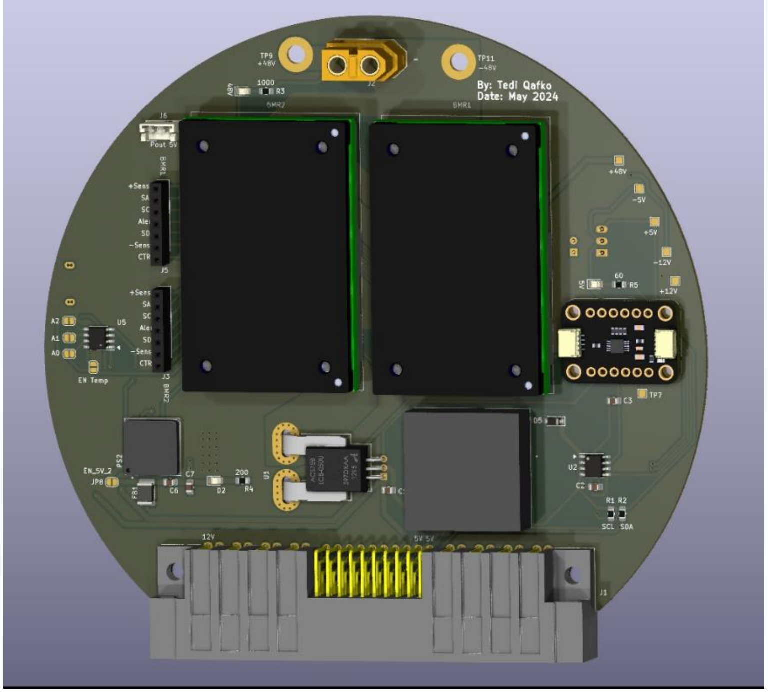


Figure 11. Power Distribution board

The power management board also implements Hall effect current sensing, with an on-board ADC slaved on the I2C bus in order to convert the analog output of the Hall effect sensors into useful data. This allows us to read the current draw on each on board rail (12V and 5V). This is useful in the event that there is a short circuit, for example if the ROV is stationary, but 25A is being drawn on the 12V line, there may be a “high impedance short” and call for the ROV to be surfaced and inspected.

Thruster Control and Electronic Speed Controllers

On the other hand, for thruster control ESC’s or Electronic Speed Controllers are implemented in the ROV to generate the necessary 3 Phase AC signal to drive the T-200 thrusters. The ESC’s PWM input signal are driven by two Programmable Counter Arrays (PCA’s). These devices communicate with our Jetson nano via I2C protocol and have status lights to represent real time functionality. This allows us to visualize where there may be a problem if a connection with the ROV is present, but motors are not working. Our navigation algorithm will command the required PWM signals from the PCA’s with respect to user joystick input.

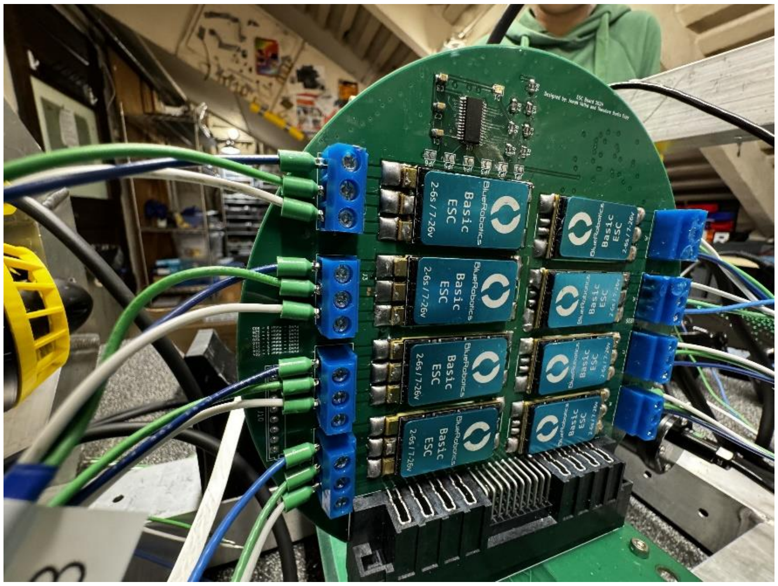


Figure 12. Electronic Speed Controller

Software

Operating System

In order to ensure that our systems would work together we had to make sure that we had the correct versions of Linux that would work with Robot Operating Systems (ROS). For our purposes we used ROS Noetic Ninjemys, which is the last current version of ROS 1 that has not reached its end of life. Due to the ROS development cycle we had to use Ubuntu 20.04. This required some workarounds to get working on the Nvidia Jetson Nano board.

For the driver to operate the WUROV installing ROS on the Surface Station is also required. The Surface station is what provides power and a network connection to the ROV allowing it to be controlled and monitored. The surface station also acts as the ROS master which provides registration and naming of all the nodes in the ROS system.

Thruster Allocation

To make sure all 8 thrusters move the robot in the direction of the desired linear vector. We use linear algebra to solve the individual thrust outputs. To solve for thrust outputs for a set of motors we use the equation $\tau = T(a)f$. Where $\boldsymbol{\tau}$ is a vector of net thrust output, T is a matrix of relations between axes and individual thrusters, represents angles of each thruster, and f is a vector of individual thrust outputs. After solving for f using singular value decomposition on T we get $f = V \begin{bmatrix} {s_T}^{-1} \\ 0 \end{bmatrix} U^T \tau_d$ This calculation is done for both horizontal and vertical sets of thrusters and results with a vector of 8 individual thrusts in kgf to form the desired net thrust vector. PWM period values for each thrust is solved for by creating two quadratic regressions for forward and backward thrust for the T200 thrust vs. PWM period data. The corresponding PWM period values are then sent to the PCA9685 to move the ROV in the desired 3D translation and rotation.

Manual Control Movement

In order to precisely control the ROV, we make use of our IMU. The first thing we do to help the driver is by having the translation input only control movement along the global XY plane. The driver can use separate buttons to control the depth of the ROV at any orientation. The depth of the ROV can also be held in place by a PIDF controller using feedback from our external pressure sensor. The second thing that we do is use a quaternion based PID controller to keep rotational axes that we don't want to change stationary while the other axes that the driver wants to rotate about able to change with joystick input.

Vision

The WUROV's vision system is mainly driven by the Intel RealSense D435 camera which is placed directly in the center of the front viewing port and connected directly to the Jetson board. The D435 camera is a stereo camera combined with an IR projector allowing for high quality depth maps. Although the D435 has an IR projector it uses underwater is futile due the refraction of the IR light in water. The RealSense D435 was chosen because of its stereoscopic capabilities and the wide range of software support for computing the disparity of in image (Depth Map). This allows us to generate a 3D mesh of an object by simply rotating around it.

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 both building and transporting the ROV. 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 a safety checklist, utilize personal protective equipment (PPE), and conduct job safety analysis (JSA). Before operating any tools or equipment, members must complete a mandatory safety training session. This training covers the essentials of PPE, JSA, 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. WUROV enforces the use of PPE, such as safety glasses, when working on the ROV. Additionally, members must follow scripted communication protocols to instruct the pilot to enable or disable the system, ensuring a safe and organized environment during pool operations.By integrating these safety measures, WUROV not only prioritizes the protection of its members but also ensures a structured and secure working atmosphere.

Accounting

WUROV creates a budget at the start of Fall semester which only includes the amount of money required to buy the materials needed to create the ROV.

2023-2024 WUROV Budget	Item Description	Amount
Income Source		
School Funding	Student Engagement	$4,000.00
	Student Government	$1,000.00
	School of Engineering	$15,000.00
	Heinstadt Grant Fund	$10,000.00
Mass Robotics	3rd Place Award Form & Function Challenge	$1,000.00
Analog Devices	ADF IMU Module (X2), Depth Sensing Camera	-
AMD	Kria Robotics Starter Kit	-
Igus	Plastic Bearings	-

Available Income	$31,000.00

Table 3. WUROV's starting budget

2023-2024 WUROV Spent	Item Description	Type	Amount
ROV Expenses			
Thrusters	8 T200 Blue Robotics, 8 Blue Robotics ESC	Purchased	$2,000.00
PCBs		Purchased	$300.00
Electronic Components	Capacitors, Resistors, Converters, Sensors	Purchased	$2,100.00
Tether & Connectors	Penetrators, Ethernet cables,	Purchased	$370.00
Surface Station	Pelican Case, Xbox controller	Re-used	-
Housing & Buoyancy	Acrylic Cylinder, Aluminum, Stainless Steel	Purchased	$1,200.00
3D Printing Materials	Filament, 3D printer	Purchased	$300.00
Controller	Xbox Controller	Purchased	$30.00
Total ROV Expenses			**$6,300.00**
Non-ROV Expenses			
Float	Electronics, Housing, Sensors	Purchased	$300.00
Total Non-ROV Expenses			**$300.00**
Operations Expenses			
Hotels	4 rooms, 8 nights	Purchased	$5,088.00
Food	2 meals per person, 8 days	Purchased	$3,375.00
Mission props	PVC Pipes	Re-used	-
Mate Registration fee	MATE ROV World Championships	Purchased	$450.00
ROV shipping	Freight Cost	Purchased	$5,000.00
Poster Printing			-
Travel flights	Roundtrip Flights	Purchased	$9,000.00

Total Operations Expenses			$22,913.00
Marketing			
T-Shirts	Individual member purchases		-
Total Project Expenses			**$29,513.00**

Table 4. 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

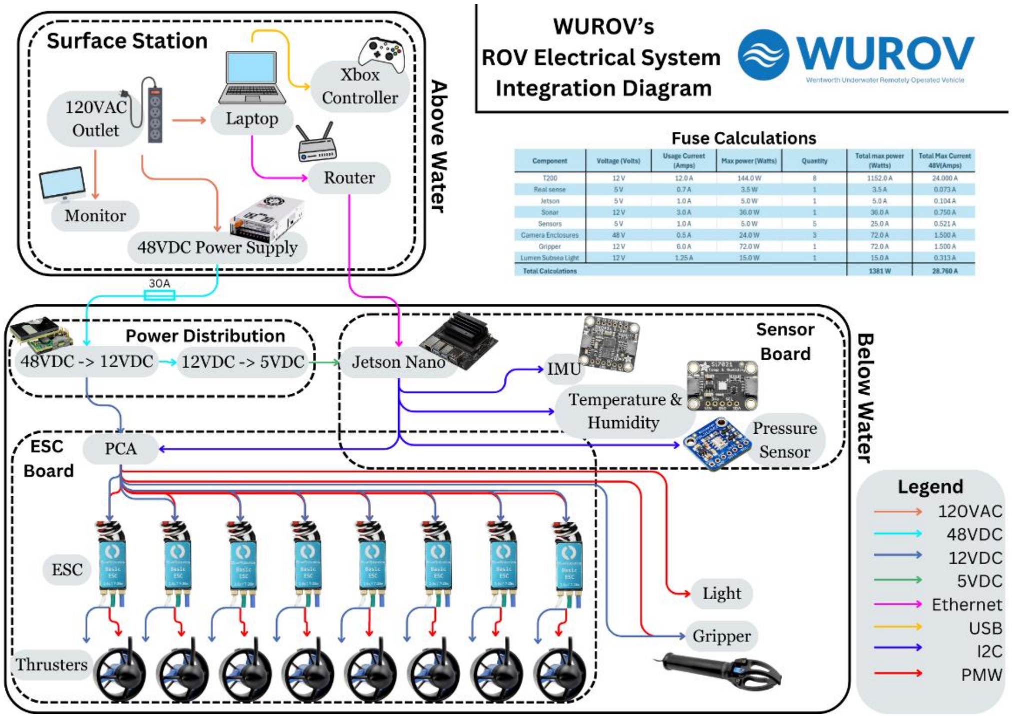
Leakage Detections Procedure

- ☐ 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.

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

Figure 10. WUROV's ROV SID

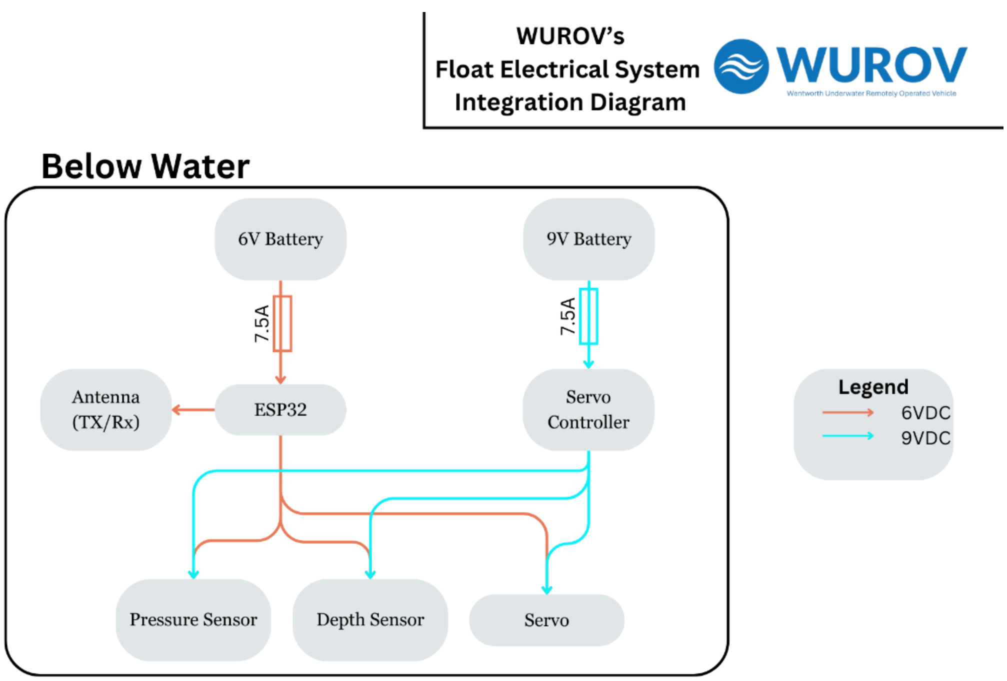


Figure 11. WUROV's Non-ROV SID