Technical Report

SeaHawk II

Cabrillo Robotics Club

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Abstract

Returning for the third consecutive year competing in MATE, Cabrillo Robotics Club proudly presents our most advanced Remotely Operated Vehicle (ROV): SeaHawk II. The SeaHawk II takes inspiration from the osprey's streamlined design and critical role in sustaining the ecosystem's well-being. It is engineered to complete tasks specified in the MATE 2024 Explorer Challenge, which include relocating ocean observing assets, deploying and inspecting deep sea data collection infrastructure, restoring and observing ecosystems, and monitoring ocean health.

Completely redesigned, the SeaHawk II continues with Cabrillo Robotics Club's philosophy of modularity and adaptability. Company subteams worked to continuously improve the software architecture and mechanical structures. The results of the Cabillo Robotics Team's hard work have been compiled into a versatile, precise, and robust platform that is ready to face the challenges at the MATE World Championship in Kingsport TN.

Project Management

Company and Personnel Overview

Cabrillo Robotics Club is a robotics company made up of community college students from Cabrillo College in Aptos, California. The company specializes in creating products which help us as a global community *"soar towards a sustainable future"*. Cabrillo Robotics Club designs specialized marine technology solutions aligned with the objectives outlined in the UN Decade of Ocean Science for Sustainable Development [1]. Our products aim to contribute to climate change solutions as well as restoring and protecting aquatic ecosystems and biodiversity [2].

The company is organized into four subteams: electrical, mechanical, software, and marketing. This decentralized structure allows for autonomy amongst individual divisions and enables members to specialize in their niche. *See cover page for company personnel overview.*

Communication and collaboration between subteams is crucial to maintain consistency and progress toward a common goal. To achieve this, club members met in person at least once per week and maintained remote communication between meetings to discuss progress. Additionally, the team utilized effective scheduling software as well as specialized resources, procedures and protocols to ensure the team remains on task.

Schedule

Early in development, members believed it would be beneficial to have a more rigorous scheduling system than used in the past. This led us to use ClickUp, an online project management tool designed for teams. The software allowed us to thoroughly plan out an organized model of deadlines and expectations we would strive to meet, however after some time we found this approach to be restricting and challenging to adhere to consistently.

As a result, we reverted to a more forgiving scheduling methodology, with goals which are mostly flexible, along with some firm deadlines. Currently, the team uses a shared Google Calendar to track planned meetings and scheduled deadlines, along with a collaborative spreadsheet based to-do lists to track remaining tasks and their priority. An agenda is created prior to each meeting, outlining the goals we aim to achieve during that time.

Resources, Procedures, and Protocols

The use of specialized resources, procedures, and protocols enabled members to smoothly and collaboratively work towards a cohesive product. These included new member onboarding and training, accessible and actively-updated documentation, and the use of Discord and GitHub for collaboration.

Recognizing the diverse range of skill sets amongst new and returning team members, we anticipated a daunting knowledge gap and aimed to ensure new members would not feel lost or discouraged from contributing. During the first few weeks of the project, we focused solely on onboarding and training. Experienced members conducted interactive presentations on fundamentals within their subteam. Some of these training sessions were recorded and published online, becoming resources for new members who joined later.

To ensure understanding between members throughout all stages of the project, we made an effort to create resources documenting changes. In software, this included writing thorough comments in the code describing its purpose and usage, as well as creating markdown documents when deemed necessary. Hardware features were documented as well. For mechanical and electrical CAD designs, version control is tracked in a spreadsheet with older versions uploaded to a repository.

Effective communication between all members was critical given the club's subteam structure and members' continuing work outside of scheduled weekly meetings. The Discord messaging platform, which proved to be a successful communication strategy for us the last few years, continued to be our primary method of remote communication. Dedicated channels were created for each subteam. These could be accessed by all members to ensure everyone had a comprehensive understanding of activities across the various subteams.

The software team extensively used various features provided by GitHub in many aspects of the subteam's project management. The team established a protocol in which new feature requests and bugs were tracked using GitHub's Issues. These Issues were managed using GitHub Projects, providing a comprehensive view of all upcoming tasks, similar to a to-do list (Figure 1). Another protocol was the usage of Pull Requests which encouraged peer review of code. This not only ensured code was nearly production-ready before being integrated, but also ensured team members were well acquainted with all software in the project, not just what they contributed to.

7	Connection does not register as seahawk.local #232	Not Started		bug (unknown cause)
8	Photogrammery #192	Not Started		priority: nice to have
9	Control panel GUI #236	Not Started	liamgilligan	priority: high
10	Reverse controls #237	Not Started	steph1111	priority: mid
11	Temperature sensor #224	In Progress	liamgilligan and st...	priority: required
12	Pressure sensor #229	In Progress	tinymassi	priority: mid
13	BME280 crash #82	In Progress	steph1111	bug (known cause)
14	Gazebo #234	In Progress	liamgilligan and st...	priority: wont do
15	Task list widget for copilot #203	Done (untested)	tinymassi	priority: high
16	Linear CoM adjustment #222	Done (untested)	liamgilligan	priority: high
17	IMU sensor #230	Done (untested)	steph1111	priority: mid
18	BME280 sensor #231	Done (untested)	steph1111	priority: mid
19	Motor kill button #221	Done (tested)	liamgilligan	priority: mid
20	Dash loses focus of keyboard on pilot tab after using the debug terminal #220	Done (tested)	steph1111	bug (known cause)

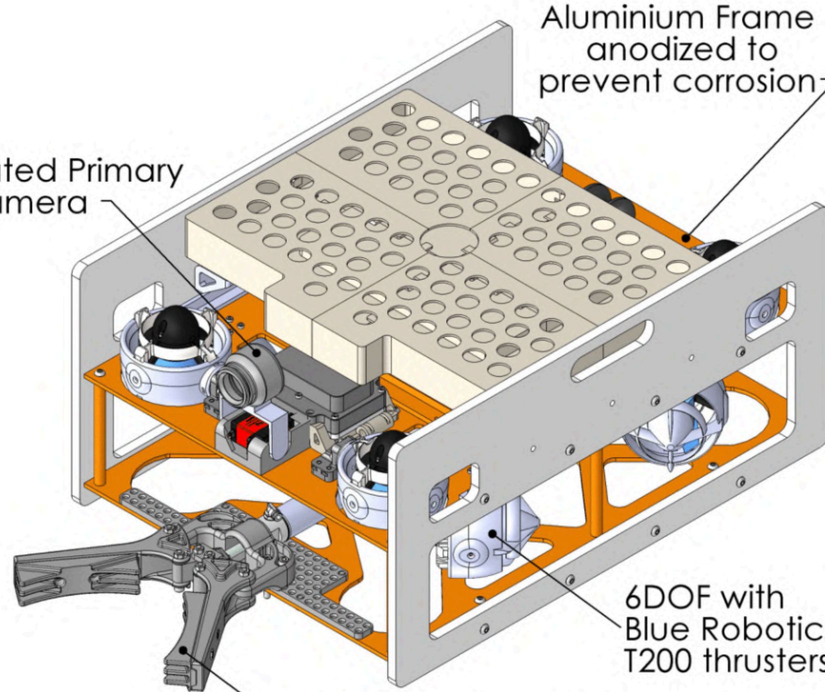
Figure 1: Upcoming software tasks in GitHub Projects

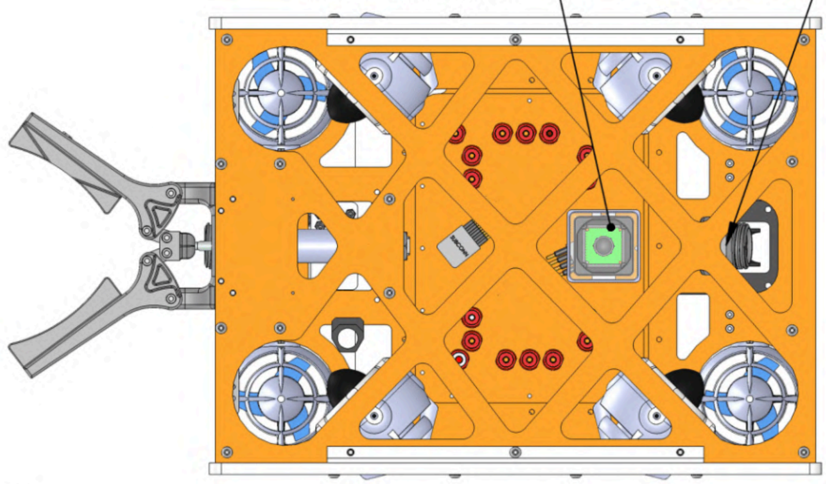
Design Rationale

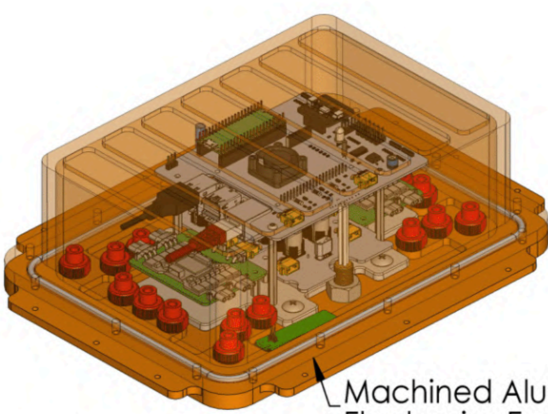
Engineering Design Rationale

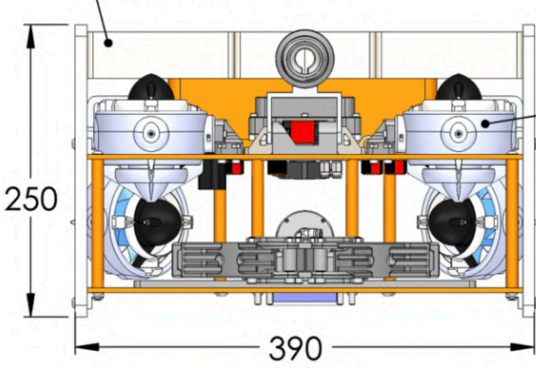
SeaHawk II is designed for ease of deployment and optimal performance while accounting for sustainability. The chassis fully encloses all features of the ROV, eliminating the dangers of snagging to avoid damage to fragile components and the surrounding environment. Shrouded thrusters, an enclosed frame with no sharp edges, over-voltage protection circuitry, and software enforced current-limiting algorithms also minimize operational risk and protect aquatic life. A modular pneumatic tooling system with an adjustable fixture plate provides easily configurable tooling to complete mission tasks. Three high resolution cameras and an array of sensors provide the pilot with feedback displayed on the dashboard interface.

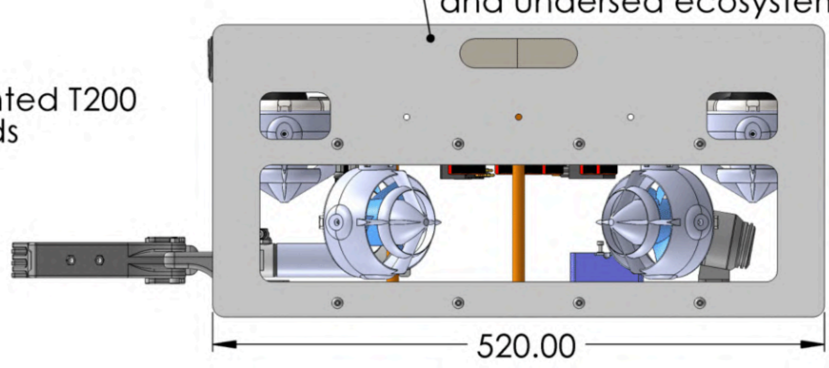
(All dimensions in millimeters)











Design decisions were informed by lessons from our past competitions, environmental sustainability, ideas from new team members, and this year's MATE competition requirements. This resulted in a list of changes and specifications for SeaHawk II and the decision to completely redesign, reusing components whenever possible.

Critical analysis techniques were employed to rank the priority of desired changes in the software, electrical, and mechanical ROV systems. The frame was redesigned to be fully enclosed with no protrusions. A custom electrical box was designed and manufactured to ensure a highly reliable enclosure that integrates electronics without risking leaks. Custom printed circuit boards (PCB) were created to minimize the overall electronics footprint and dramatically increase reliability.

Like its predecessor, SeaHawk II's software is based on the Robot Operating System 2 (ROS2). ROS provides tools and software libraries specialized for development of robotics applications [3]. It is open source and widely adopted in research institutions and companies [4], making it the optimal choice for Cabrillo Robotics. See Appendix C for the software diagram.

While we continued using ROS, the software evolved significantly. Initially, the plan was to lightly refactor existing code, but it became clear that a near-complete rewrite would be beneficial. The overall architecture was mostly preserved, but code was refactored and optimized. Significant changes included a custom dashboard interface opposed to built-in RQT for flexibility and customization, a sophisticated data driven kinematics system for reliability, and the introduction of micro-ROS for modular, extensible integration with the Raspberry Pi Pico Microcontroller.

Systems Approach

A systems engineering approach was used for designing the ROV SeaHawk II. Considering the interaction of the mechanical, electrical, and software systems was crucial to achieve a cohesive and functioning final product. When designing electrical or mechanical systems that interact with each other, an electromechanical engineering approach was adopted. This involved cross-integration between SolidWorks and Kicad EDA in our design flow. To assist in software hardware integration, we employed tools such as ROS Visualization (RViz) to accelerate developing and testing software independent of physical hardware. Our electrical design workflow took software architecture into account. Electronics were designed to support micro-ROS. We also utilized finite element analysis (FEA) to simulate mechanical ROV aspects. This system design approach was critical to our development process.

Vehicle Structure

The ROV features a compact, streamlined design for maneuverability, ease of transport, and speed. Any losses in control and stability due to the smaller vehicle size were maintained via robust software control design. Taking lessons learned from last year's model, we designed an enclosed frame to prevent snagging on cables. The modularity of subsystems facilitated testing and troubleshooting as well as allowing rapid drop and swap-in repairs. A novel structural feature developed this year is a custom-designed electrical box that integrates with the ROV frame and houses electronics for easy access.

The frame consists of two sheet cut aluminum plates held together with spacers, as well as two sheet cut High Density Polyethylene (HDPE) side plates which act as skids and lifting handles. The upper plate holds the thrusters and electrical box, while the lower is a fixture plate for modular tooling attachment. We opted for this design because sheet cut parts are affordable and allow for a frame with any form-factor. The T-slot aluminum extrusion frame used in prior years was similar in cost. It had utility as a research-frame, allowing interactive design and rapid fine-tuned adjustment. Unfortunately, this modularity resulted in a less streamlined and more fragile vehicle. This year we underwent an extensive design process prior to the build, allowing for a fixed frame.

A custom electrical housing was designed in tandem with our custom electrical stack resulting in an optimal integrated profile. The box was machined in-house from billet aluminum. While manufacturing labor was intensive, the result was comparable in cost to off-the-shelf options and out-performed in heat dissipation, durability, reliability, and ease of use. The custom box allowed us to design a to-spec O-ring seal that protected against leaks at greater than MATE task depths with high reliability. The box lifts off the frame for full access to all electronics to allow for seamless maintenance and troubleshooting of the electronics stack. The box was anodized to add a protective layer to prevent scratching and galvanic corrosion. While somewhat heavier in weight, the box is highly compact and customized in order to improve durability, reliability, modularity and performance of the ROV.

Vehicle Systems

When determining a frame design we compared last year's material, T-slot aluminum extrusion, to other options. We did a study to determine the best material for our frame (Table 1).

Material	Cost	Work	Weight	Modularity	Manufacturability	Durability
Importance	1	2	1	1	1	5
Aluminum Extrusion	Moderate	Low	High	High	High	Low
Sheet Cut Plastic	High	High	High	Low	Moderate	Moderate
Sheet Cut Aluminum	Low	Moderate	Low	Moderate	High	High

Table 1: Frame material ranking based on performance, manufacturability, and affordability

Based on this study, we determined that we should migrate from aluminum extrusions to a sheet cut aluminum frame system. Sheet cut aluminum has the lowest cost, weight, manufacturability and significantly increased durability.

Control and Electrical Systems

Electronic Design and Cabling

Electrical system design prioritized safety, performance, modularity, and simplicity. The electrical stack consists of three PCBs designed in KiCAD EDA: the power board (Figure 4), Electronic Speed Controller (ESC) carrier board (Figure 5), and logic circuit board (Pi Hat) (Figure 6). All three of these boards are bolted to a custom frame. When the boards are attached to the bottom plate of the electrical box, it effectively dissipates heat eliminating any risk of overheating. The PCBs in the electrical stack were designed to reduce footprint, minimize the amount of wires within the electrical housing to keep the stackup organized and improve durability.

The custom electrical stack is situated on top of a machined aluminum plate with a 12V 1/4 brick securely bolted directly to the plate. The ESC carrier and power boards connect via standoffs.

The Pi Hat is also connected via standoffs above the power board. This rack mounting system facilitates easy removal of boards and the full electrical stack, secured by only four bolts, without compromising heat transfer through the electrical box.

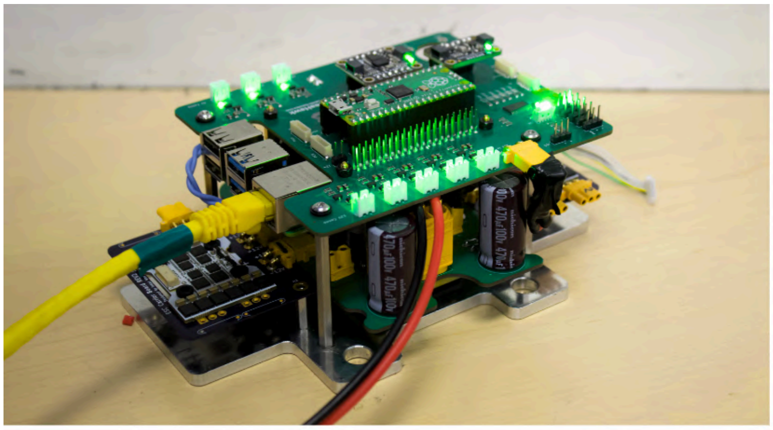


Figure 2: Physical custom electrical stack

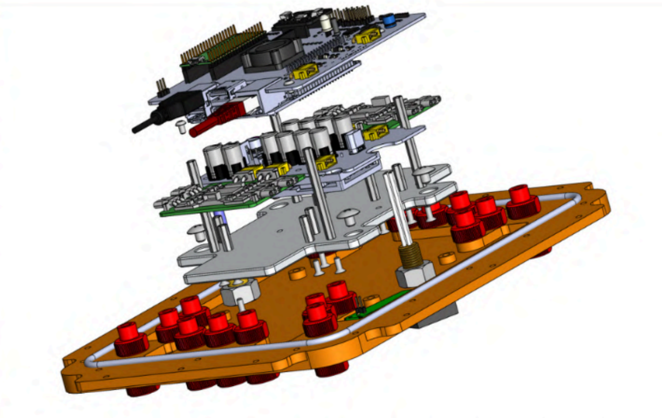


Figure 3: Custom electrical stack exploded view

All ROV power distribution is via the power board PCB. It is powered directly from the 48V power supply on the surface which is converted to 12V using a 1/4 brick [5]. The 48V surface power supply produced random voltage spikes above 48V upon power up. This prompted the hardware team to integrate overvoltage protection on the 48V node. While the tether alone provides a substantial amount of inductance, our team also integrated filtering capacitors and a zener diode to ensure protection against voltage spikes [6]. If the inductor-capacitor filtering fails, the zener diode will pass its breakdown voltage causing an instantaneous short, preventing the transient voltage spike from entering the powerboard.

The 12V board supplies power to the ESC carrier boards and the Pi Hat. A 5V 1/16 brick converts the 12V to 5V to supply power to the Pi Hat and the Pi 4. The board delivers a peak power of 900W to the ESC carrier boards. Both of these power modules have built-in overtemperature protection and short circuit protection. The heat from the system is dissipated into the water via conduction. This board is made from 2oz copper to reduce internal resistance of the board. The power bricks utilize the Power Management Bus protocol to allow monitoring of power sensors.

The Pi Hat, a custom designed PCB which interfaces with the Raspberry Pi 4, acts as the main interface for all the electronics. The Pi Hat connects the Raspberry Pi 4 with a Raspberry Pi Pico using the universal asynchronous receiver-transmitter (UART) protocol in order to control our sensors and thrusters using a micro-ROS bridge, providing direct control of the Pico to the ROS network. It also connects to external temperature and depth sensors, and a status LED. The Pi Hat provides the circuitry to send pulse-width modulation (PWM) signals to the Lumineer ESCs [7] to drive the thrusters. In order to control the pneumatics cooling fans and lights, 12V and 5V transistor switching circuits were included in the design. Finally, it has slots for additional breakout boards, such as the BNO085, BME280, and another custom PCB expansion board. In the physical stackup, it sits neatly on top of both the Raspberry Pi and power distribution board, allowing communication between the two via the Inter-Integrated Circuit (I2C) protocol.

Two Lumeineer ESCs drive the eight Blue Robotics T200 Thrusters. These ESCs are mounted to a custom carrier board PCB which directly plugs into the power board and are cooled by convection. The thrusters are connected to the carrier boards using MR-30 connectors. This pluggable module is easily removable, replaceable, and highly compact.

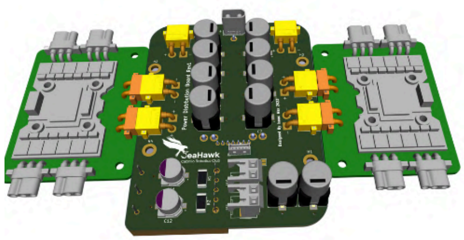


Figure 4: Power board

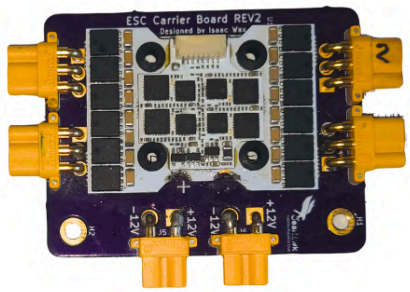


Figure 5: ESC carrier board

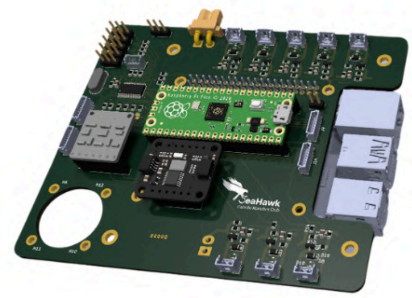


Figure 6: Pi hat

Control System Software

The control system for the SeaHawk II was designed to allow for precise control of the ROV by taking into account its geometry while accounting for parametric uncertainties. The control system consists of a surface pilot interface as well as an onboard Raspberry Pi 4, a single-board computer.

The pilot interface is responsible for interpreting pilot and copilot inputs, providing each with fine control and observation over the ROV's various functionalities. Inputs are read and interpreted, then displayed on the dashboard (if applicable), and sent to the onboard Raspberry Pi 4. To enhance the piloting experience, a variety of feedback is provided by the dashboard (Appendix B) in addition to the camera display. The magnitude and direction measured by the inertial measurement unit (IMU) is displayed, giving the pilot a more accurate understanding of the ROV's movements. Active control modifiers are displayed as well, allowing the pilot to know which thrust normalization techniques are being applied. Temperature, depth, and the location of the center of mass are also displayed.

Primary pilot inputs are derived from an Xbox One controller, providing control over movement, tooling, and linear center of mass adjustment. Copilot input is supported through a keyboard which controls the thrust normalization and more refined center of mass adjustment.

Various normalization techniques are used to improve precision, such as the use of thrust curves, which nonlinearly map pilot input to thrust magnitude. One such technique, Bambi Mode, divides thrust vectors in half for tasks that require precise movements, such as installing the power connector inserted into the SMART repeater.

Of course, the motors will affect the ROV differently depending on the distribution of its mass, which will change with tooling as well as when the ROV is lifting any objects. To handle these changes, the pilot and copilot can dynamically change the location of center of mass in software while piloting, allowing the ROV to move precisely even in changing conditions. This proved especially useful for moving the irrigation system, as it significantly shifts the center of mass.

Tether Design

The tether was designed to optimize flexibility and minimize weight, all while supporting reliable transport of power, data, and pneumatic air. Two strands of flexible twelve gauge silicone wire with low internal resistance, were used to provide power and optimized efficiency to weight ratio. A solid core CAT 6 ethernet cable provided gigabit ethernet data transfer and sufficient flexibility. Two 6mm polypropylene pneumatic lines provide air to our pneumatic manifold and safe venting for the purged air during claw operation. The ethernet and power cables connect to the electrical box via MacArthery connectors allowing seamless removal of the tether from the ROV for transportation purposes. A 12.7 mm grout filler runs through the tether to provide neutral buoyancy. Braided polyester sheathing covers the cables, providing abrasion protection during operations and strain relief when the ROV is lifted via the tether. Nylon webbing is integrated into the tether at both ends to provide strain relief and secure connection of the tether to the surface hard point and frame of the ROV. Based on MATE ROV specifications, we calculated the minimum required length to be 25m. This was sufficient length to complete MATE tasks while minimizing voltage drop. At a maximum load of 20A, the voltage drop does not exceed 8V leaving 40V which is above the ROV power board minimum voltage of 38V.

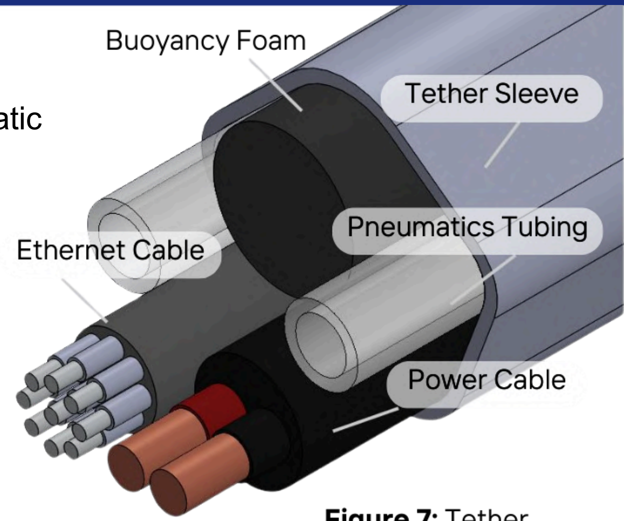


Figure 7: Tether

Tether Management Protocol

- ☐ Tether manager designated in advance of pool test.
- ☐ Unravel tether and connect to ROV electrical box and pneumatics.
- ☐ Connect ROV strain relief and install cotter pin.
- ☐ Connect surface strain relief.
- ☐ During operation, tether remains under tether manager control.
- ☐ Maintain tether slack to allow free movement of ROV.
- ☐ Maintain a perimeter to avoid tripping hazards and damage.
- ☐ Upon pool test completion, break down, clean and store tether.

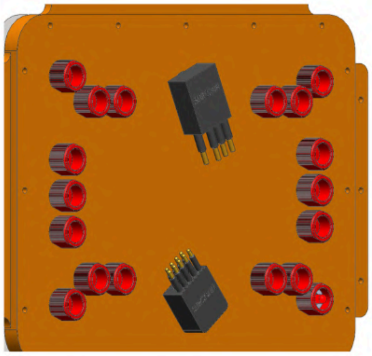


Figure 8: Tether connectors

Propulsion

The propulsion system consists of eight strategically positioned Blue Robotics T200 thrusters encased in custom 3D-printed housings. The motors were awarded to us as a prize for achieving first place in the Pioneer class last year. Aside from the cost factor, these thrusters were selected due to being lightweight, reliable, safe, and from a trusted MATE sponsor.

The thrusters are arranged to enable six degrees of freedom (6DOF) (Table 2). The four horizontal thrusters are mounted at 45-degree angles inside of the frame to provide planar translation and yaw. The vertical thrusters are mounted on the far corners of the ROV to maximize the moment arm relative to the center of mass (COM). They provide vertical translation as well as responsive pitch and roll. The propellers on the vertical thrusters are staggered clockwise and counterclockwise to reduce moment force coupling. The custom thruster housings have IP2X motor safety shrouds integrated into the design to reduce part

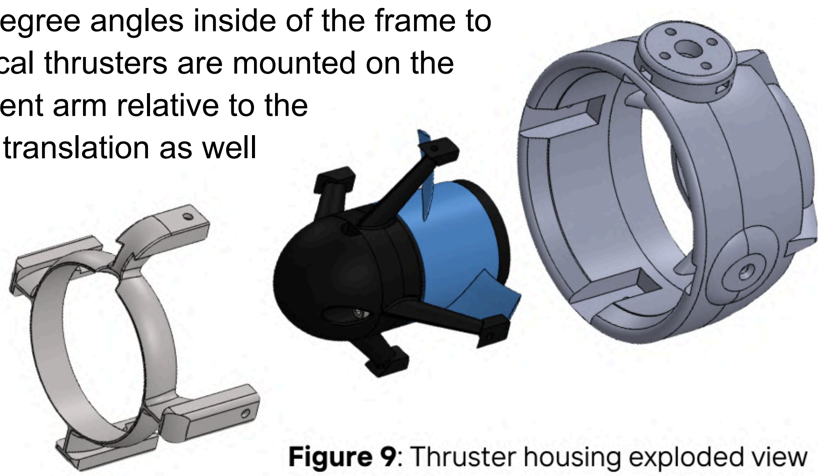


Figure 9: Thruster housing exploded view

count (Figure 8 & 9). The shroud was designed to optimize efficiency, assure operator safety, and protect the marine environment.

Alternatives considered included custom motors, but this was rejected due to cost factors and risk of failure. Another alternative was to use fewer thrusters, but this was rejected due to the advantage of gaining an additional degree of freedom. The selected configuration with eight thrusters proved best for completing mission tasks with efficiency and stability.

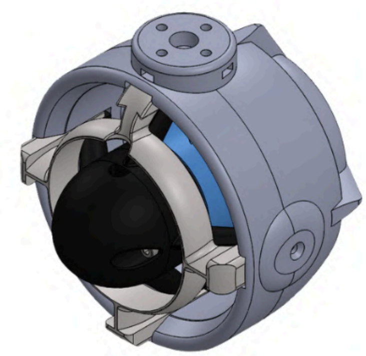


Figure 10: Thruster housing

Each thruster is limited to drawing a maximum of 100W at 12V, for a total of 800W, which is within the ROV power budget of 900W for onboard systems. At maximum an individual thruster provides 36N when moving forward and 28N in reverse. When working together, four thrusters provide 144N to translate vertically at neutral buoyancy.

Input from the control system allows variable thrust to optimize precision of motion. By modeling the locations of the motors and center of mass (COM) of the ROV using a Moore-Penrose pseudoinverse matrix, the pilot's desired direction is converted to the amount of thrust each motor should produce to achieve said direction in a physically driven and computationally efficient method.

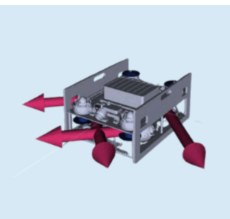
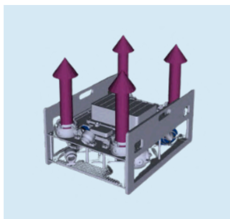
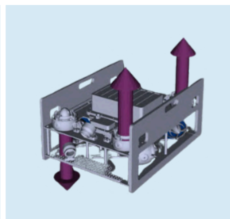
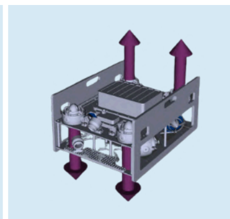
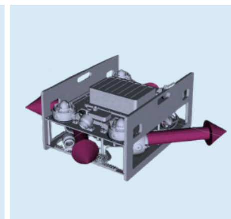
Linear +x	Linear +y	Linear +z	Angular +x	Angular +y	Angular +z
					

Table 2: Thrust directions for each axis of movement

Buoyancy and Ballast

The buoyancy and ballast system was designed to create net-neutral buoyancy to optimize conditions for pilot control. Utilizing CAD and Archimedes' principle, we calculated the net positive buoyancy needed for our ROV to achieve neutral buoyancy.

The air-filled electrical box offered some static buoyancy, yet it proved insufficient to offset the overall density of the robot. As a result, we designed a custom 3D printed buoyancy shell filled with expanding polyurethane foam. Buoyancy was calculated by weighing the robot fully equipped, calculating the volume of foam needed from the density of the foam, and then taking into account the volume of the 3D printed shell. Cabrillo Robotics has gone through three revisions of this part to achieve desired buoyancy. The shell was mounted on the top of the ROV with the center of buoyancy shifted vertically above the center of mass (COM) in the z-positive direction and shifted forward in the x-positive direction. Multiple iterations of the

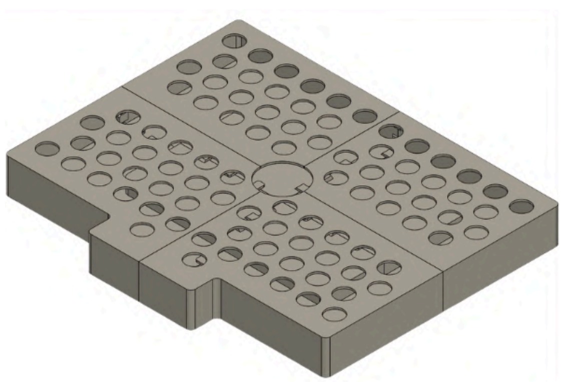


Figure 11: 3D printed buoyancy shell

design addressed issues with the center of buoyancy (COB) being in line with the COM. To enhance driving performance, we shifted the COB forward. In addition, we addressed issues with flashing that occurred due to improper venting in the 3D printed shells. The buoyancy shell and dynamic blocks are mounted using a cotter pin spring system to allow for rapid adjustment with changing tooling. Foam was attached to the negatively buoyant tether to bring it to neutral buoyancy.

While piloting the ROV, holding any object, such as the irrigation system, will shift the COM towards the claw. This will cause the ROV to move in ways that the pilot has not intended, as the kinematics system assumes that the COM is where it is when the ROV is unburdened. In order to account for these shifts in the COM, functionality was given to the pilot to dynamically shift the location of the COM of the ROV in software towards the claw, changing how the motors are driven to account for the weight added on the claw.

Payload and Tools

Cameras

SeaHawk II is equipped with three strategically placed cameras which provide the pilot with a comprehensive view of the robot's underwater environment. Two exploreHD cameras were chosen for their waterproof rating of up to 400m, high image quality, and direct compatibility with a single board computer [8]. Unfortunately, two cameras did not provide an adequate field of view. The Raspberry Pi 4 is only equipped with two USB 3.0 ports, so connecting a third camera to the alternate USB 2.0 ports [9][10] would result in significant limitations, namely ten times slower data transfer. Due to this constraint, we determined it was not cost effective to purchase another exploreHD camera as the quality would be reduced. Instead, we opted to waterproof a USB Arducam in a custom housing.

Figure 12: exploreHD housing

Figure 13: USB Arducam housing

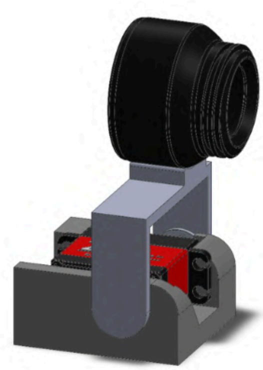
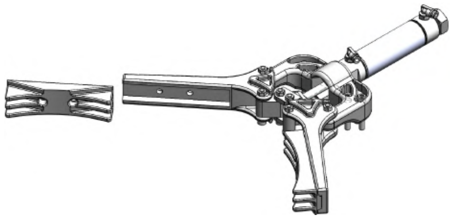


Figure 14: Front camera on servo

The cameras are positioned in a configuration determined to be the most beneficial to the pilot. The primary camera faces forward on a tilting servo, and the two others are positioned on the rear and the bottom of the ROV, respectively. The tilting servo the primary camera is mounted on allows the pilot to actively adjust the field of view. The camera at the back of the ROV permits reverse navigation, enhancing maneuverability. The downward facing camera gives the pilot an aerial view of the tasks.

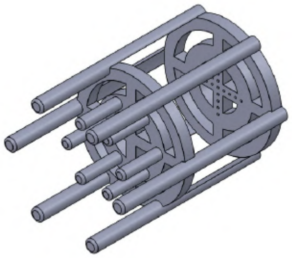
Sending the raw camera data directly to the pilot interface from the ROV is not feasible given the network bandwidth and processing capabilities. For this reason, the feed is encoded in H.264 format before being transmitted and decoded on the surface. The live video is displayed to the pilot on the custom dashboard interface.

Tooling



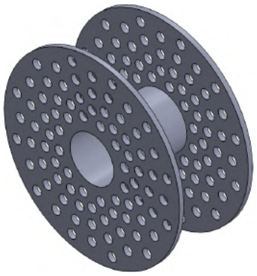
Articulated Pneumatic Claw

SeaHawk II has an articulated claw designed to be modular and adaptable to any task. The claw is pneumatically actuated by the custom manifold and is supplied air through the pneumatic tube in our tether.



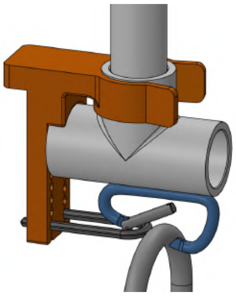
Valve Coupler

The coupler is designed so that the ROV can interact with the valve on the irrigation device and complete the MATE 2024 task “Activate the irrigation system”. The coupler also allows SeaHawk II to deploy cables under water when used with the Cable Deploying Spool



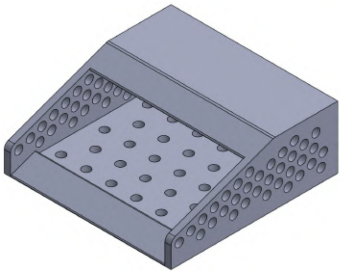
Cable Deploying Spool

The design allows the ROV to deploy the cable precisely underwater and complete the MATE 2024 task “Measure the temperature to check the SMART cable sensor readings".



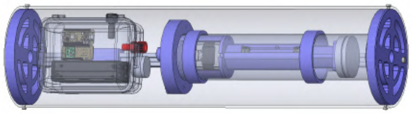
Carabiner Deploying Device

The design is inspired by a stick clip, a device used by climbers to precisely and efficiently place carabiners. The tool allows SeaHawk II to reliably attach lifting hooks to deepsea equipment for an efficient retrieval.



Sample Retrieval Device

The design helps SeaHawk II to easily and reliably retrieve mineral samples from the bottom. Holes eliminate the majority of the drag that would be produced allowing SeaHawk II to maintain its agility and precision.



Vertical Profiling Float

The vertical profiling float (VPF) ascends or descends via a buoyancy engine. A Bar02 depth sensor and 900Mhz LoraWan Radio module send data to the surface.

Sensors

An array of sensors support navigation, data collection, and ensure operational safety. Sensors were selected based on mission requirements, sensor accuracy, and ease of integration. Data is transmitted from the sensors to the pilot interface and displayed to the dashboard.

DS18B20: Temperature Sensor

The Science Monitoring and Reliable Telecommunications (SMART) Subsea Cables initiative intends to enhance monitoring of the deep ocean by leveraging transoceanic cables, equipping them with SMART repeaters. These repeaters house sensors to measure temperature, pressure, and seismic acceleration [11], all qualities which are insufficiently recorded [1]. The MATE 2024 task “Measure the temperature to check the SMART cable sensor readings" requires accurate measurements to verify the functionality of a SMART repeater’s temperature sensor. We choose to equip the ROV with a Waterproof 1-Wire DS18B20 Digital temperature sensor for its waterproof design and accuracy of ±0.5°C with a range of -55 to 125°C [12]. Temperature readings are collected every 0.1 seconds and displayed to the dashboard.

BNO085: 9-DOF Orientation IMU

An Adafruit BNO055 IMU is utilized to provide information about the robot's movement. The BNO085 includes an accelerometer, gyroscope, and magnetometer [13]. The pilot dashboard’s “IMU widget” displays the lateral acceleration on a circular icon as a dot representing the magnitude and direction of the lateral acceleration. Accompanying this graphic is a set of two arrows representing upwards/downwards acceleration. This visual aid assists the pilot in understanding the direction of motion of the ROV to allow ease of navigation throughout the pool.

Bar02: Pressure Sensor

A pressure sensor provides insight into the ROV's vertical position, enhancing understanding of its location. The Bar02 pressure sensor from Blue Robotics was selected for its 0.16mm depth resolution and rating up to 10m [14]. Utilizing the Bar02’s built in pressure and depth sensor readings, we are able to collect data on the current depth (m) and pressure (pa) and display said data on a widget on the pilots main dashboard. These readings will provide us with relevant information regarding the ROV’s vertical position in the pool therefore improving the pilots ability to navigate.

BME280: Environmental Sensor

The electronics housing includes an environmental sensor that monitors temperature, barometric pressure, and humidity to detect any irregularities [15]. While not required for a specific MATE task, the Adafruit BME280 provides insights into the robot's condition.

Leak Sensor

Much like the BME280, the leak sensor is located within the onboard electronics housing and primary purpose is to detect abnormalities ensuring operational safety. If a leak is detected, the pilot is notified via the dashboard and instructed to remove the ROV from the water for inspection. We designed a custom resistive sensor to maximize surface area, and therefore sensitivity, as off-the-shelf options didn't fit our needs.

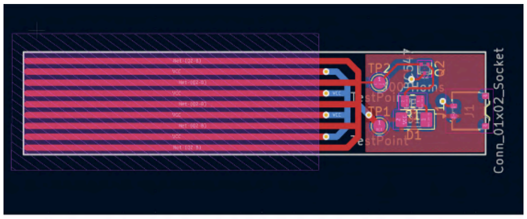


Figure 15: Leak detector PCB

Build vs. Buy, New vs. Used

Components are reused when the result is a cost saving,they meet ROV requirements and have proven reliable based on prior use. New system components were purchased or manufactured when they resulted in improved ROV performance. Last year we manufactured a pneumatic manifold that was highly reliable and reused it this year. New systems this year included off-the-shelf (OTS) camera systems and connectors. In addition, we manufactured a custom frame, electrical box, ESC carrier board PCB, Pi Hat PCB and Power Board PCB in order to make the ROV more compact, maneuverable, and reliable when completing mission tasks.

	System	Justification
Reused OTS systems	**T200 Thrusters**	Meet requirements: Power draw, thrust and efficiency. Sufficient power to complete task (3.1), requires heavy lifting.
	BME280 Temperature and Humidity Sensor	Meet requirements: Accurate ambient temperature and humidity readings of the electrical box.
	Pneumatic Pistons	Meet requirements: High duty cycle, cross sectional area provides sufficient force.
	Raspberry Pi	Meet requirements: Low power draw, highly compatible, sufficient compute power, and extensible GPIO pins
Reused Custom Systems	**Pneumatics Manifold**	Meets requirements: High duty cycle, can drive up to 3 pistons, small size, and lightweight.
New OTS Systems	**Deep Water Exploration Cameras**	Adds support for H.264 video compression and provides far better image quality.
	MacArthery Connectors	Team lacks the ability to manufacture custom overmolded connectors. Disconnectable connectors increase the usability and durability of the ROV.
New Custom Systems	**Chassis**	At comparable cost, a custom frame made from sheet cut parts reduces weight and eliminates protruding features reducing snagging risk on SMART cables.
	Electrical Box	A highly reliable hold for custom electrical stack. Can be opened swiftly and seals properly when closed again.
	ESC Carrier Board PCB	More compact than an OTS option, eliminates cabling.
	Pi Hat PCB	Constrained by the tight space of the electrical box. No OTS option available that meets all requirements.
	Power Board PCB	Constrained by tight spaces, with demands for close to 1kW power draw, lack of OTS options necessitated a custom solution.

Table 3: Build vs Buy, New vs Used justification

Problem Solving

After the 2023 MATE competition, one of the primary issues with the SeaHawk was identified as its drivability, which was attributed to its kinematics software. Improving the kinematics system became a primary goal for the software team as well as the Cabrillo Robotics Club at large. The first meeting of the year dedicated a block of time towards determining a proper replacement for the code of last year. After some discussion, it was decided that modeling the kinematics using pseudo inverses would provide a significant increase in handling as opposed to the SeaHawk's kinematics. After this decision, the Control Systems subteam began to further research ROV control systems, reading papers from the International Journal of Advanced Robotic Systems [16], the School of Mechatronical Engineering of Beijing Institute of Technology [17], and California Polytechnic State University, San Luis Obispo [18]. Informed by the research done by these institutions, the Control Systems subteam was able to make more motivated decisions about the kinematics system.

Safety

Safety Rationale

The safety philosophy of Cabrillo Robotics Club centers around reducing risk in advance of unsafe situations. A dedicated safety officer oversees personnel and equipment safety as well as implementation of operational safety checklists to prevent injuries and increase productivity.

Personnel and Equipment Safety

Mandatory lab safety training of all returning and new team members supported risk reduction and was required in advance of being granted access to work in the team space. The safety officer delivered a general safety training that familiarized members with safety equipment location, accident protocols, personal protective equipment (PPE) requirements (Figure 16), hazmat storage requirements and emergency contacts. Additional training in equipment safety was required in advance of use of power tools. Cabrillo Robotics Club was located on the college campus and followed college safety standards and OSHA guidelines [19]. In the case that an employee worked in an alternate location, the stricter of the two sets of safety standards were applied. Training supported members to demonstrate mastery of risk reduction to help ensure a safe work environment.

Figure 16: PPE usage

One safety improvement that was made this year was the reorganization of our lab space. We cleared our old e-waste, secured network cables to prevent tripping hazards, added tables to increase the number of workstations, and installed shelving to improve storage capacity. Hazardous waste was cataloged and safely stored in a dedicated location. As a result this freed up space, reduced crowding, and allowed us to follow OSHA guidelines closely when working in the lab.

Operational Safety

We identified possible safety hazards through a Jobsite Safety Analysis (JSA). This was used to create an operational safety checklist for risk reduction. See Appendix A for a complete listing of the safety checklist that we developed.

Safety Features

ROV SeaHawk II was equipped with a suite of safety features that reduced the opportunities for injury and streamlined robot operation. To protect ROV operators and the marine environment, all tooling edges are broken. The tether was equipped with a master fuse and strain relief webbing (Figure #). Custom 3D printed thruster shrouds that met IP20 standards, blocked objects larger than 12 mm (Figure 17). Software current limiting prevented thruster mapping from going over maximum power draw. Over voltage protection circuits protected the ROV from voltage spikes. Software enabled a systems check before the pilot instructed tether handlers to deploy the ROV. Once in the water, the software continuously monitored ROV systems. A leak sensor alerted the pilot to seal failure. If any system became unsafe, a kill switch facilitated immediate shut down. An air prep system valve purged potentially dangerous pressure build up in the manifold. In addition, the buoyancy float design included a pressure release valve that is activated in excess of 6 kilopascal in case of emergency or float failure.

Figure 17: Shrouds meet IP2X standards

Testing and Troubleshooting

Testing

Our approach to ROV testing focuses on the design of subsystems that are verified through analysis to test performance in a simulated environment. Once verified, the subsystem is prototyped and physically tested in real world conditions. Finally, components are integrated into the ROV and validated during mission testing.

The primary manipulator components were tested using FEA analysis using SolidWorks non-linear, static stress simulations. A static gripper was tested for human factors to determine if the gripper would break if stepped on by an operator weighing 80kg. It was confirmed that the gripper would remain intact and the bending moment caused by this incident would not cause structural damage to the ROV frame or fixture plate. In addition, the implementation was tested against a load of 100N, it exceeded the threshold required for mission tasks.

FEA analysis

FEA analysis allowed for the evaluation of parts and identified failure modes during the initial design phase as well as during subsequent troubleshooting (Figure 18). It provided valuable insights into how to revise designs to avoid failure. As a result, time and money were saved due to a reduction in physical prototypes.

Oscilloscopes and SPICE simulations

Oscilloscopes were used to do physical troubleshooting of electrical systems. Simulation Program with Integrated Circuit Emphasis (SPICE) simulations were used to build virtual models of power systems. This provided a valuable reference during physical testing.

RViz

ROS offers a powerful 3D software visualization tool called ROS Visualization (RViz) [20], which proved useful for software testing (Figure 19). RViz allowed us to subscribe to a topic which published the newtons that should be produced by each motor and then visualize the corresponding thrust vectors on a CAD model of the robot in real time. This facilitated continuous development and testing of software, independent of hardware. RViz played a crucial role in validating the correctness of the kinematics system.

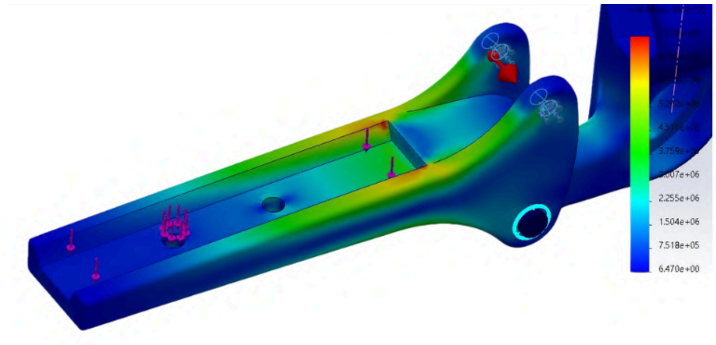


Figure 18: Static stress claw simulation

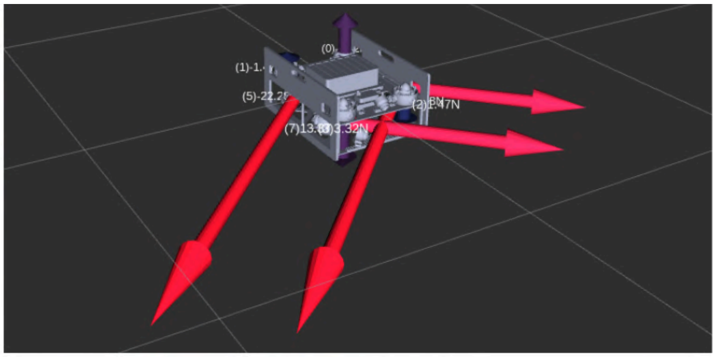


Figure 19: RViz

Troubleshooting

Methodology

In order to properly troubleshoot the ROV during testing, a strong emphasis was placed on using the principles of the scientific method. Before each test, details were recorded about the current setup of the robot, including its current version of software, the different tooling attached, how it was attached, and even the specific controller used by the pilot. Whenever a problem would arise during testing, differences in the setup used between the current and past trials were analyzed, and any specific failure points were tested in isolation in order to determine the root of the issue. By keeping track of the various variables and testing them in isolation, troubleshooting was kept efficient and informative.

Debug Tab

The dashboard interface features a dedicated debug tab for troubleshooting purposes. It displays a graphical representation of diagnostic information from the Raspberry Pi, alongside readings from the BME280 sensor and a fully functional integrated terminal. The graphs provide real time feedback on the state of the Pi, with information including the temperature, bytes sent and received over the network, and CPU and memory usage. The plots enable rapid diagnosis of any abnormalities. A BME280 sensor located in the electronics housing reports the temperature, humidity, and pressure of the environment, which is also displayed. The integrated terminal allows for troubleshooting without having to leave the pilot interface. It supports the usage of troubleshooting command line tools provided by ROS.

Accounting

During our third year competing in MATE, Cabrillo Robotics Club created a budget listing estimated expenses and income. Forecasting the budget this year was challenging due to the complete redesign of all ROV systems except for the pneumatic manifold. Rough high level designs were used to generate a complete bill of materials to the best of our abilities early in the design phase. Based on this, allocations were made to the Mechanical, Electrical, Software, and Marketing teams and adjusted as needed throughout the year, so as not to exceed the total income. Expenses included materials and supplies for robot construction, as well as travel expenses to the 2024 MATE competition. Income came from Cabrillo College, Inner College Council (ICC), and the Student Senate as well as a travel stipend from the Cabrillo Foundation. In addition, the club received sponsorships from companies and discounts on purchases. Finally, income also included funds and donations of materials from our first place win during the 2023 MATE championship.

To ensure that the projected budget is followed, purchase requests are prepared and submitted via club meeting agenda to a vote by club members in accordance with Cabrillo College club bylaws. Purchase receipts are tracked by the club treasurer in a project account balance sheet which is reviewed monthly. Variance in excess of 25% of allocation requires a vote of approval by club members. A project costing report is included in Appendix G.

Acknowledgements

Cabrillo Robotics Club thanks...

Special thanks to

- Parents, family, mentors and friends for their support
- MATE II for hosting the 2024 Competition
- MATE II coordinators, judges, and volunteers
- Cabrillo College Student Senate and ICC for financial support
- Mark Cowell, alumni of Cabrillo's Engr Dept, for generously providing a travel stipend

- Corporate sponsors for discounted and donated materials, parts and software
- Cabrillo Athletic Department for pool access

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Appendix

A. Safety Checklist

Pre-Power

- ☐ Clear the area of any obstructions
- ☐ Verify power supply is OFF
- ☐ Unroll teather and clear tangles
- ☐ Connect the 4 parts of tether to ROV
- ☐ Connect SBS50 connector to power supply
- ☐ Visual check ROV
- ☐ Pull vacuum in electrical housings
- ☐ Check ROV mission tools attached

Power Up

- ☐ Pilot boots up topside laptop
- ☐ Pilot calls team to attention
- ☐ Turn on power supply
- ☐ ROV deployment team verifies ROV electronic status lights
  Green = Clear | Red = Error State
  - ☐ If Red go to **Communication Lost**
- ☐ ROV enters water under control of Tether management team
- ☐ Tether team checks for signs of leaks
  - ☐ If leaks occur, go to **Leak Check**
- ☐ Tether team ensure that ROV remains stationary in the water
- ☐ Ensure ROV is neutrally buoyant
- ☐ Pilot arms ROV and starts thruster test Continue to Launch procedures if no issues arise

Launch

- ☐ Pilot calls for launch of the ROV and starts mission timer
- ☐ ROV tether team lets go of ROV and call, “ROV released”
- ☐ Communicate if any problem occurs during the mission
- ☐ Go to **ROV Retrieval** if mission completed

ROV Retrieval

- ☐ Pilot calls that ROV needs retrieval
- ☐ Tether team pulls up ROV to poolside

Demobilization

- ☐ Pilot turns power supply off and calls out, “Power off”
- ☐ Tether team does inspection for leaks or damage on ROV
- ☐ Leaks are found
  - ☐ Pilot stops ROS and powers off control box
  - ☐ SBS50 connectors of tether are removed from power supply

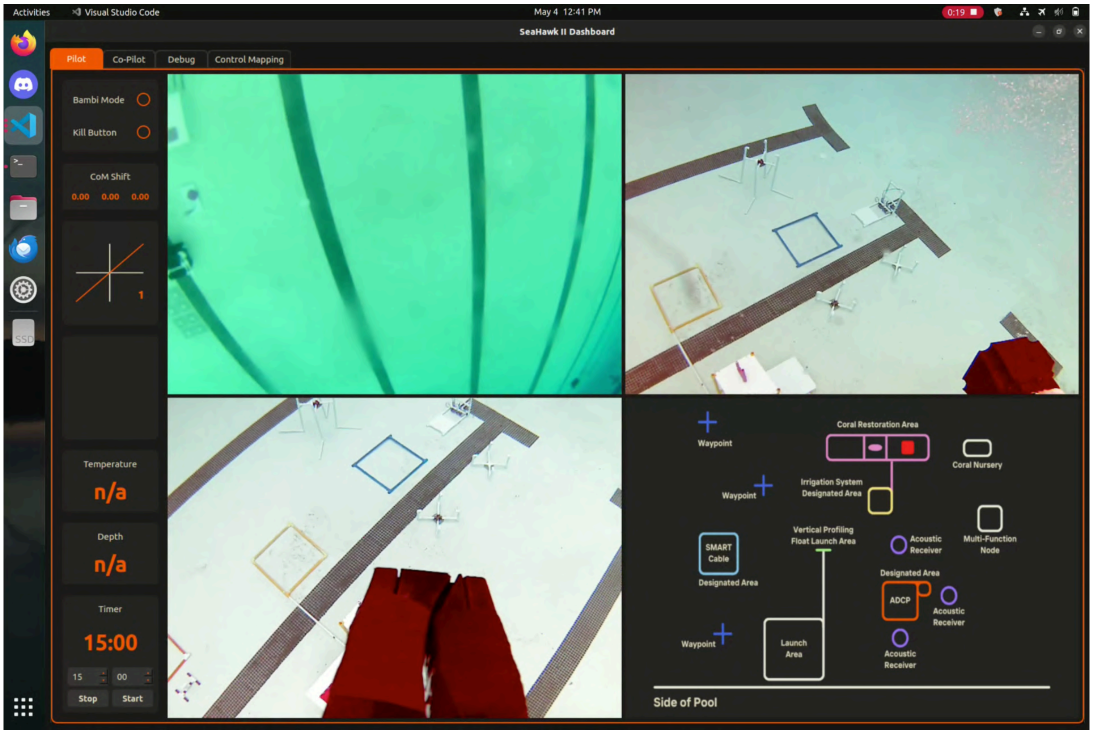
Leak Check

- ☐ Pilot quickly surfaces the vehicle if to many bubbles are spotted during a mission
- ☐ Topside crew powers off ROV and calls “power off”
- ☐ Tether team retrieves ROV

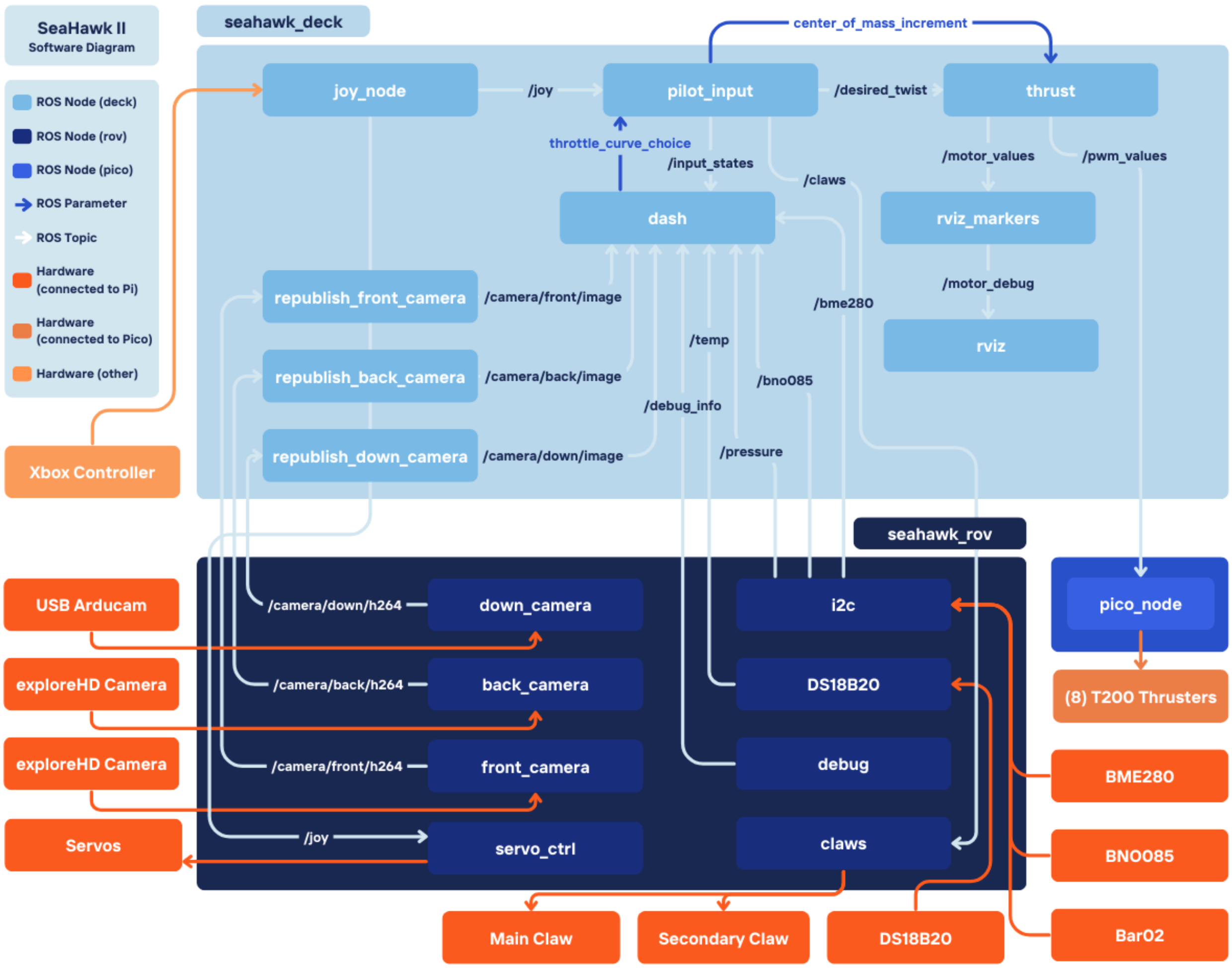
Communication Lost

- ☐ Pilot checks connections on the surface
- ☐ Pilot resets ROS
- ☐ Pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
- ☐ Pilot turns power supply off and calls out, “Communication Lost, Power off”

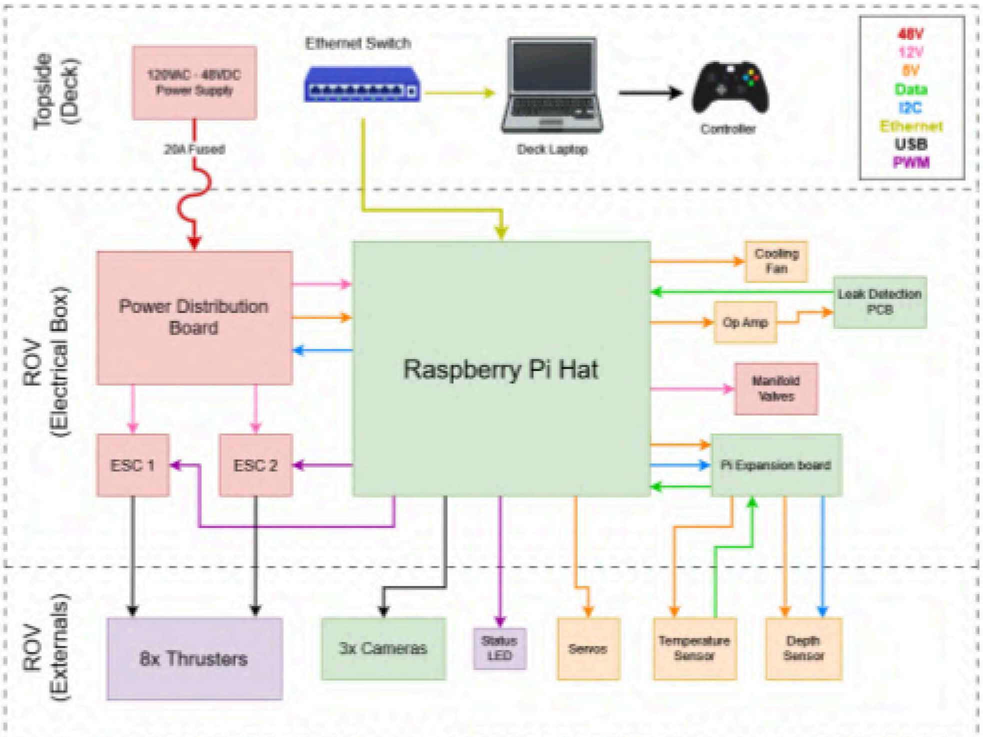
B. Pilot Dashboard



C. Software Architecture



D. Electrical SID



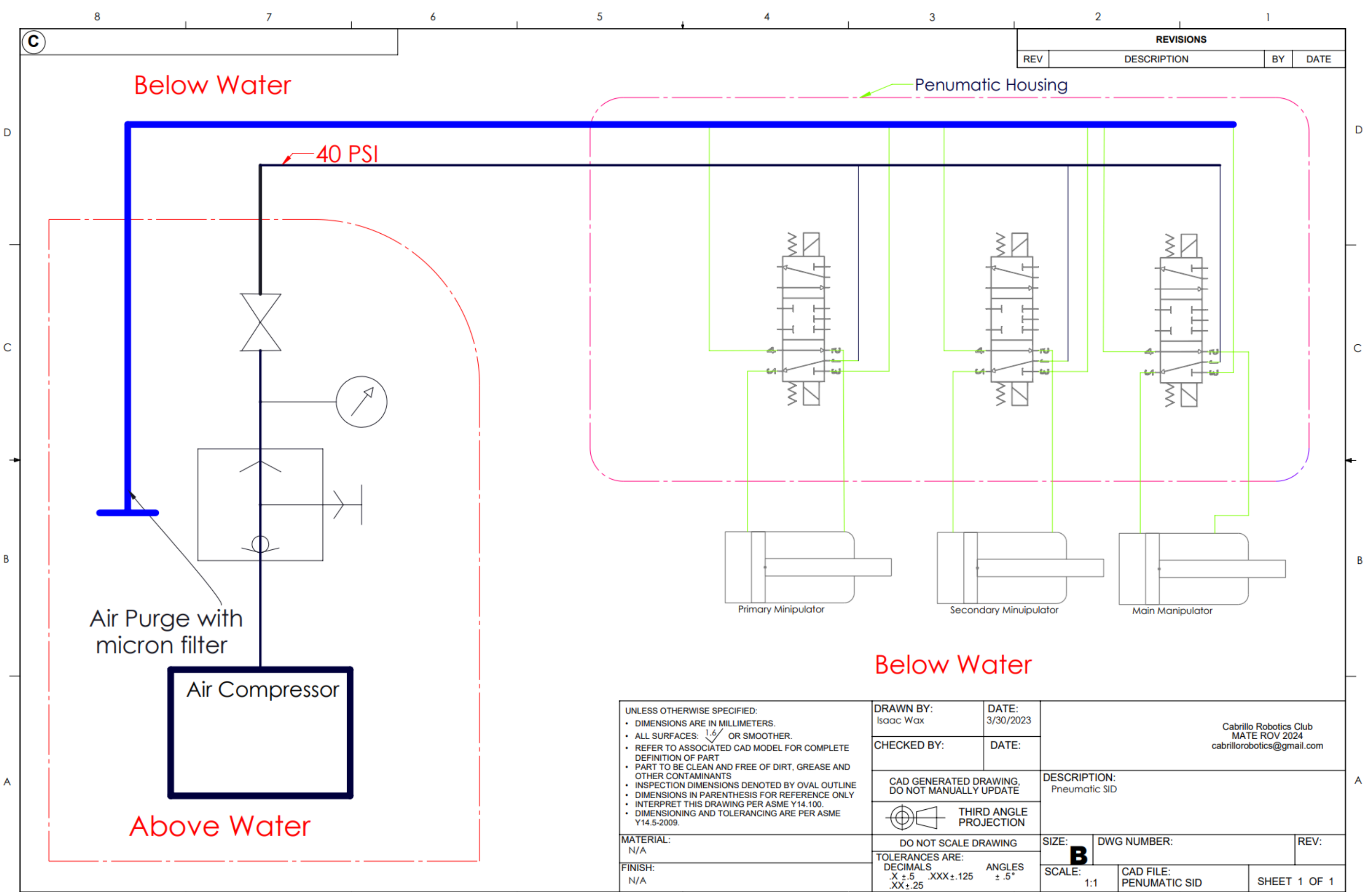
Fuse Calculations:

2x ESC (8x Thrusters),	30A @ 12V, 720W
Pi 4,	2A @ 5V, 10W
Pi Hat,	0.5A @ 5V, 2.5W
Manifold,	1.5A @ 12V, 18W
Cameras,	1A @ 5V, 5W
2x Servo Motors,	2A @ 5V, 20W

Total Power Draw = 776W @ 48V = 16.17A

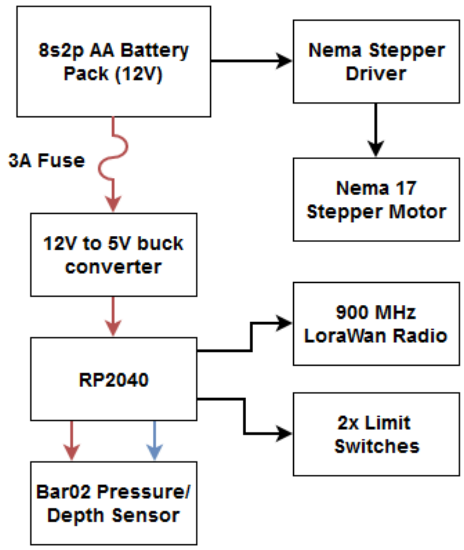
Safety Factor (25%) = 20.2A → **20A Fuse**

E. Pneumatics SID

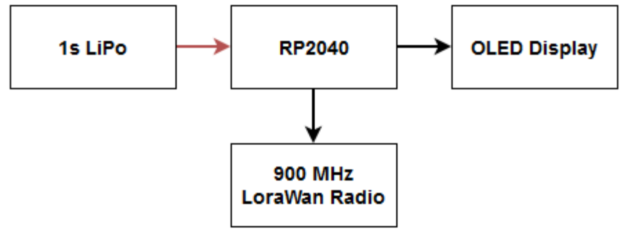


F. Non ROV Device SID

Vertical Profiling Float



Deck



Fuse Calculations:
Battery = 16 AA, 8s2p = 12V, 5700mAh
1x Nema 17 Stepper, 12V 1.7A = 20.4W
1x Feather RP2040, 3.3V 500mA = 1.7W
= 22.1W = ~23 W
23W at 12V = approx 1.9A
1.9A * 150% safety factor = 2.85A
3A fuse was chosen

G. Budget Report

Income	Budget	Type	Productions & Operations Budget & Cost Analysis	Project Cost
Cabrillo College Inter-Club Council	$7,438.18		Available Funds	$18,119.51
Cabrillo College Foundation Account	$4,431.33		Total Budget	$12,925.00
MATE Grant*	$5,750.00		Unbudgeted Funds	$5,194.51
MATE Competition Awards (2023)	$500.00		Production Expenses	$1,955.32
			R&D Expenses	$62.99
			Operations Expenses	$5,561.78
			Value of Re-used Components	$1,824.48
Net Total Income	$18,119.51			
			Remaining Funds	$10,539.42
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Chassis	$400.00	Purchased	Sheet cut parts, mounting hardware	$243.30
Thrusters	$0.00	Re-used	(8) T200 Blue Robotics Thrusters	$0.00
Tether & Connectors	$1,000.00	Purchased	Tether & MacArtney Connectors	$603.52
Single-Board Computers	$0.00	Re-used	Raspberry Pi SBCs	$0.00
Electronics & Connectors	$400.00	Purchased	PCBs and Electronic Speed Controllers	$161.48
Pneumatics	$0.00	Re-used	Valves, fittings, tubing	$0.00

Deckside Computer	$0.00	Re-used	Xbox Controller, Monitor, Laptop	$0.00
Mission Tools	$800.00	Purchased	Claws, Cameras, Sensors	$759.73
Raw Materials	$300.00	Purchased	Plastic, Aluminum Cutoffs, Kapton Tape, fasteners, Epoxy, Consumables, 3D printer filament	$187.29
Subtotal Production Budget	$2,900.00		**Subtotal ROV Production Costs**	$1,955.32
R&D Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Electronic Debugging Equipment	$0.00	Re-used	Set of ROV electronics for software testing	$0.00
Materials	$100.00	Purchased	Fasteners, pistons, o-rings	$62.99
Subtotal R&D Budget	$100.00		**Subtotal R&D Costs**	$62.99
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Mission Props	$300.00	Purchased	MATE mission props	$81.73
MATE Entry Fee	$400.00	Purchased	MATE Entry Fee	$400.00
Fluid Power Quiz Fee	$25.00	Purchased	Fluid Power Quiz Fee	$25.00
Lab Supplies	$50.00	Purchased	PPE, cables	$33.51
Printing	$150.00	Purchased	Poster and other documents	$108.43
Lodging	$1,000.00	Purchased	Airbnb	$636.54
Plane Tickets	$5,000.00	Purchased	Plane Tickets	$3,502.25
Rental Cars	$1,500.00	Purchased	Rental Cars	$774.32
Competition Meals	$1,500.00	Purchased		
Subtotal Operations Budget	$9,925.00		**Subtotal Operations Costs**	$5,561.78