Technical Documentation

ROV Seahawk

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Abstract

Cabrillo Robotics Club designed the Underwater Remotely Operated Vehicle (ROV) Seahawk to meet the needs of our ocean community and global clients. Taking inspiration from the seahawk or osprey's streamlined design, precision, and critical role in sustaining the ecosystem's well-being; ROV Seahawk was engineered to support efforts in revitalizing ocean health. It was optimized to perform tasks in marine renewable energy, to monitor marine and freshwater ecosystem health, and to deploy advanced technologies to track oceanic conditions.

The company is returning to MATE for its second year and has built a reliable, and expandable platform to address this year's challenge and evolve in the future. The simple yet elegant design leveraged robust software to empower a dependable and cost-efficient vehicle.

Cabrillo Robotics Club is organized into four teams: Mechanical, Electrical, Software, and Administrative. Cross-disciplinary teams work together to integrate ROV subsystems. An emphasis on project management, careful budget oversight, and cycles of design review led to the successful completion of ROV Seahawk.

This technical documentation provides in-depth insights into the mechanical, electrical, and software design of the ROV Seahawk, as well as the company behind its creation, and measures taken to ensure safety.

Introduction

Warming, expanding, and acidifying oceans, as well as plummeting biodiversity at near-mass extinction rates are the challenges scientists and policymakers around the globe face today [1]. These leaders and scientists need the data and tools to make informed decisions and execute them on the scale that these problems demand.

Recent advances in technology are empowering a new generation of engineers and scientists to tackle these issues with unparalleled efficacy and scale. That is where we come in. To tackle these challenges, Cabrillo Robotics Club designed the Remotely Operated Underwater Vehicle (ROV) Seahawk.

The ROV is named after Cabrillo College's mascot, the seahawk. A type of osprey, it patrols over both salt and fresh, shallow water and uses its acute vision to spot fish. It plunges into the water to grasp its prey with sharp talons. We took inspiration from the seahawk's sleek design, precision when hunting, and its critical role in maintaining aquatic ecosystem health. ROV Seahawk's simple and elegant design leveraged a robust software architecture running a dependable and cost-efficient vehicle. It was optimized to construct and maintain marine renewable energy infrastructure, monitor marine and freshwater health, and deploy technology to monitor ocean conditions.

In its second year, our ten-member company focused on building a reliable and expandable platform to address this year's MATE tasks and to create a platform that can evolve to meet future challenges. Careful project management, prudent budget allocation, and rigorous design review allowed our team to build an affordable and effective robot to meet this year's MATE challenges (Figure 1).

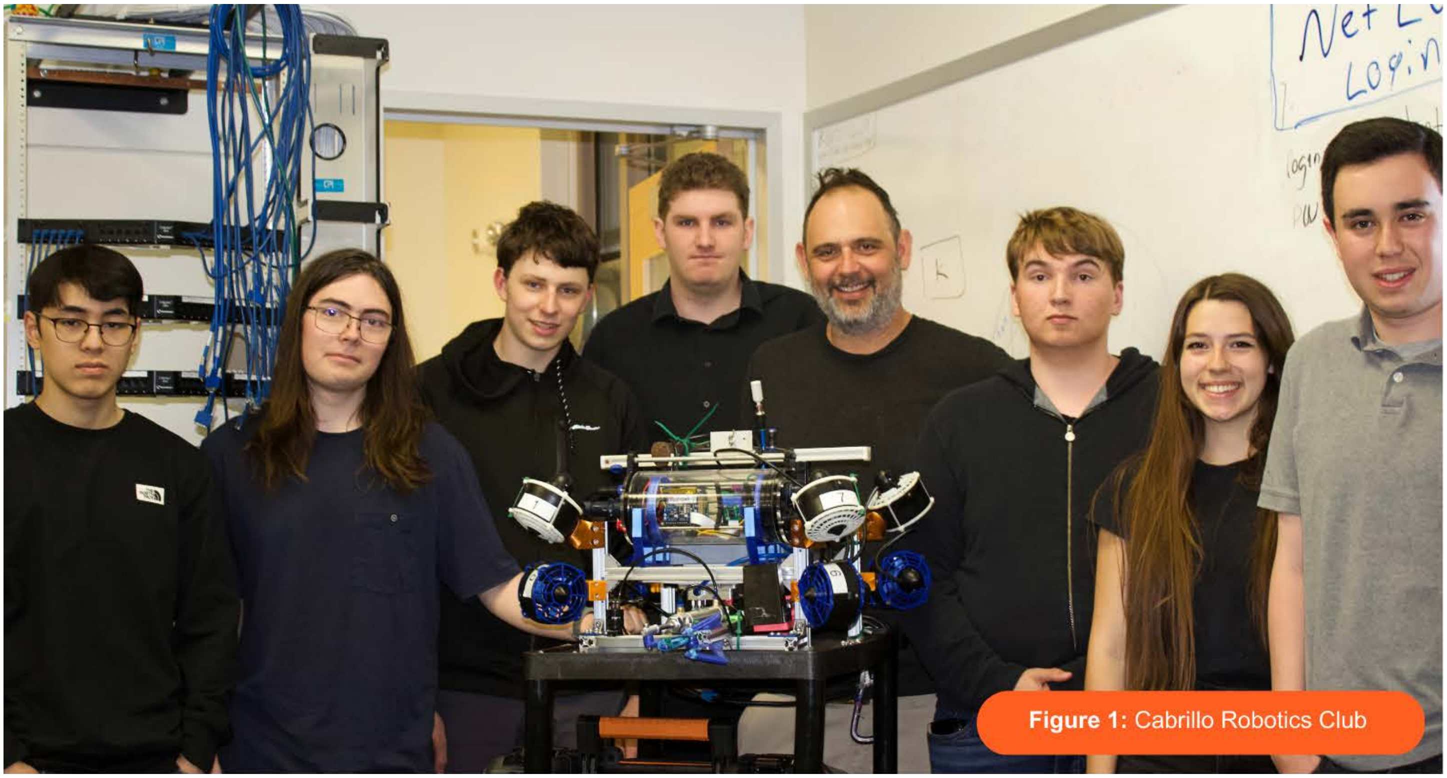


Figure 1: Cabrillo Robotics Club

Safety

Safety Philosophy

Safety was a top priority of Cabrillo Robotics Club when working on ROV Seahawk. A safe environment not only prevents injuries but also increases productivity and comfort. In advance of work on a project, the safety of all workers and bystanders was assured through a thorough inspection of equipment and the work environment. Safety training was completed by all team members before using hazardous equipment or chemicals. Mentoring and supervision of new team members ensured a high standard of workplace safety.

Safety Standards

When working on the ROV Seahawk, Cabrillo Robotics Club required that all employees adhere to a standardized set of safety procedures. The team provided and required that all members use personal protective equipment (PPE) such as eye protection, face masks, eyewash stations, shower stations, first aid kits, and fire extinguishers. Team members were required to wear safety glasses when working with power tools. Cabrillo Robotics Club was located on the college campus and followed college safety standards and OSHA guidelines [2]. In the case that an employee worked in an alternate location, the stricter of the two sets of safety standards were applied.

Safety Features

ROV Seahawk was equipped with a suite of safety features that limited the opportunities for injury and streamlined robot operation. The tether was equipped with a master fuse and strain relief webbing (Figure 2). All sharp edges on the frame were covered by 3D printed custom caps (Figure 3).

A safety checklist was used in advance of the deployment of the ROV Seahawk to protect operators, observers, and the robot (See Appendix A).

ROV Seahawk was equipped with custom 3D printed shrouds that met IP20 standards, blocking objects larger than 12 mm (Figure 4). The shrouds were mounted using M3 bolts to allow for quick replacement. In addition, a maximum rotational speed was set on the software PWM interface limiting current draw on the thrusters to 7 A.

Figure 2: Tether strain relief

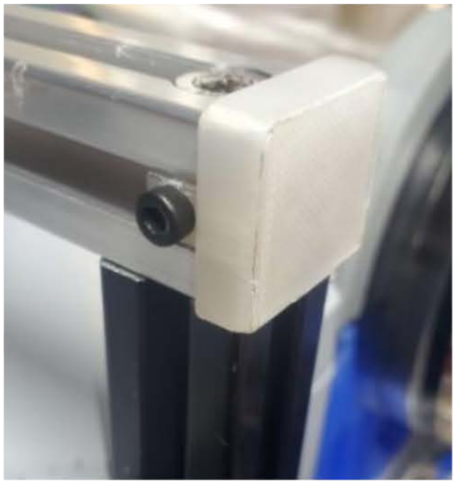


Figure 3: 3D printed custom caps

Figure 4: T200 thruster shrouds

The ROV software provided the pilot with a check on the system in advance of the ROV launch into the water. Once all systems were confirmed safe, the pilot instructed tether handlers to deploy the ROV. Once in the water, the software continuously monitored ROV systems. If any system became unsafe, the pilot was able to immediately shut down the ROV.

Mechanical Design Rationale

Mechanical Overview

In the development of ROV Seahawk, the Mechanical Engineering team prioritized modularity, simplicity, and flexibility. The process of design involved brainstorming, design in SOLIDWORKS, finite element analysis (FEA), and rapid prototyping using additive manufacturing. The design was optimized through rigorous review and improvement of each component and refinement of electrical integration. All electrical housings were first tested using hydrostatic FEA, then rigorously tested in a pool. The ROV was designed and tested to withstand depths up to 10 meters. It was constructed with aluminum extrusions joined with custom-made, anodized, aluminum brackets. We harnessed the power of additive manufacturing to quickly prototype tools and accessories. This allowed tools to be efficiently modified through successive rounds of testing and improvement to meet the demands of many missions. The completed ROV fit within an 85 cm diameter sphere and weighed 12.5 kg, qualifying for membership in the smallest weight and size class. This workflow resulted in a high-value ROV capable of achieving mission tasks with great efficiency and reliability. It allowed for the option of rapid modification to tackle new mission objectives (Figure 5).

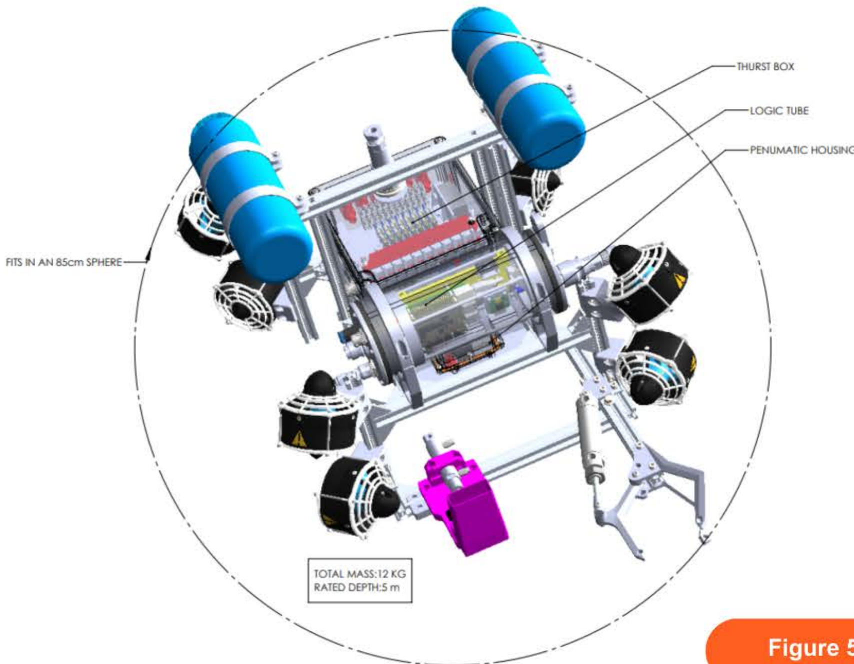


Figure 5: Mechanical overview

Frame

When we set out to design the frame of our robot, we had four goals: modularity, low price, consistent buoyancy, and ease of use. These goals provided guidelines for selecting materials and overall design.

Several frame materials were considered for the design. PVC plumbing pipe was affordable and relatively strong, but lacked design flexibility and affected buoyancy. Carbon fiber tubing was stronger but had many of the same challenges as PVC and a significantly higher cost. To accomplish our goals, we choose a 20x20 t-slot Aluminum extrusion. The slots allow for effortless mounting and dynamic vehicle configuration. The extrusion was rigid, strong, and relatively inexpensive. To connect the extrusion, single common corner brackets were used to join the frame together. This commonality reduced the cost of manufacture and simplified the vehicle's design. All manufactured aluminum parts were made from grade 6061 aluminum and anodized to prevent galvanic corrosion when in contact with stainless steel mounting hardware [3].

Enclosures and grippers were attached so that the center of buoyancy (COB) was placed in line on the x-y plane and was an optimal distance above the center of mass (COM). This resulted in optimized passive stability and control. A ballast system allowed for swift buoyancy adjustments.
Eight Blue Robotics T200 propulsion thrusters, four canted vertically and four horizontally, were mounted using custom FDM printed brackets. Shroud guards were designed and printed for increased safety. Using flow simulations, we were able to minimize shroud impact on thrusters from a 23% to 15% reduction in efficiency compared to the initial shroud prototype (Figure 6).

The initial configuration for camera and gripper placement was improved by using SolidWorks to draw vectors between the camera lens and target view to assure acceptable placement of cameras for ease of view and operation of grippers.

To improve human factors and ergonomics for operators we added a set of lifting handles, an easily adjustable ballast system as well as quick disconnect connectors for electrical and pneumatic systems.

To avoid wear and tear, we designed a swiveling strain-relief system for the tether that was easily detachable and had more than forty degrees of freedom. Replaceable FDM printed caps were placed to cover all exposed corners. Finally, all onboard electronics were positioned conveniently for ease of access.

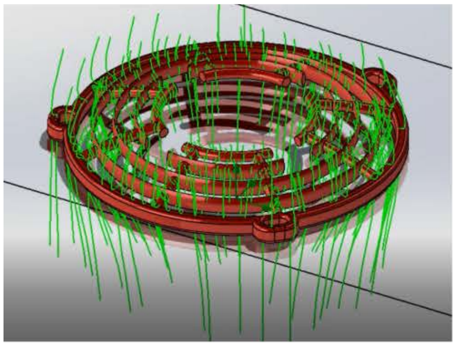


Figure 6: Flow simulation

Logic Tube

ROV Seahawk was designed around a single logic tube made of a modified Blue Robotics four-inch enclosure (Figure 7). The logic tube contained sensors, logic components, and the auxiliary pivoting camera on a custom servo mount. The housing consisted of two old edition Blue Robotics four-inch flanges, an off-the-shelf (OTS) acrylic tube, and two custom sheet-cut polycarbonate end plates. Custom clamping bars locked the end caps into the tube, removing any possibility of them coming loose during a mission. Our analysis and testing showed that this enclosure withstood pressure much above what was required for the mission. Components inside of the logic tube were mounted taking thermal and electromagnetic interference (EMI) factors into account. All power distribution was in the backside of the FDM-printed chassis. More sensitive electronics were placed on the front side. The IMU was placed a maximal distance away from power distribution. The buck converters were mounted to press against the aluminum O-ring flanges to efficiently dissipate thermal energy. Penetrations were made using Bulgin 7000, 6000, 4000, 400, and standard series USB connectors (Figure 8). A blue robotics vent was utilized to pull a vacuum on the housing before every mission to ensure no leakage.

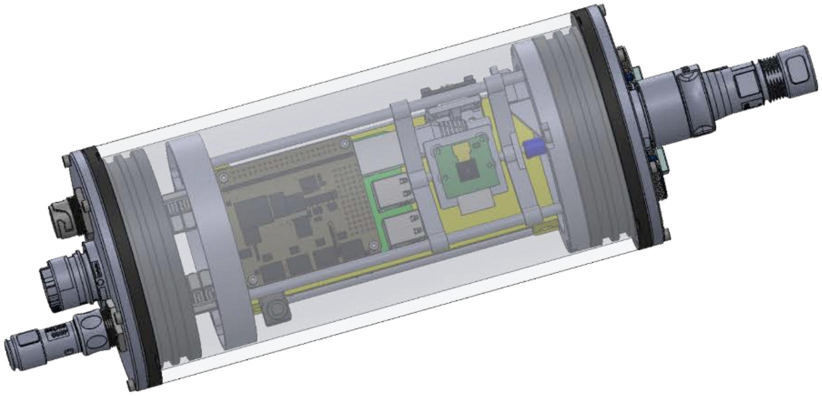


Figure 7: Logic tube enclosure

Figure 8: Logic tube connectors

Thrust Box

ROV Seahawk electronic components were housed in an OTS powder-coated IP68 aluminum box (Figure 9). The enclosure contained high voltage and noisy electronics such as the main buck converters and electronic speed controllers (ESCs). The box had a replaceable neoprene gasket which was compressed with four bolts. Ejector pins were mounted inside of the box and height adjusted to assure that the gasket was compressed evenly into an appropriate aspect ratio. The pins served as a hard stop when they contacted the lid. This assured reliable closing of the box to a set position. This eliminated the need for a torque wrench, saved time, and increased reliability.

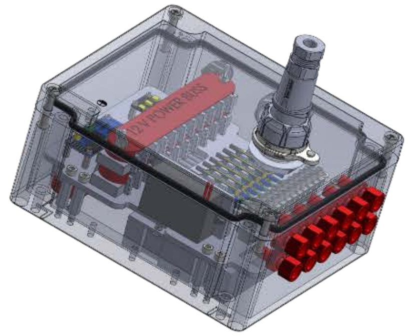


Figure 9: Thrust box

Thrust box electronics were mounted to a custom sheet-cut polycarbonate plate. The eight Blue Robotics ESCs and the 12 V power distribution were mounted and isolated on half of the top side of the plate. The other half of the topside plate housed more sensitive electronics. Wires ran to the bottom side of the plate. The bottom side of the plate housed the main 48 V power distribution as well as the two 48-12 V buck converters. These were modified OTS buck converters. To save space, ribs were machined off the front face of the buck converter to a high surface finish. This maximized the contact area of the buck converter with the thrust box. The aluminum thrust box served as a heat sink to disperse excess thermal energy (Figure 10). Shoulder bolts and springs were used to compress the buck converters against a thermal pad which was compressed against the thrust box. After experimenting with a range of preloads, 40 N was identified as the optimal spring compression force to disperse heat without compromising the structure of the polycarbonate mounting plate.

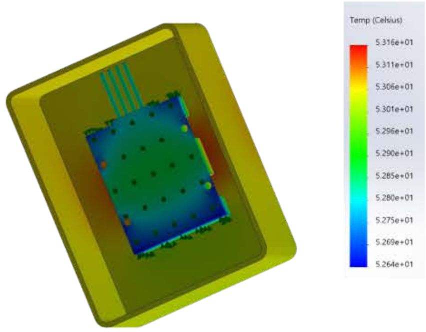


Figure 10: Thermal FEA simulation

Cameras

ROV Seahawk was equipped with three cameras to provide the pilot with clear views of grippers and props (Figure 11). The primary camera was housed in the logic tube. It was a Raspberry Pi 2 camera on a pivot mount attached to a servo that gave a wide range of views (Figure 12). Three external Ardu Cameras provided a wide field of view [4]. One provided views of mission tools, another had a straight-down view for mission tasks and a third had face-up views for profiling float tasks. To allow for adjustment post-manufacture, external cameras were not potted. Instead, they were mounted in a custom housing designed to be opened (Figure 13). An SLS printed flange with two O-ring seals pressed into a 57 mm inner diameter acrylic tube [5]. The other end of the tube was sealed with an optically clear machined acrylic window. The window was pressed into the tube and sealed with epoxy. Inside the tube, an FDM-printed bezel prevented light refraction into the housing and provided mounting holes for the camera. A Bulgin 4000 series USB connector facilitated effortless connection and disconnection.

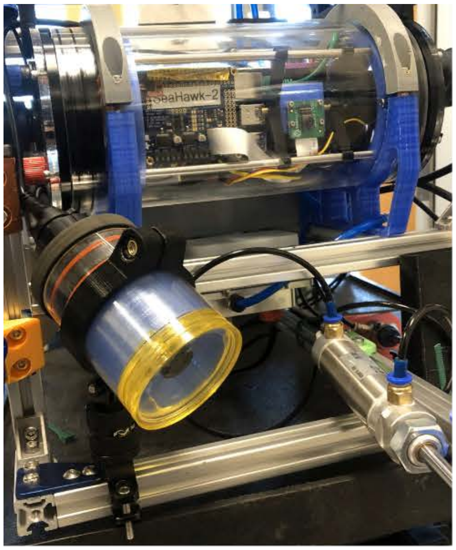


Figure 11: Cameras overview

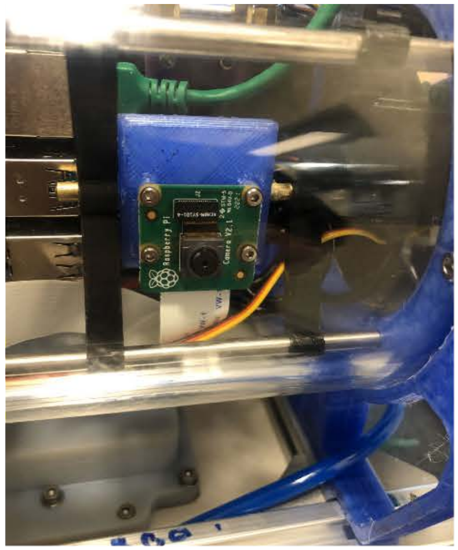


Figure 12: Logic tube pivot camera

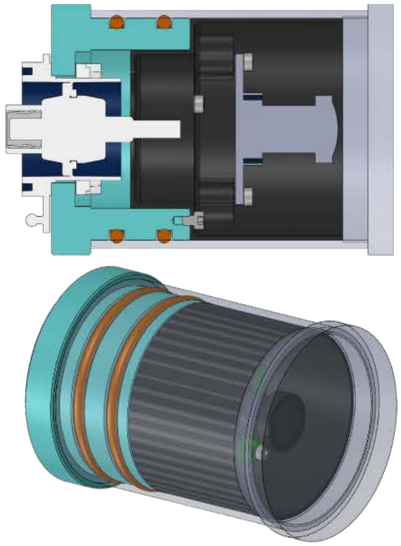


Figure 13: Camera housing

Buoyancy and Ballast

The buoyancy and ballast system was designed to create net-neutral buoyancy to optimize conditions for pilot control. We achieved net-neutral buoyancy through the use of two 1.5 L Nalgene water bottles as a primary external buoyancy source. They were attached to the frame using custom FDM-printed straps. Enclosures and tools were attached so that the center of buoyancy (COB) was placed in line on the x-y plane and was an optimal distance above the center of mass (COM) (Figure 14). This resulted in optimized passive stability and control. A ballast system allowed for swift buoyancy adjustments. For small adjustments, the ballast was added by dropping 6 mm, 34 g, steel pins into custom sheet metal ballast racks. Ballast racks were placed on all four corners of the ROV frame to trim and level the ROV as tools were added or removed (Figure 15).

Tether

The tether was designed to be flexible, but sufficiently stiff to avoid twisting. All cabling was fed through a braided nylon sheath which served as strain relief and evenly distributed external stress across all cables to prevent breakage. Sections of closed-cell polyurethane foam attached to the tether established neutral buoyancy. Nylon webbing was braided around the tether and wrapped with silicon tape to create durable strain relief (Figure 16).

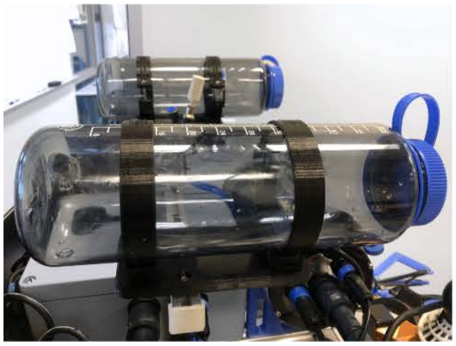


Figure 14: Buoyancy

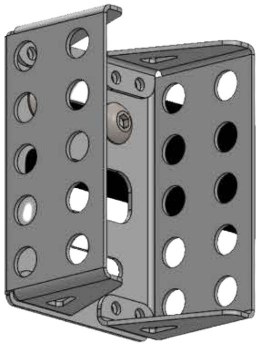


Figure 15: Ballast racks

Figure 16: Tether

Pneumatic System

ROV Seahawk mission tools were powered by pneumatic cylinders (See pneumatic SID design in Appendix C). An air compressor from the surface provided 275 kPa through the tether to the manifold. The manifold mounted three, 4 port, 5-way solenoid valves, which controlled each of the mission tools (Figure 17). Each time a cylinder cycled, the exhaust was vented through the manifold into the pool through a check valve and a micron filter, to prevent water from making its way into the manifold. This lowered pressure on the gripper and resulted in a higher working pressure differential without the need to run a second air line through the tether. The valves were face-mounted to a custom aluminum manifold. On top of the manifold was an SLS-printed case with a custom sheet-cut gasket to form the manifold enclosure.

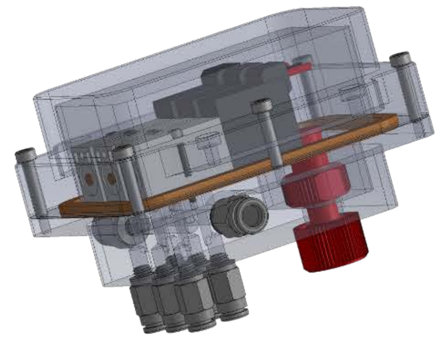


Figure 17: Pneumatic overview

When designing the manifold, we prioritized optimization of flow rate and minimization of cylinder cycle time. Due to the high complexity of air routing channels and small tapped holes, machining was deemed the most reliable manufacturing method. The pressure inlet, purge, and tool I/O lines all used threaded push-to-connect pneumatic fittings to interface with the manifold. The solenoids used were SMC's VQD1151-6MO [5], which had an effective area of 17.6 mm^2 and a Cv of 0.78. These valves were selected for their small footprint, high flow rate, and high-duty cycle. With these valves, the ROV was able to cycle at 3 Hz, a marked improvement over the prior design that used small servo motors.

Manipulators and Mission Tooling

ROV Seahawk had a highly configurable tooling system. Up to three pneumatic cylinders were driven to activate mission tools. The primary manipulator was located in a horizontal gripping position on the front of the ROV. The gripper was mounted with T-slot nuts to the aluminum extrusion frame. The position on the frame and horizontal extension out from the frame was adjusted by repositioning relative to the frame and locked down by T-nuts. Two stationary overlapping jaws and one pivoting overlapping jaw were driven by pistons providing 70 N of clamping force. Surgical tubing stretched across the jaw provided a cushion for jaw action. All jaw parts were FDM printed out of PETG and assured high strength, impact resistance, and adequate thermal properties (Figure 18). A fry release fixture was designed with a hopper for the fry payload. A sliding gate across the bottom of the hopper

Figure 18: Manipulator

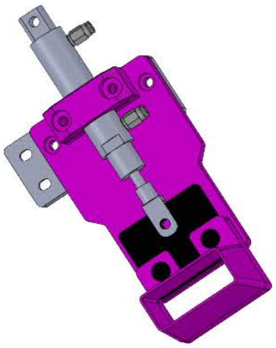


Figure 19: Fry release

Figure 20: Syringe

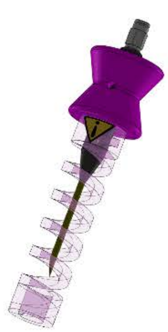


Figure 21: Water sampling

was actuated by a pneumatic piston and released fry gently (Figure 19). For tasks that require syringe injection, a tool was developed and manufactured to allow for reliable syringe injecting tasks (Figure 20). For the water sampling task, a sharp probe was attached to a tube that ran to the surface. On the surface, a pump collected the water sample in a blader. To avoid the risk of large dead volumes, a 2 mm ID tube was chosen for pumping the fluid to the surface (Figure 21).

Vertical Profiling Float

The vertical profiling float was driven by a buoyancy engine, according to competition guidelines. An internal reservoir was pumped or drained with water pulled from outside the float by two 9 V electric air diaphragm motors to change the buoyancy and allow the float to move up or down in the water. The float was powered with an onboard battery pack made from alkaline AA batteries, with a 5 A fuse to prevent overcurrent (See SID design in Appendix D). Upon a successful vertical profile, defined by MATE ROV as a descent to the pool floor, and ascent back up to the surface, the float continuously transmitted data including team number and an accurate time reading in UTC to the control station that refreshed every second. The float accomplished this through a packetized radio module operating on 900 MHz for transmission, and a GPS module for keeping time. The entire assembly was enclosed in acrylic tubing for a sleek outer design. A machined pressure relief plug was fitted to the bottom that detached in the scenario where unwanted pressure buildup occurred within the battery housing. The float also included a marked antenna on top, for easy identification when surfacing (Figure 22).

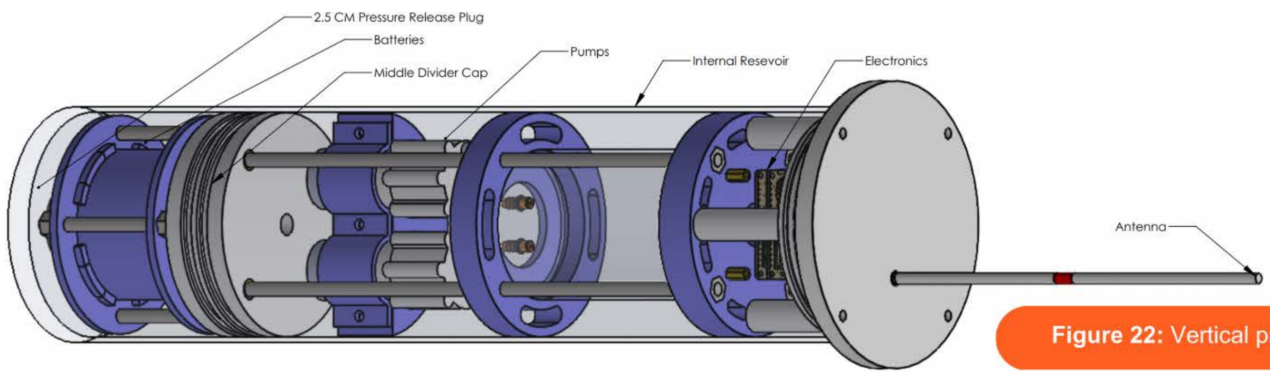


Figure 22: Vertical profiling float

Material Selection and Manufacturing

For manufacturing of the ROV, we utilized two key disciplines: additive manufacturing and machining. Due to budget and time constraints, additive manufacturing was used whenever possible.

CAD data and BOM

Organization was key to our team's success. We opted to use SOLIDWORKS PDM to store CAD data to make it easily accessible from all remote locations. SOLIDWORKS PDM prevented team members from saving files that overwrote others' work. This solved the overwrite problem we encountered when using the Google Drive desktop application. To easily track company parts and status we created a proscribed numbering system utilized in our bill of materials (BOM). The numbering system consisted of a number pulled from our part database and a number that denoted if the part was an assembly, an OTS component, or a custom part. This allowed us to instantly track down information, CAD files, drawings, and CAM programs.

Electrical Design Rationale

Overview

The electrical design of ROV Seahawk prioritized repairability, modularity, accessibility, reliability, and cost-effectiveness (See SID design in Appendix B). The ROV control was initiated via a shore base station. The station consisted of a pilot, a computer, a monitor, a router, and an Xbox 360 controller. A CAT6 ethernet cable and 48 V power supply were the electrical connections in the tether. A CAT6 ethernet cable was used to minimize noise and entered the logic tube. The power cable sent 48 V to the thrust box via 2 strands of 12 gauge marine-grade wire with an in-line 25 A fuse [6].

Power Distribution

We opted to use 48 V power. Power entered the thrust box and was converted from 48 to 12 V using two 12 V 30 A buck converters to power the eight thrusters. The 48 V was converted to 5 V using a 5 V 3 A buck converter to power thrust box sensors. The 48 V leaving the thrust box entered the logic tube and was converted to 5 V with two 5 V 3 A buck converters. One buck converter powered the Raspberry Pi and a second powered the logic tube sensors. In addition, a 48 to 12 V buck converter in the logic tube powered the solenoid board that drove the pneumatic system (Figure 23).

Sensors

ROV Seahawk was equipped with a 9-axis IMU, including an accelerometer, gyroscope, and magnetometer as well as multiple cameras (Figure 24) [7]. A BME280 sensor in the thrust box and a second sensor in the logic tube detected temperature and humidity [8].

Tether

The tether consisted of a siamese cable of two strands of 12 gauge wire and one CAT6 ethernet cable (Figure 25). It was 30.5 m long. Using 48 V allowed us to use a much thinner power cable. This significantly reduced cost and weight.

Figure 23: 12V buck converter

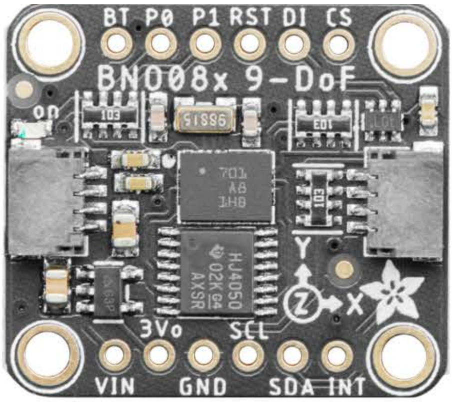


Figure 24: IMU sensor

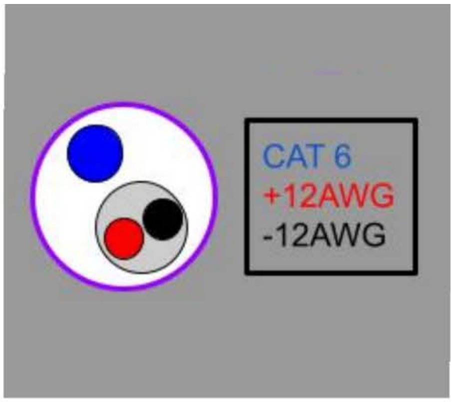


Figure 25: Tether cross section

Computers

On the surface, a single board computer was connected to an open WRT router. The router talked to a 4 Gb Raspberry Pi 4 in the logic tube. This was connected to an Adafruit PWM hat and an

Adafruit stepper motor driver hat used to control solenoid valves. The I2C bus was used on the Raspberry Pi 4 to connect to the logic tube IMU and BME280 sensors. Then the I2C bus exited the logic tube and entered the thrust box. It connected to the thrust box PWM board which controlled the thrusters using hardware-generated signals. It is also connected to the thrust box BME280 sensor.

Valves

Solenoid valves operated on 12 V with a 0 V or 12 V logic. Application of 12 V activated air intake; 0 V released air. An Adafruit stepper motor-hat was programmed to act as a relay by either disabling the output or shifting it to a full duty cycle.

Topside Control Box

The topside control box comprised a durable project box equipped with plates for surface mount electronics, including a single board computer. In this year's model, the topside control box was updated with the inclusion of a portable screen, a server motherboard, and a router, all built into the same box as the mate PSU. This design represented a more integrated solution than the previous year's setup, where all the components were stacked on a cart. This updated design offered streamlined functionality, allowing users to quickly and easily set up the ROV system. Users needed only to pull up, open the topside control box, plug in the ROV, power up the system, and begin operations. This new configuration was intended to reduce setup time and minimize the potential for error during the ROV operation.

Wiring Harnesses and Electrical Connections

To facilitate easy connection and disconnection, Bulgin series connectors were utilized. Specifically, we employed standard series USB for the USB external cameras, 400 series power for the STEMMA QT I2C connections, 4000 series power for the pneumatic solenoids, 6000 series power for the 48 V connection between the two boxes, and 7000 series power for the tether 48 V connection. To avoid catastrophic connection errors and ensure proper connections, all wiring harnesses followed a strict color-coding scheme that corresponded to pin-out spreadsheets. Furthermore, OTS wiring harnesses of the Adafruit STEMMA QT series were utilized for the I2C BUS. This approach eliminated the potential for human error during the wiring process, resulting in a significant reduction in electrical troubleshooting.

Software Design Rationale

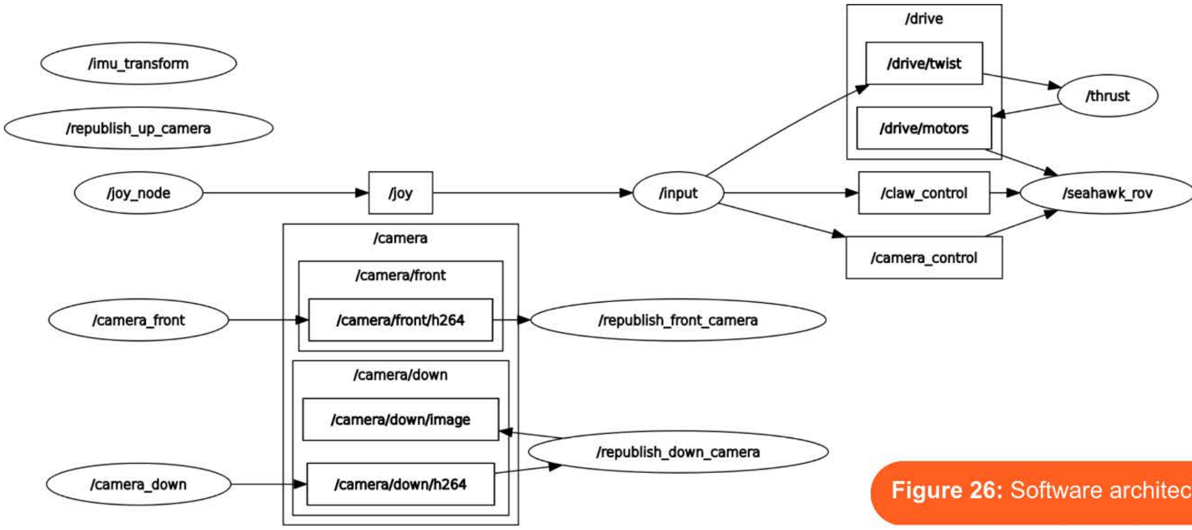


Figure 26: Software architecture graph

Overview

ROV Seahawk carried on the legacy of last year's champion ROV Hydrozoa by using the Robot Operating System (ROS). However, this year there were many substantial changes, including the major version jump between ROS1 and ROS2. This was an incredible challenge, and in fact, the only constant between the software for both years was the fact that ROS was used at all. Everything else was completely redone. The newer functionality of ROS2 enabled a more modular design approach, allowing our Python code to be separated more clearly by files and thus be more reusable and maintainable [9]. The additional decision to use a distinct control box for ROV Seahawk permitted the creation of Ansible scripts for replicable state deployment and system modification. Our Ansible scripts meant that we could turn a brand new Raspberry Pi into a functioning ROV in just 20 minutes (Figure 26).

Pilot Interface

The ROV Seahawk was equipped with a diverse array of sensors, resulting in a significant concern regarding how to display the voluminous data generated. However, utilizing the RQt system of GUI ROS components, we were able to readily create a pilot interface. The interface includes a front camera view, along with a secondary Picture-in-Picture view overlaid atop the front camera, which allowed for switching between ROV Seahawk secondary cameras. Additionally, the interface featured dynamic indicators for control modifier state, internal pressure, humidity, and temperature warnings, as well as a visualization of the IMU. These data visualizations were positioned on the side of the interface (Figure 27).

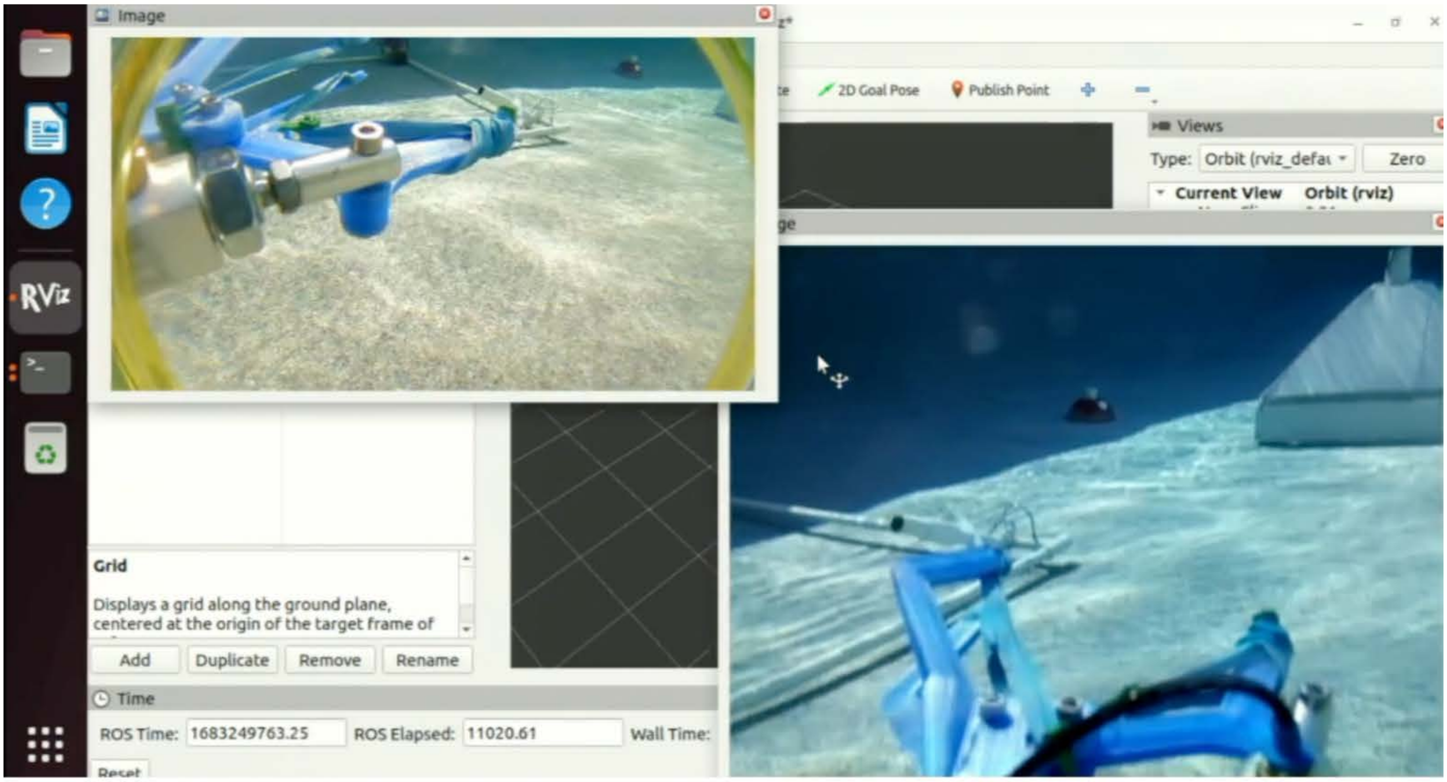


Figure 27: Pilot interface

ROS

ROS played a crucial role in enabling communication among processes running on multiple systems. ROS's support for modularity and communication among processes and systems facilitated the creation of independent ROS nodes, which communicated via ROS topics, the interprocess communication system. To enhance our development process, we leveraged third-party libraries and packages for ROS, such as Adafruit files, which utilize solutions that exist within the ROS community to address known issues. In addition, we implemented a PID controller with the help of these third-party resources, enabling the software team to focus on innovation and tackle challenges specific to ROV Seahawk.

Control Systems

ROV Seahawk was programmed to be controlled using an Xbox One controller ROS node. This X Y Z input was then manipulated to provide vectors to each motor. Multiple inputs that tell a thruster to go in the same direction were handled using a formula modeled after probability union operations. For more precise control, there was an option to cut all input signals in half. ROS parameters were used to set limits on movement along the axes if necessary.

Cameras

Remotely operated robots need a way for human pilots to gather context about the current operating environment. Fortunately, ROV Seahawk's 3 cameras provided an abundance of vision all around the robot. Sending these camera feeds to the control box as raw data would have overloaded both the network and processing capabilities of both ROV Seahawk and the control box. That's why native h.264 stream codec support was implemented, which freed up a large amount of both network and encoding bandwidth.

Team Management

Our company utilized the multitude of features provided by GitHub for many levels of our project. The primary organization and communication platform was Discord. However, for design ideas, improvements, and flaws, these were all categorized using GitHub Issues, then managed using the various features of a GitHub projects board, including Kanban and Spreadsheet view. This enabled a high-level overview of all known upcoming work.

Rviz Testing environment

One of the features of ROS is a bit of software called Rviz. Rviz permits the viewing of many things, from 3 dimensional robot models and movement information, to camera feeds and visualized published ROS topics. Given the motor's 45° offset from the primary coordinate system, we had to be sure each manipulation of the control device would push the motors at the correct velocity in the correct direction (Figure 28).

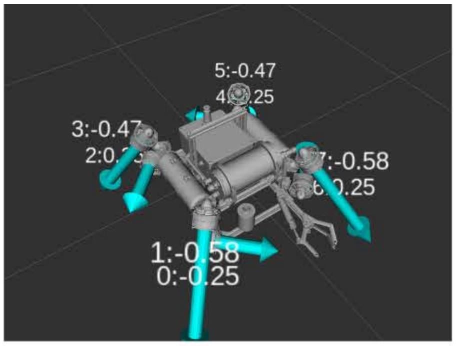


Figure 28: Rviz Testing environment

Logistics

Company organization

The Cabrillo Robotics Club organizational structure was based on experience gained in our first year as well as the prior experiences of the CEO, CFO, and other team members who led MATE ROV teams in high school. Three technical teams, Mechanical, Electrical, and Software, handled the technical needs of the ROV. Each team was headed by a lead or co-leads. In addition, Project Management, Finance, and Marketing teams provided administrative support. All leads reported directly to the CEO. Interdisciplinary project groups worked on the integration of the ROV subsystems. Engineering Integration groups formed subsystem project teams to work on the frame and buoyancy, manipulators, power enclosure, electronics, and ROS. This approach supported the communication required for complex engineering integration tasks.

Project management

Cabrillo Robotics Club prioritized robust project management to increase productivity and efficiencies for onboarding new members and managing teams. The design cycle had four stages: training, designing, manufacturing, and testing. The training phase onboarded all new members in relevant areas of SolidWorks CAD, FEA, CAM, CMAKE, Python, and GitHub use for their team. Training processes were documented and were utilized to train returning members as needed and will be used with new members next year.

The CEO and technical leads utilized Discord, Google Calendar, and GitHub scheduler to deliver project management. Task boards organized deadlines and were housed in the company GitHub Repo to visualize workflows and production dependencies (Appendix E). Weekly meetings were held to help team members understand task priorities and what tasks depended on task completion. Blockers were reviewed and timelines were revised to accommodate workflow revisions. For communication and meetings, we made Discord channels for all teams and subteams. Technical leads made general architecture decisions utilizing SIDs before mission tasks were announced. The design phase continued and made refinements once mission requirements were announced. Sketches and prototypes were posted to Discord channels for team discussion and revision. Weekly the company held an All Hands meeting to discuss progress and high-level planning. Employees collaborated during meetings and additionally met in person in small groups to finalize the design phase. Final prototypes were made and submitted for design review by company advisors. Revisions were made based on design reviews to get ready for the manufacturing phase.

System teams worked together to manufacture ROV components according to the project management plan. Essential components were prioritized and all components were manufactured to meet scheduled deadlines. Upon completion, each component was tested in isolation, then added to the system and tested in the air before being introduced to water. If a component failed it was redesigned to address problems. Once all systems passed testing, the ROV was assembled and tested. Finally, non-essential tools and software features were introduced to complete the manufacturing phase.

The testing phase of the fully assembled ROV included the addition and refinement of tools and software. Buoyancy adjustments were made as tools or other components changed. Piloting software was refined to adjust to pilot and vehicle operation needs while performing mission tasks. Mission tasks were prioritized based on success rate and time of completion to assure a high score for the mission.

Budgeting

During our second year competing in MATE, Cabrillo Robotics Club created a budget listing expenses and income (Appendix F). Allocations were made to the Mechanical, Electrical, Software, and Administrative 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 2023 MATE competition. Income came from Cabrillo College, Inner College Council (ICC), and the Student Senate. In addition, the club received sponsorships from companies and discounts on purchases. Finally, income included funds and donations of materials from our first place win during the 2022 MATE championship.

Conclusions

Testing and Troubleshooting

In its second year of ROV development, the Cabrillo Robotics Club designed, tested, and improved fundamental ROV systems. The software was tested and improved. All electrical connections and circuit boards were checked for continuity and functionality. Seals were pressure tested in advance of ROV assembly. Cameras, thrusters, and grippers were tested in the air before deployment in water. When a component failed, technical documentation and testing were used to address the malfunction. Once fully functional, the ROV was deployed to execute mission tasks in the pool. To further develop components, they were tested in isolation. In some cases, simulations provided data to help optimize designs.

The Safety Checklist (see Appendix A) was followed before powering the vehicle. Control, piloting, and buoyancy were adjusted based on pool tests. Once optimized, pool tests allowed the practice of mission runs to assess difficulty and time to completion.

Challenges

Cabrillo Robotics Club faced new challenges this year. Struggles with full remote protocols, funding delays, and supply chain shortages were resolved. This freed us to focus on new demands as we radically rebuilt and boosted our ROV to the next level. One challenge was identifying the source of leaks in electrical housings. After much troubleshooting, we identified the source as malfunctioning Bulgin waterproof connectors. We pulled a vacuum on our enclosure on land to verify the seal of the enclosure. We discovered that even a small force applied to the connectors caused the O-ring to not compress properly leading to leaks once the enclosure was submerged in water. To address this problem, we potted the backsides of the connectors to assure that if water seeped in, it would not enter the enclosure. Another challenge was associated with the I2C bus. To implement control systems, we needed to pull data from the IMU at a high sample rate. The bus was overwhelmed and latency was drastically increased when the ROV was operated. We were able to solve this problem through the implementation of multithreading in the ROV software.

Lessons Learned and Skills Gained

Cabrillo Robotics Club members learned valuable technical skills while working on ROV Seahawk. Teams shared knowledge and skills while working to integrate systems. The Mechanical team shared knowledge about SolidWorks, FEA, CAM, 3D printing, and machining. The Electrical team shared experience in schematic design, soldering, and proper use of oscilloscopes. The Software team shared knowledge of Git, ROS, Linux, and Python. The administrative team provided best practices for time management, budget management, documentation, outreach, and communication.

Weekly meetings provided opportunities for team members to work on presentation, communication, and writing skills. Teams presented their work and received feedback from team members and advisors. Written documentation was created to list the design rationale, testing data, implementation results, and plans for future improvements for all ROV components.

Outreach activities allowed team members to share knowledge learned with the general public at local talks, expos, and student club recruitment events. We created a video about robotics featuring our club ROV and were invited to demonstrate the ROV at local public schools to encourage students to study STEM [10]. We mentored local middle and high school ROV teams who were preparing for this year’s MATE competition.

Future Improvements

Custom Electrical Box: An OTS box served us well this year, however, even better would be a custom-made box that is designed around our electronics with mounting holes and sufficient surfaces for penetrations. This would allow us to include all electronics in one enclosure, reduce the number of penetrations and minimize weight.

Custom Buck Converter: Our current Buck converters were affordable and reliable. A custom Buck converter would address low efficiency and current inadequacy to allow the running of all thrusters off one Buck converter. In addition, customization would allow a reduction in footprint and weight.

RVIZ Model of Competition Environment: The current RVIZ environment included the ROV with all linkages which was useful when developing and debugging software for the ROV. In the future, we hope to integrate a swimming pool and all MATE ROV mission props into the environment to allow pilots to conduct virtual test drives. This also would facilitate training the ROV for AI tasks without the physical use of a pool.

Reflection

Cabrillo Robotics Club values the MATE ROV competition for the chance it provides to explore our limits, take risks, and devise unconventional solutions to problems. Our primary focus is on the learning journey and the fun we have while playing with robots and making new friends.

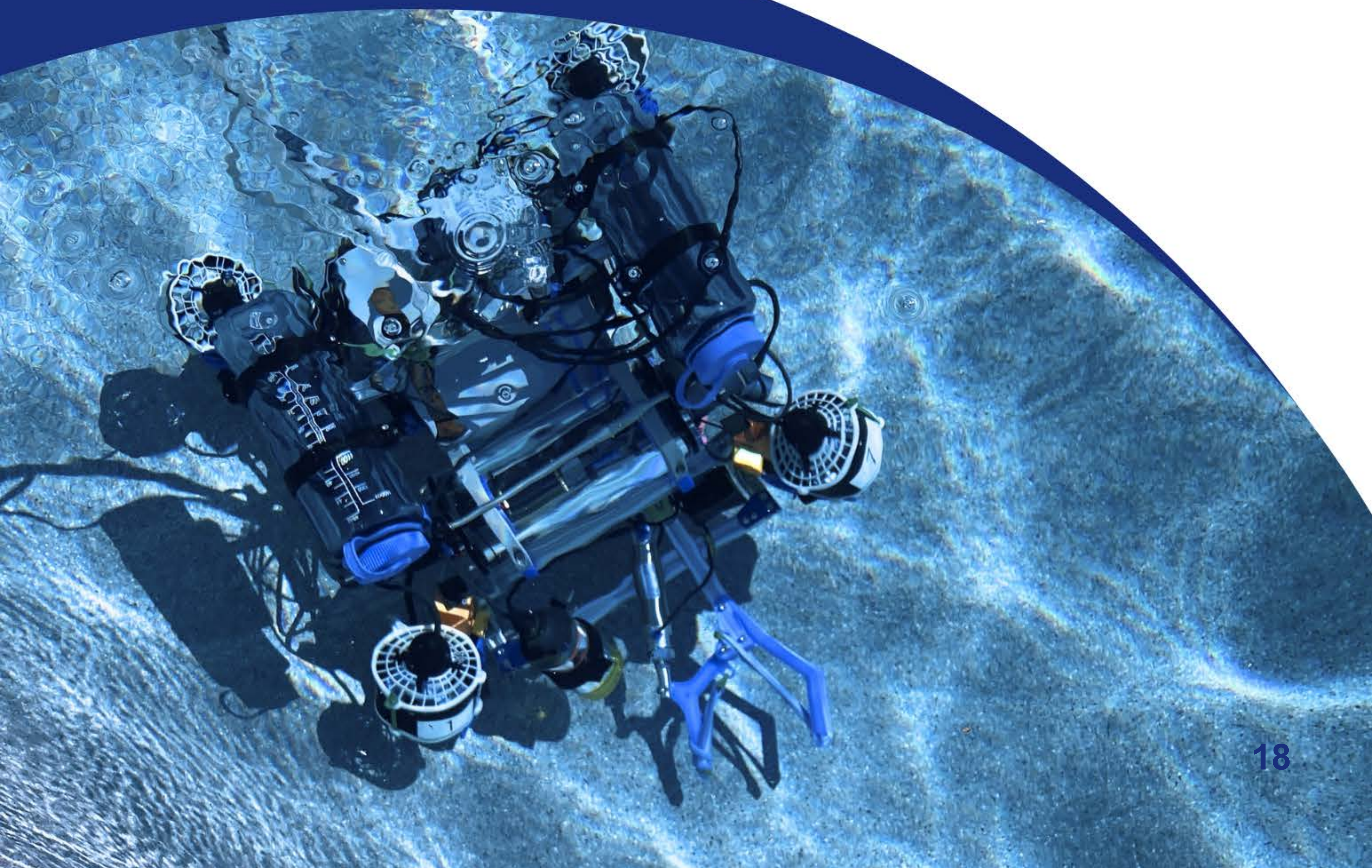
Team member quotes

"It's really interesting dealing with the added complexity of designing a robot to be underwater in a chlorinated pool" - Ciaran Farley

"Making a robot is easy, the hard part is making it last" - Orion Ellefson

"Every year I participate in the MATE Challenge. I think the experience cannot get better. This year was even more fun than usual. It's amazing how the previous year's ROV design seems perfect, but by the next year, it seems like a heap of garbage, and there's so much you want to change. I grow my knowledge so much with each MATE participation. It's awesome how there's always room for improvement, and the ROV changes like crazy every year."
-Isaac Wax

"Being a part of the software team has been a valuable experience that has deepened my understanding of programming complex robots and collaborating with a group of individuals working toward a common goal. This was my first time working on software development within a team setting, and the skills I have acquired will be beneficial in future endeavors, from more ROV building and beyond." -Stephanie L'Heureux



Appendix

A. Safety Checklist

Pre-Power

- ☐ Clear the area of any obstructions
- ☐ Verify power supply is OFF
- ☐ Connect tether to ROV
- ☐ Connect SBS50 connectors of tether to power supply
- ☐ Check ROV
- ☐ Pull vacuum in electrical housings
- ☐ Check ROV attached mission tools

Power Up

- ☐ Pilot boots up topside control box
- ☐ Pilot calls team to attention
- ☐ Turn on power supply
- ☐ ROV deployment team verifies ROV electronic status lights
- ☐ ROV enters water under control of Tether management team
- ☐ Tether team checks for signs of leaks
    - ☐ If leaks occur, go to Leak Check
    - ☐ Otherwise, continue the Power Up sequence
- ☐ 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

Leak Check

- ☐ If any bubbles are spotted during a mission, the pilot quickly surfaces the vehicle
- ☐ Topside crew powers off ROV and calls "power off"
- ☐ Tether team retrieves ROV

Launch

- ☐ Pilot calls for launch of the ROV and starts mission timer
- ☐ ROV tether team lets go of ROV and shout, "ROV released"
- ☐ Communication if any problem occurs during the mission
- ☐ Continue to ROV Retrieval if mission completed

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, "Power off"

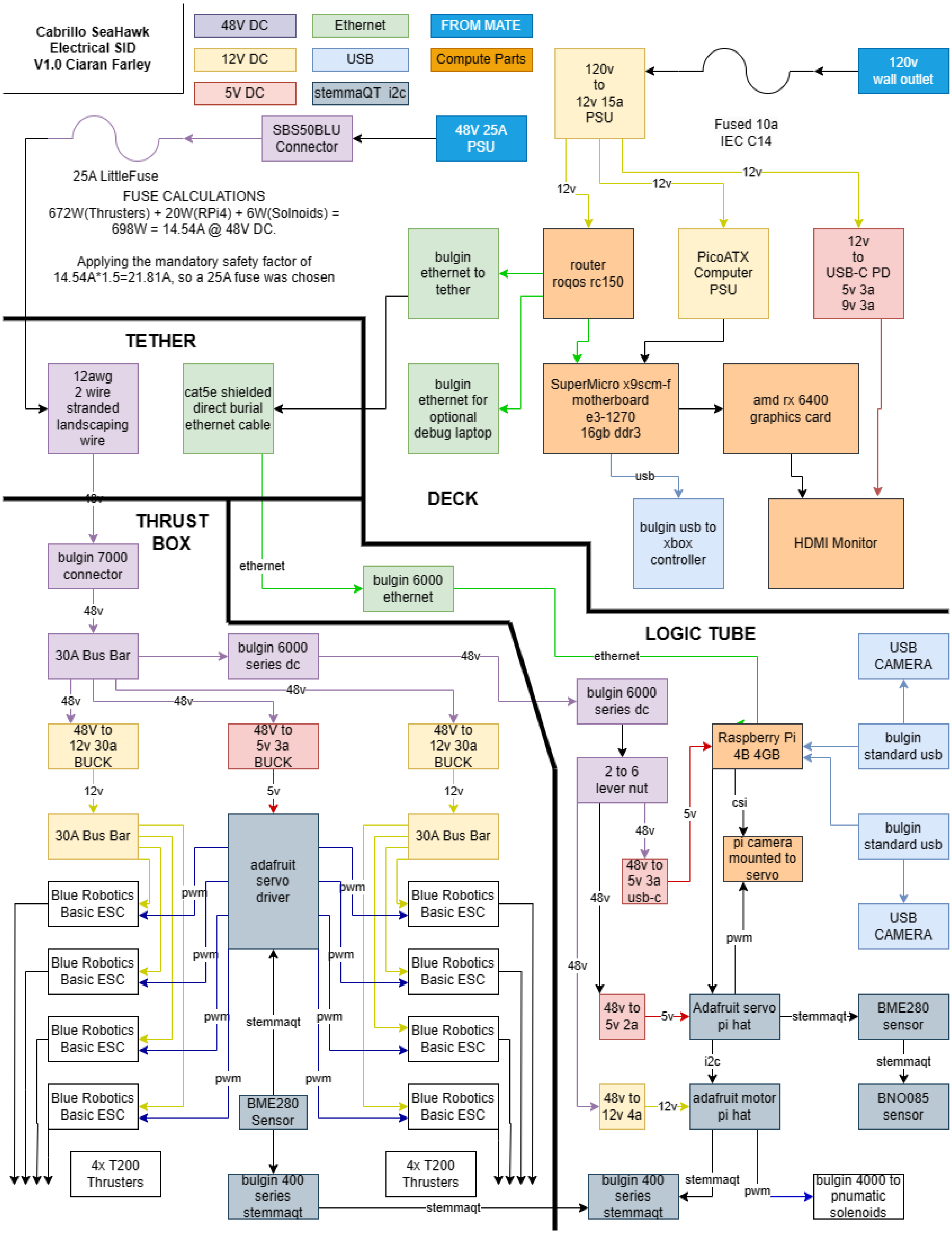
ROV Retrieval

- ☐ Pilot informs tether team that ROV needs retrieval
- ☐ Tether team pulls the ROV up from water after making contact
- ☐ Deployment team yells, "ROV retrieved"

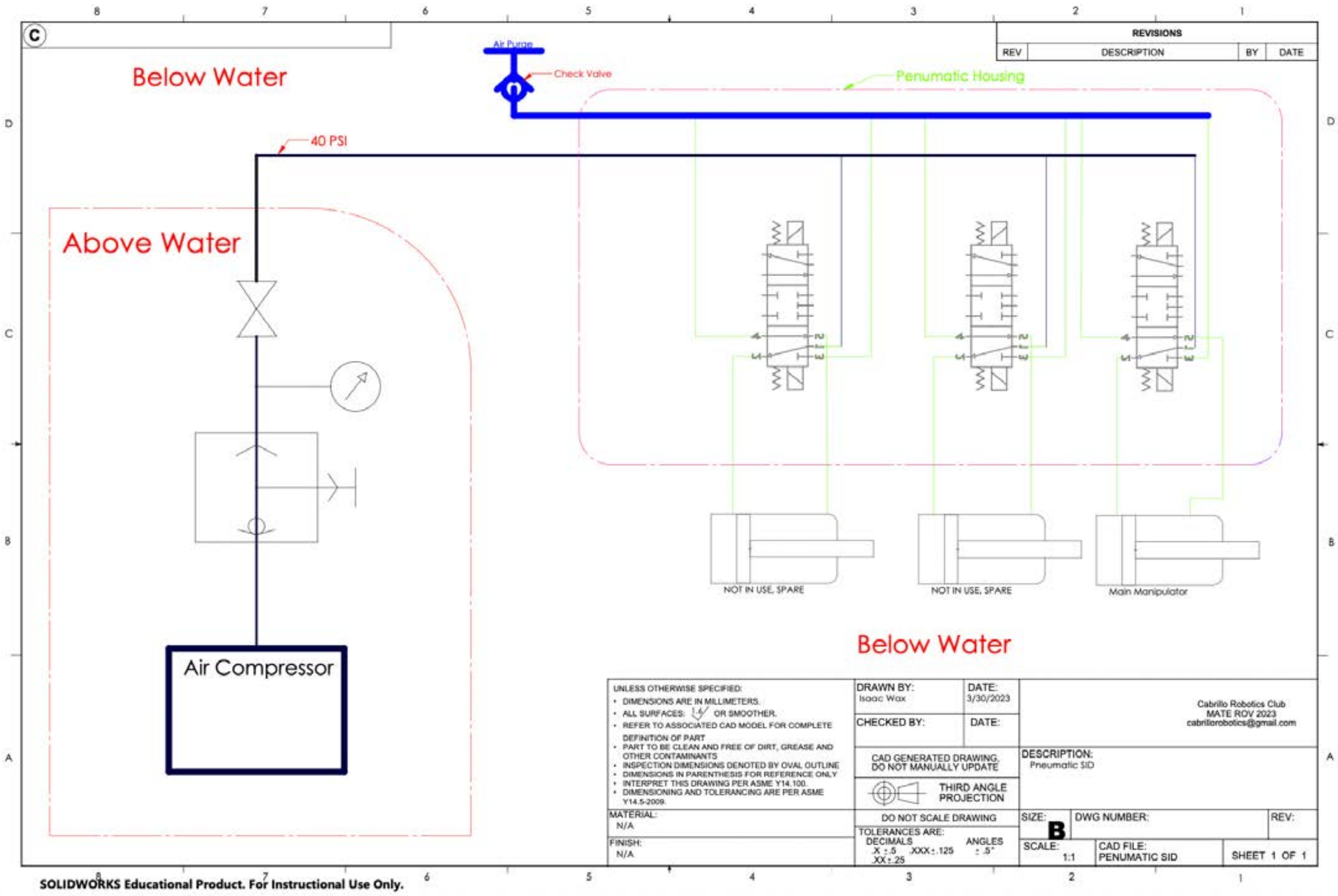
Demobilization

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

B. Electrical SID



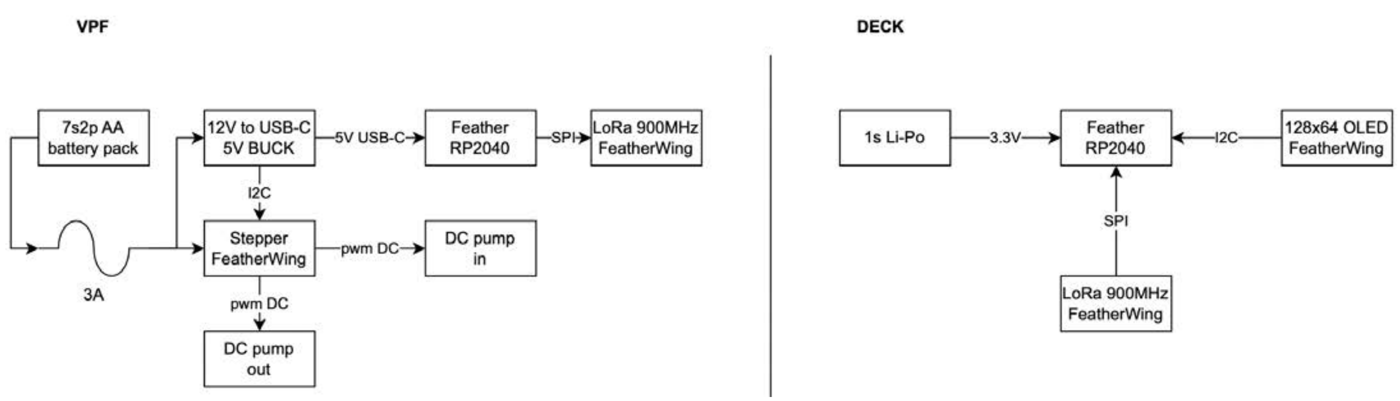
C. Pneumatic SID



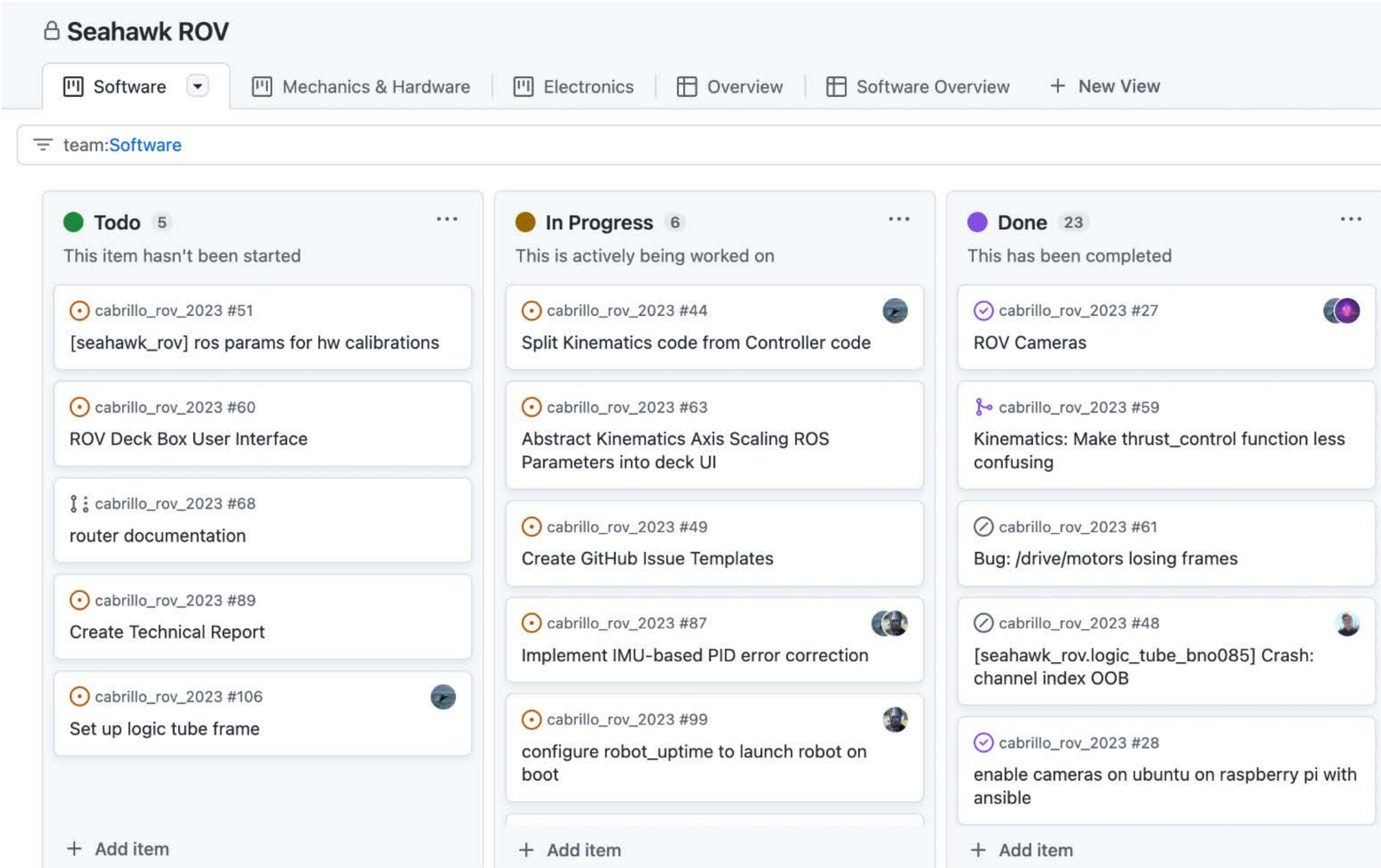
D. Non ROV Device SID

Cabrillo Robotics Club Vertical Profiling Float SID V1.1 Ciaran Farley & Stephanie L'Heureux

Fuse Calculations
Battery = 14 AA, 7s2p = 10.5V 5.7Ah
2x DC water pump, 500mA 10V = 10W
1x feather rp2040 500mA 3.3V = 1.7W
approx 12W
12Ω at 10.5V = approx 1.2A
1.2A * 150% safety factor = 1.8A
3A fuse was chosen



E. Simplified Task List



F. Budget

Income	Budget	Type	Productions & Operations Budget & Cost Analysis	Project Cost
Cabrillo College Inter-Club Council	$1,418.18		Available Funds	$21,249.51
Cabrillo College Foundation Account	$4,431.33		Total Budget	$21,025.00
Student Senate	$5,000.00		Unbudgeted Funds	$224.51
Inter Club Council	$700.00			
Donations	$4,500.00			$5,207.82
MATE Grant*	$2,200.00		Production Expenses	$5,007.82
MATE Competition Awards (2022)	$3,000.00		R&D Expenses	$512.99
Net Total Income	$21,249.51		Operations Expenses	$11,770.04
			Remaining Funds	$3,958.66
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Frame & Housings	$400.00	Purchased	aluminum extrusions, Thrust Box, Acrylic Tube, Fasteners	$376.84
Thrusters	$0.00	Re-used	(8) T200 Blue Robotics Thrusters & ESCs	$1,888.00
Tether & Connectors	$500.00	Purchased	Tether & Connectors	$219.00
Electronics & Connectors	$1,500.00	Purchased	Raspberry Pis, Adafruit Boards, connectors, wire, cameras	$1,656.00
Pneumatics	$300.00	Purchased	Valves, fittings, tubing	$223.98
Deck Box	$450.00	Purchased	Cables, adapters, display, X-Box controller, Router, Server Motherboard	$200.00
Mission Tools	$600.00	Purchased	Gripper, Fish Release, Vertical Profiling Float	$344.00
Raw Materials	$200.00	Donated	Plastic, Aluminum Cutoffs, Kapton Tape, fasteners, Epoxy, Consumables	$100.00
Subtotal Production Budget	$3,950.00		**Subtotal ROV Production Costs**	$5,007.82
R&D Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Debugging Robot Brain	$500.00	Purchased	Set of ROV electronics for software testing	$450.00
Materials	$100.00	Purchased	Fasteners, pistons, o-rings	$62.99
Subtotal R&D Budget	$600.00		**Subtotal R&D Costs**	$512.99
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**
Mission Props	$300.00	Purchased	MATE mission props	$530.86
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	$100.00	Purchased	Poster and other documents	
Lodging	$7,600.00	Purchased	Airbnb	$3,892.20
Plane Tickets	$6,000.00	Purchased	Plane Tickets	$5,963.65
Rental Cars	$2,000.00	Purchased	Rental Cars	$924.82
Competition Meals	N/A	Purchased		
Subtotal Operations Budget	$16,475.00	Purchased	**Subtotal Operations Costs**	$11,770.04

G. References

[1] https://www.epa.gov/climate-indicators/oceans

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[9] https://docs.ros.org/en/humble/index.html

[10] https://drive.google.com/file/d/17YgPLc2_TZ9MZGHGS6MWe3qcH80WbCWH/view?usp=share_link

H. Sponsors & Acknowledgements:

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MATE Center for Leading the 2023 Competition

MATE coordinators, judges, and volunteers

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Cabrillo College Makerspace for help with manufacturing parts