Cascade RoboSub 2024 Technical Design Report

An AUV by the Okanagan Marine Design from UBC Okanagan

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Abstract: The Okanagan Marine Design team at UBC Okanagan presents *Cascade*, our first AUV for the 2024 RoboSub competition. Developed over the 2023-2024 semesters, Cascade features a meticulous design for our mechanical, electrical, and software systems designed for adaptability and efficiency. This report outlines our competition strategy, design, and testing methods, highlighting our team's dedication to innovation in preparation for Robosub.

I. INTRODUCTION

The Okanagan Marine Design team at the University of British Columbia is an interdisciplinary team from 4 engineering backgrounds that work together to design, build, test and run an Autonomous Underwater Vehicle (AUV) for the Robosub Competition that is a competitive international competition which attract the best universities from across the world every single year. Our AUV - *Cascade* showcases a strategy of innovative engineering and practical design, for the ability to perform the various tasks at the competition. By the extensive design of our subsystems in mechanical, electrical and software teams, Cascade is equipped to navigate complex tasks efficiently, positioning our team for success in the tasks we plan to complete. This document details the mechanical, electrical and software design choices and strategic considerations that underpin our vehicle, showcasing our commitment to excellence in robotics and engineering.

Fig 1. Rendered image of Cascade

II. COMPETITION STRATEGY

1) *Gate - Enter the Pacific*: Cascade will begin by completing the gate task, essential for accessing subsequent challenges. The vehicle will dive, locate the gate using our search algorithm, align with the center, and identify the “clockwise” symbol. Cascade will then maneuver underneath, performing a spin in the yaw orientation for style points before moving to the next task.

2) *Buoys - Hydrothermal Vent*: Following the gate, Cascade will focus on attempting the buoy task. It will locate the path marker to orient itself towards the Polyform A-0 Red Hydrothermal Vent. Using a similar search pattern, it will locate the buoy, circumnavigate as required, and strategically touch the buoy to complete the task.

For the remaining tasks (Ocean temperatures, Mapping, Collect samples, and Octagon) Cascade's current strategy does not prioritize their completion. However, we remain open to developing strategies for these tasks in the future, contingent upon further assessments of our vehicle's capabilities and the competition landscape. This focus allows us to refine our performance in the gate and buoy tasks, maximizing our efficiency and scoring potential. We are working on having a stronger hydrophone plan for the next year, as we learnt a few things from our experience attempting to build our own hydrophone and our team are currently planning for the next year, in hopes to attempt the remaining tasks.

III. DESIGN STRATEGY

A. *Mechanical Design*

The Cascade RoboSub's mechanical design integrates strategic and engineering principles to achieve optimal performance in underwater environments. The design incorporates 3D-printed components with Polylactic Acid (PLA) on an Fused Deposition Modelling (FDM) printer for critical structural elements such as thruster mounts and frame connectors. This approach allows for rapid prototyping and customization, enabling any quick adjustments to meet mission-specific requirements. The central transparent cylindrical hull houses all the electronics, providing both protection and visibility for onboard sensors. With our current design for the year, our AUV will be able to maneuver easily during the competition. Due to the materials chosen for our first AUV, our main goal was to keep the AUV lightweight and inexpensive.

Propulsion System - Thruster Arm Appendage

The propulsion system features four strategically placed thrusters at the corners of the frame. These thrusters sit on a small wedge to give us the opportunity to test different angles that help us to achieve 6 degrees of freedom (DOF) which helps us to control surge, sway and yaw movements in the X and Y planes. This configuration enhances maneuverability, allowing the vehicle to execute precise movements in complex underwater tasks. We also have 4 additional thrusters facing upwards to maintain heading, help dive and rise up to the surface as required during the competition run. The thruster mounts are made from 3D-printed materials, minimize drag, are easy to manufacture and each appendage holds two thrusters.

Fig 2. Rendered image of the thruster appendage

Frame and Structure

The lightweight frame, constructed from durable aluminum T-slots, facilitates modularity, enabling the easy integration of additional sensors or equipment as needed and allows any change of location of parts within the assembly. The open frame design minimizes water resistance, improving speed and efficiency. During the design process, trade-offs between system complexity and reliability were carefully considered.

Electronics Tray

We have developed an electronics tray that can be easily removed for maintenance during the competition. The tray has been designed to pull out of the hull and be placed on top of the table. With this, each vertical slat can be slid out for ease of maintenance, avoiding the need to disassemble any other components. The tray is also 3-D printed making it easy to manufacture and keeping the hull as light as possible.

A key improvement we aim to achieve in the future is our wire management within our electronics tray that we have learnt from our assembly this year. We aim to avoid any risk of shorting components and or any disconnections.

Buoyancy

With the help of our 6 inch-diameter watertight enclosure, it helps produce a significant buoyant force. Additionally, the DVL weighs 3 kgs in air and is placed at the bottom under the enclosure, which keeps the Centre of Gravity (COG) low. This helps increase the difference between the Centre of Buoyancy (COB) and COG, enabling a more stable AUV.

B. Electrical Design

The electrical design of the Cascade RoboSub ensures reliable power management and robust control for all onboard systems. Our electrical subteam focused on creating a power distribution system that efficiently steps down battery voltage to supply various electronic components with stable and sufficient power. Custom-designed boards, such as the Power Distribution Board (PDB) and the Electronic Speed Controller (ESC) Board, are built to handle the high demands of the AUV's thrusters and other subsystems. With a keen emphasis on safety and efficiency, the electrical architecture incorporates built-in diagnostic features to facilitate quick troubleshooting and maintenance. This meticulous approach to electrical design aims to maximize the performance and reliability of the AUV during competition, ensuring that all systems function seamlessly under the demanding conditions of underwater operations.

Power Distribution

The Power Distribution Board was designed to step down the 4s LiPo battery voltage to 12V and 5V, which can be used to power the electronics. The board was designed to be overbuilt for the application to ensure that the AUV's power system will always work. The board also had built-in LEDs to quickly troubleshoot which DC-DC convertors are working.

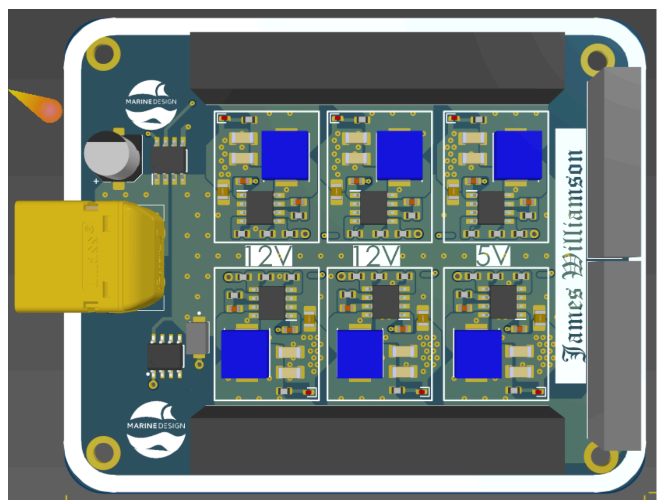


Fig 3: PDB Board

ESC Board

The ESC Board is the second half of the power system. It was designed to have very little power waste as well as a built-in kill switch. To ensure it could handle the high power draw of the 8 thrusters, a Keysight Power Analyser was used to ensure the PCB would not melt.

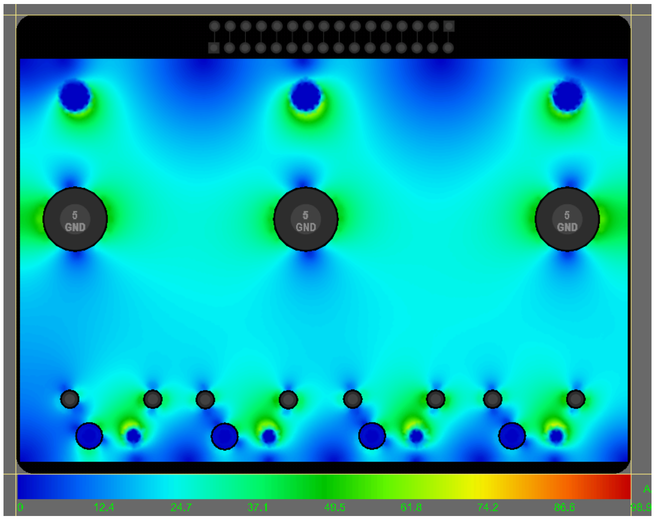


Fig 4: ESC Power Board

Batteries

It was decided to run a 4s (13.2V-16.8V system), which is then downconverted to 12V and 5V by our power distribution board. This maximizes our motor efficiency and allows us to work in an extensive range of voltages. It was also decided to aim for a capacity of around 10000 mAh, allowing us to run all thrusters at an average power of 30% through the 20-minute competition. Due to availability, we settled on placing 2 8200mAh 2s batteries in series and another set in parallel to achieve an overall 16400mAh 4s setup. This setup allows for great flexibility, primarily due to the smaller size factor of the 2s batteries, which allows for a better packing factor and a max of 9 batteries to be stacked in the hull. This allows us to run the thrusters at higher average power, closer to not needing to throttle them.

C. *Software Design*

Since this is our first year working on the Cascade AUV, our software team had to design and build its software systems from the ground up. Each software component has much room to grow and will be improved in the coming years.

ROS2

In order to facilitate the modular structure of our various software nodes, we opted to utilize ROS2 (Robot Operating System 2) for our communications layer.

By splitting up our system into as many discrete nodes as practically possible, we hope to streamline future development and simplify testing. Lastly, using ROS2 nodes allowed for easy interaction between Python and C++ code.

Mapping

Although we probably could have gotten by without 3D mapping this year, we decided it would be best to implement it alongside the rest of our system this year instead of cutting corners to ensure we don't amass significant technical debt for future years.

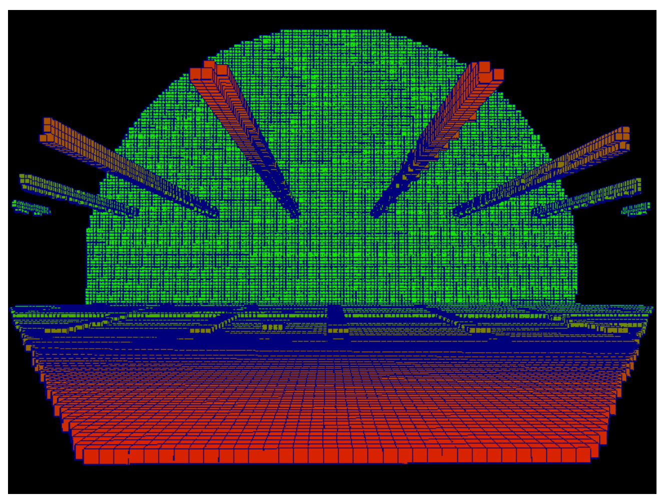


Fig 5: Screenshot of in-house tool written to visualize the mapping systems internal data

Our mapping system combines the object detection system and our stereo camera to estimate the position of competition elements in 3D space relative to the Cascade AUV. In order to achieve this, we utilized the Bonxai voxel grid data structure, which itself is based on OpenVDB. Although we believe the Octomap library is a more popular choice within the robotics industry, we found that Bonxai outperforms Octomap in several benchmarks and is easier to implement.

Object Detection

Cascade's object detection system is based on the recent YOLOv9 model and is fine-tuned to relevant photos of competition elements (e.g., Gate, buoy, etc.).

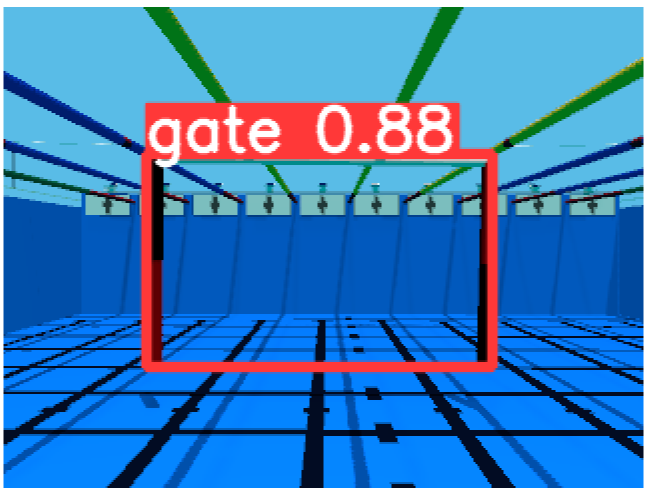


Fig 6: Example Object detection model inference

Gathering images of competition elements has proven challenging. Our main options this year have been getting photographs from Robosub's data-sharing platform and from simulation. Both approaches have their own issues. Much of the data from the data-sharing folder has been hard to sort through or is of low quality. Furthermore, our simulations lack realism at the moment, so getting high-quality data from there has also proven difficult. We hope to capture our own data of competition elements at the competition this year and at more in-pool tests next year.

Navigation

Cascade's navigation system builds on its mapping system, utilizing the gathered 3d data to avoid obstacles and locate competition elements. The system is split into three distinct sections: the navigator, motion planner, and motor cortex.

At the highest level is the navigator, which takes in abstract commands like "go forward 1 meter" or "go to the gate." These high-level commands are then processed and passed to the motion planner, which utilizes A-star pathfinding for global navigation and obstacle avoidance. The path generated by the motion planner is then passed to the motor cortex. The motor cortex is at the lowest level of the navigation subsystem, utilizing a cascading PID controller to calculate motor throttles.

Automated Planning

The automated planning system controlling Cascade is a behavioral tree powered by the Python library Pytrees. Each action within the behavior tree is an abstract command that can be sent to the navigator; this ensures easy mission planning and editing.

Localization

Early on in the year, we experimented with visual SLAM to estimate Cascade's position. However, this proved unfeasible, seeing as the competition pool is a low-texture environment. If we have more time, we may return to this approach in future years. For this year's design, we've opted for a simple dead reckoning algorithm which utilizes the IMU built into our stereo camera and possibly velocity readings from our DVL.

IV. TESTING STRATEGY

A. Pre-Qualification test

The Pre-qualification test helps us to progress in the Robosub competition, and we plan to test out AUV to maneuver autonomously from this test. The mission involves the AUV passing through the gate, navigating around the pole, returning through the gate, and surfacing. The test is considered a pass if the AUV successfully completes the mission, and a fail if it misses the gate or marker, or fails to navigate correctly.

B. PDB / ESC board test

To test the power system, use a multimeter or charger to check that the battery voltages are equal. Ensure the kill switch is on, then connect the ESC to the thrusters, the ESC to the ESC board, and the batteries. Verify that the PDB lights are on, then flip the kill switch to listen for the ESC startup noise. Finally, use the ESP32 to briefly run each motor for a quick check.

C. Watertight enclosure test

To test the watertight enclosure, ensure all penetrators are installed and sealed correctly, and place dry tissues or paper towels inside as moisture indicators. Seal the enclosure, ensuring clean and lubricated O-rings, then submerge it in a water container. The test is conducted to make sure no water leaks into our electrical system.

D. Software test

Since we didn't have a physical prototype to test with for most of the year, we extensively utilized simulations to test our software systems.

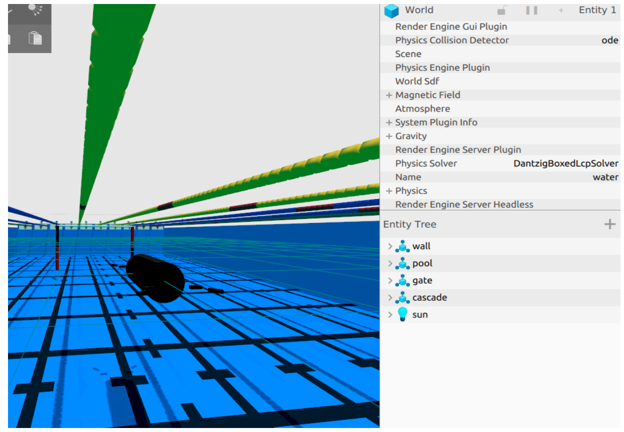


Fig 7: Screenshot of Gazebo Fortress Simulator, used to simulate various sensor readings

The main software we used was Gazebo Fortress, a simulator integrated with ROS2. By testing our software systems as they were being built, we eliminated many problems early on, speeding up development.

V. CONCLUSION

Okanagan Marine Design has made tremendous progress since our first meeting in the last week of September 2023. We have been able to learn from a lot of mistakes, provide guidance, and ideas as the sub teams have been working together cohesively to make our designs come alive. We plan to network, speak, learn and discuss with other teams present at Robosub 2024 in order to take in experiences and tips from the competition. We hope to qualify for the semi finals and complete our planned tasks efficiently. In the future we plan to iterate and spend more time in testing, both simulations and in-water, which is something we have lacked this year.

VI. ACKNOWLEDGMENTS

UBC Okanagan Marine Design is a student team that is run by the Students' Union of UBC Okanagan (SUO) at the University of British Columbia. We would like to thank them and acknowledge our sponsors, advisors and companies that have provided generous discounts and parts for us this academic year: Professional Activities Fund (PAF - UBC Applied Science), Okanagan Engineering Society, Cellula Robotics, Altium, Mearls Machine Shop, Rocky Mountain Motion Control (RMMC), Bloom Technical, Blue Robotics, Mouser Electronics, Tuum Est Student Initiative Fund (TESIF).

We would like to thank our members who have contributed a lot of hours into building our first AUV in a very short timeframe. We would also like to thank all the post grad students and professors from UBC Okanagan School of Engineering (SOE) and Irving. K. Barber Faculty of Science who have mentored and advised us as we began this project.

VII. REFERENCES

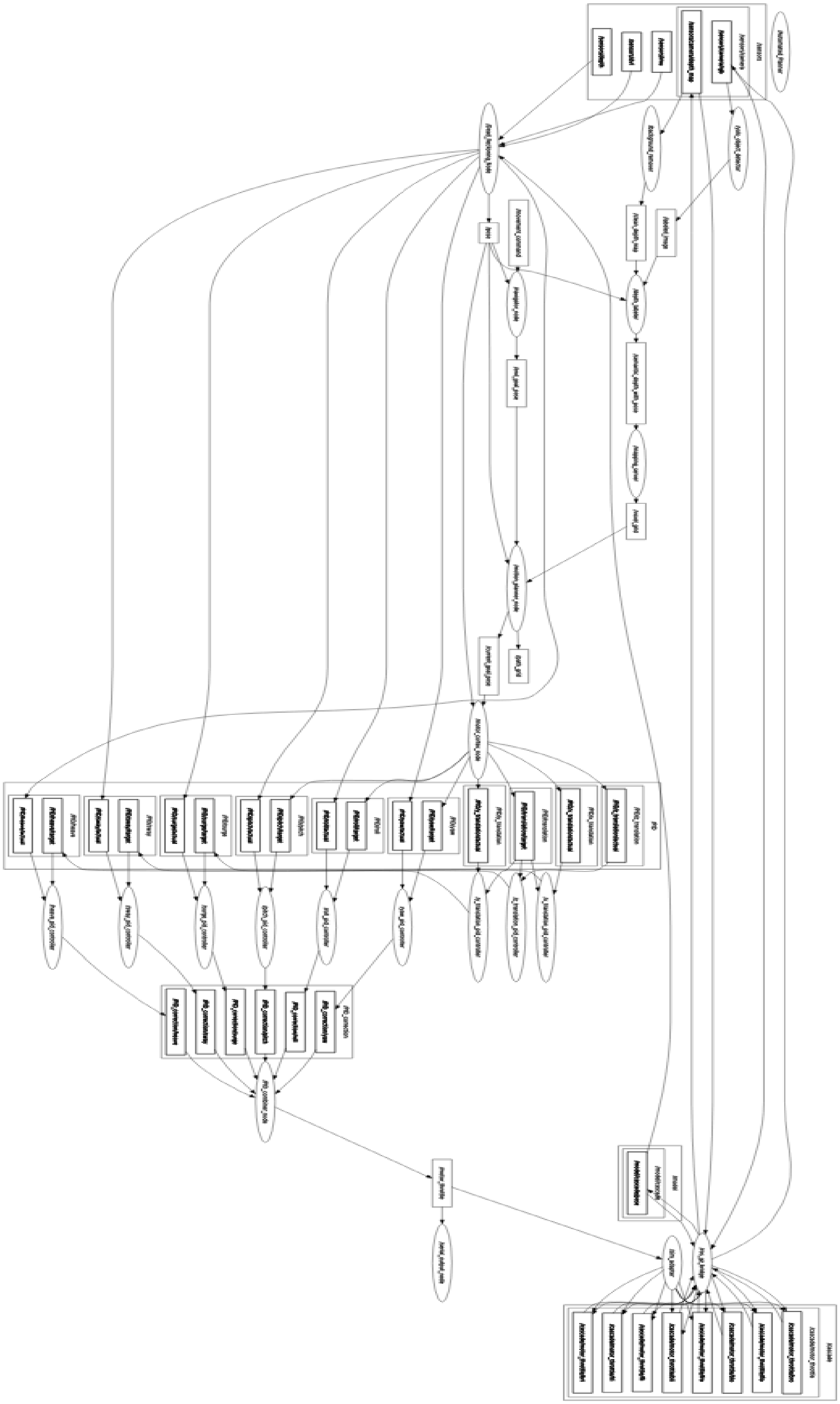
1. Association for Unmanned Vehicle Systems International (AUVSI) Foundation US Navy Office of Naval Research (ONR). (n.d.). *Auvsi Foundation and ONR*. AUVSI Foundation and ONR Engineering Primer Document for RoboSub Competitions.
2. Brege, E. D. (2011, June). *Design and construction of a low cost, modular ...* Design and Construction of a Low Cost, Modular Autonomous Underwater Vehicle.

VIII. APPENDIX A: COMPONENT SPECIFICATION

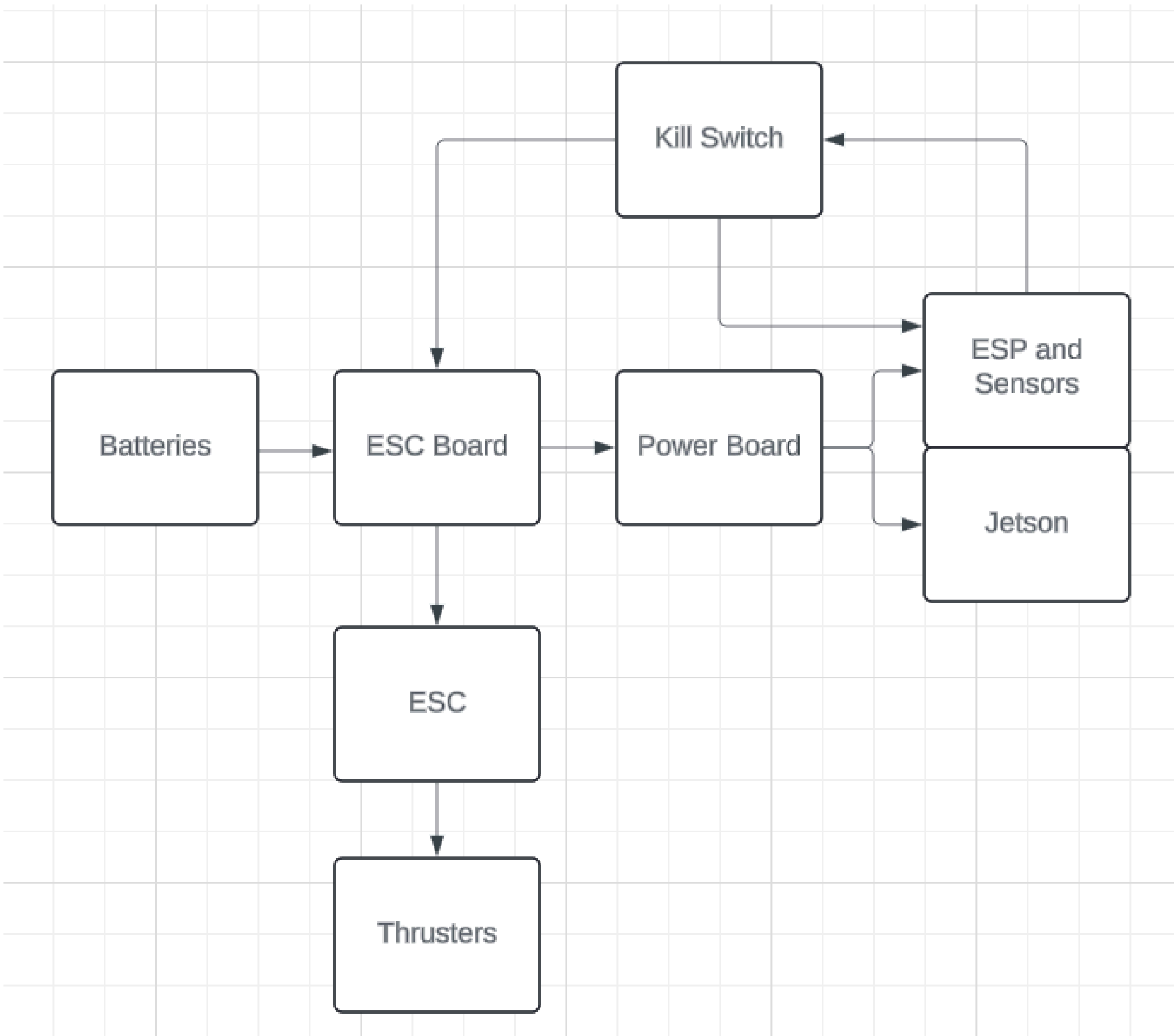
TABLE 1: COMPONENT COST BREAKDOWN

Component	Vendor	Model/Type	Custom/ Purchased	Cost (USD)	Year of Purchase
Watertight Enclosure	Blue Robotics	6-inch hull	Purchased	$476	2024
Thrusters	Blue Robotics	T 200	Purchased	$200	2024
Frame	Rocky Mountain Motion Control	2020 Aluminum	Sponsored		2024
Battery	HOOVO	Li-Po 8200 mAh 7.4V	Purchased	$280	2024
Motor Controls	Blue Robotics				2024
CPU	Nvidia	Jetson Orin Nano	Purchased	$499	2024
Inertial measuring Unit (IMU)	BOSCH	BMI088 Shuttle Board 3.0	Purchased	$47	2024
Doppler Velocity Logger (DVL)	Nortek	DVL 1000 1 MHz	Sponsored		2024
Camera	Intel	RealSense D455	Purchased	$500	2024
Algorithms		A* Pathfinding			
Vision		YoloV9			
Localization and mapping		Bonxai Data Structure used for 3D voxel grid Dead Reckoning Sensor Integration for localization			
Autonomy		Behavior tree			
Open-source Software		ROS2, PyTorch, PyTrees, Bonxai			

X. APPENDIX B: ROS



X. APPENDIX C: POWER SYSTEM DIAGRAM



XI. APPENDIX D: TEST PLAN

01. Pre-Qualification

Required Equipment:

- Cascade AUV full assembly
- Spare components / Tool box
- Ethernet cable
- Charged batteries (8)
- PVC pipe marker
- PVC pipe gate
- Pool access (YMCA Kelowna)

Test:

1. Preparation:

- Insert 4 charged batteries into the AUV and secure them in the hull.
- Conduct Watertight test (Appendix D 03.)
- Connect the Ethernet cable to the AUV.

2. Software Setup:

- Ensure stable connection to the AUV's main on-board computer (Jetson Orin Nano) by trying to establish an ssh connection
- Run ROS2 launch file, starting the entire software system
- Run rqt_graph tool to inspect ROS2 node structure, ensuring all nodes are running correctly

3. Mission run:

- Allow the AUV to autonomously complete the mission according to RoboSub specifications, which includes diving below water, passing through the gate, navigating around the pole, passing back through the gate, and surfacing.
- Additionally, test the kill switch, and observe the AUV to see if it stops and floats to the surface.

4. Pass/Fail Criteria:

Pass:The AUV successfully dives, navigates through the gate, circles the marker, returns through the gate, and surfaces.

Fail: The AUV misses the gate or marker, or fails to navigate or orient correctly.

02. Power System Test

Components:

- ESC
- PDB
- ESC Board
- Multimeter or Battery Charger
- ESP32
- Kill Switch
- Power System Wires

Test:

1. Use a multimeter or charger to check the voltage of the Batteries to ensure they are the same.
2. Ensure the kill switch is turned on
3. Connect the ESC to the thrusters then the ESC to the ESC Board then connect the batteries. Check that the PDB lights are on.
4. Flip the switch kill switch and listen for the ESCs to make their start up noise.
5. Use the ESP32 to do a quick test of each motor by running them for a few seconds.

03. Watertight enclosure test

Components:

- Watertight enclosure (Blue Robotics 6-inch hull)
- Dry tissues or paper towels
- Penetrators (cables, connectors, etc., that will be used with the enclosure)
- Water container or test tank (large enough to fully submerge the enclosure)

Test:

1. Preparation:
   - Ensure that all penetrators are properly installed and sealed.
   - Place a few dry tissues or paper towels inside the enclosure. These will act as indicators for any water ingress.

2. Sealing the Enclosure:
   - Carefully close and seal the watertight enclosure. Ensure that the O-rings and sealing surfaces are clean and free of debris. Lube the o-rings for ease of installation.

3. Submersion Test:
   - Fill the water container or test tank with enough water to completely submerge the enclosure.
   - Slowly lower the sealed enclosure into the water, ensuring it is fully submerged.

4. Observation Period:
   - Leave the enclosure submerged for 30 seconds to 2 minutes. Keep an eye for any bubbles or any

5. Pass/Fail Criteria:

Thoroughly dry the exterior of the enclosure to prevent any external water from entering when you open it.

- Pass: The tissues or paper towels inside the enclosure remain completely dry, indicating no water inside the hull.
- Fail: Any signs of moisture or water on the tissues or paper towels indicate a failure in the watertight seal.

If the enclosure fails the test, recheck the installation of the penetrators, O-rings, and sealing surfaces. Make any necessary adjustments or repairs and repeat the test until the enclosure passes.

This test ensures that your watertight enclosure is properly sealed and ready for use in environments where it will be exposed to water.

XII. APPENDIX E: OUTREACH ACTIVITIES

As first-time competitors in the RoboSub competition, our team is dedicated not only to showcasing our technical prowess but also to fostering a sense of community and inspiring the next generation of innovators in marine robotics. We recognize the importance of educational outreach and have engaged with our local community through two significant events.

Outreach Event 1: Royal Canadian Sea Cadets Corps Kelowna (RCSCC)

Our initial outreach event was held with the Royal Canadian Sea Cadets Corps Kelowna (RCSCC), where we welcomed approximately 30-40 youths. This event provided an exciting platform for us to introduce the cadets to the world of engineering and marine robotics. Through interactive activities, we shared insights into our sub-teams, giving the cadets a glimpse into the various facets of our engineering endeavors. The cadets had the opportunity to engage with our team members, ask questions, and explore the practical applications of STEM in marine robotics.

This interaction was an incredible opportunity to motivate these young individuals, encouraging them to think creatively and innovate. By connecting with the cadets, we aimed to ignite a passion for engineering and marine robotics, showcasing the potential for future careers in these fields. The enthusiasm and curiosity displayed by the cadets were truly inspiring, reinforcing our commitment to educational outreach.

Fig & captured during the outreach with RSCSS

Outreach Event 2: Expo of Awesome with Okanagan Region Schools

Our second outreach initiative was part of the Expo of Awesome, an event designed to engage students in hands-on STEAM (Science, Technology, Engineering, Arts, and Mathematics) activities. We collaborated with four groups, totalling 120 students from three schools in the Okanagan region: Shannon Lake Elementary, Dorothea Walker Elementary, and Watson Road Elementary. Held on May 29, this event welcomed Grade 4-6 students to the UBC campus for a day of interactive learning.

During the Expo of Awesome, we organized a fun and educational boat-building competition. Students were challenged to construct boats using cardboard and duct tape, to create a vessel that could carry weight. This activity not only fostered teamwork and creativity but also provided a practical introduction to basic engineering principles and problem-solving skills.

By involving the students in a hands-on project, we aimed to spark their interest in engineering and marine robotics, showing them that learning can be both fun and impactful. These outreach events have been instrumental in strengthening our community ties and promoting the values of creativity, innovation, and collaboration.

Our commitment to educational outreach aligns perfectly with the objectives of the RoboSub program. We are proud to have made a positive impact on our community and look forward to continuing our efforts to motivate and nurture the next generation of engineers and innovators.

With these initiatives, we aim to create a lasting legacy that extends beyond the RoboSub competition, fostering a vibrant and engaged community of future STEM leaders

Fig & captured during the outreach with RSCSS