CORAL CRUSADERS

Redmond, WA, USA
Unaffiliated

MATE 24

Company Members

Dylan Wu * ’25	Electrical Lead + Float Design
Kounish Bhattacharjee * ’26	Finance Lead + Tool Specialist
Vehd Reddy ** ’26	Mechanical Lead + ROV Design
Rishi Pudipeddi ** ’26	Software Lead + Control Design
Jesse Li ** ’25	Science Lead + Camera Design

* Returning Members ** New Members

Coach

Mike Pesavento

Table of Contents

I. Abstract

Coral Crusaders is a returning, second-year team based out of Redmond, Washington. An unaffiliated company that manufactures subsea Remotely Operated Vehicles (ROVs), Coral Crusaders has 5 members, each of them leading the electrical, mechanical, programming, financial, and science departments with their respective expertise.

The all-new *Spooky Jobs* ROV is designed from the ground up, with completely custom chassis design, tooling, and control systems tailor made to protect the ocean's ecosystems. *Spooky Jobs* is incredibly mobile yet precise, running 6 high thrust T200 thrusters in a vectored, omnidirectional configuration. It utilizes 2 adjustable HD IP cameras directly accessible from topside control and an adaptable gripper designed to manipulate many types of objects.

Spooky Jobs went through multiple rounds of design and quality assurance before a final design was landed on. Buoyancy calculations, center of mass calculations, weight, size, strength, mobility, tooling, modularity, extensibility, and ease of use were factored in before CNC machining, 3D printing, laser cutting, and assembling the final chassis complete with tooling and an electronics enclosure.

This combination of factors created a customizable, versatile robot capable of completing a wide variety of fine-grained ocean conservation tasks. *Spooky Jobs* is highly capable in multiple domains, including coral transplantation, underwater data gathering, place and retrieve missions, and underwater mapping. This technical document will detail the design, prototyping, and production stage of each facet of *Spooky Jobs*.

II. Project Management

A. Company Profile

Coral Crusaders is a second-year unaffiliated company that designs and produces Remotely Operated Vehicles (ROVs) specialized for high precision ocean conservation tasks. The 5 company members – Dylan Wu, Vehd Reddy, Rishi Pudipeddi, Kounish Bhattacharjee, and Jesse Li lead each of electrical, mechanical, software, tooling, and vision departments respectively.

With only 5 members, mentoring was done onsite between the leads of each department. All divisions learned extensively about the others from their leads, and integrated that knowledge into the development of each of their own subsystems. Dylan, the CEO, and Kounish, the CFO, performed both ROV and team management duties. The CEO tracked the team schedule and kept the team on pace to meet expected progress and the CFO led accounting and budgeting review at each meeting.

Despite a small team, Coral Crusaders can efficiently divide the ROV's subsystems and company structure and management between each other, producing an advanced submersible to protect and conserve, all while maintaining company viability and a stable structure.

B. Scheduled Project Management

From the beginning of the season, efficient project management was the highest priority. With only a 5-member team with no organizational affiliation, there was limited manpower and productivity needed to be maximized. The team was managed through dedicated OneNote sections and pages. The administration section of the OneNote consists of a color-coded master schedule (Figure 1) with deadlines to help meet all regional requirements and goals, notes, and analysis from past and future meetings.

Legend:
ROV = ...
Float = ...
Software = ...
Administration = ...
Documentation = ...
Team Member Absences = ...
Team Member No School! = ...

Mon	Tue	Wed	Thu	Fri	Sat	Sun	Tasks to be completed by EOW
3/11	3/12 Afterschool meeting (RP, VR, DW, JL): • Disassemble cameras • Bring all components to school • Perfboard	3/13 Afterschool meeting (VR, DW, JL): • Work on reducing camera latency • CAD • Cut ABS plastic • Drill holes in waterproof box for passthroughs • Call TAP plastics • Perfboard	3/14 Afterschool meeting (RP, VR, DW, JL): • CAD • Software for camera system • Perfboard	3/15 Afterschool meeting (RP, VR, DW, JL): • CAD • Full network with camera, rpi, etc. • Perfboard	3/16	3/17 Set plan for next week afterschool meetings Update/Revise/Add to Team Schedule	ROV • Build ◦ Test cutting ABS plastic ◦ Full frame CAD with camera cylinders ◦ Reach out to TAP plastics • Cameras ◦ Disassemble Anpviz camera ◦ Lay out system like it would be in ROV • Thrusters ◦ Debug control of 2 thrusters Float • Mapped out Perfboard ◦ Soldered • Learn how to use python for visualizing data • Think about bottom detection ◦ Physical with reed switch Software • Fully complete gamepad control system (omnidirectional, slowmode, etc.)

Figure 1: Sample Schedule by Rishi

III. Design Rationale

A. Key Design Objectives

The goal for this year's ROV was to improve upon last year's PVC frame that had topside control of pump motor thrusters using the Barracuda Kit. Specifically, the ROV's speed and maneuverability, precision and stability, and flexibility in terms of tooling could be improved. The six Blue Robotics T200 thrusters, an onboard control system with ethernet communication to the surface, a fully custom ABS frame, and digital IP cameras were all upgrades from last year. The six T200 thrusters provide improved speed and maneuverability. The onboard control system and IP cameras provide improved precision and stability. As the onboard control enables the addition of sensors such as an IMU for stabilization while the IP cameras provide a low latency video system with high resolution. The custom ABS frame provides a flexible mounting system that can accommodate multiple static or active tools and can support fast tool changes. The onboard electronics system also enables flexibility within the tooling system by providing the option for digital tools such as the external temperature sensor or future digital actuators.

B. *Coral Crusaders* Design Methodology

The Coral Crusaders design methodology focuses on rapid iterative design. The first idea is rarely the best and so the best approach to design prioritizes revision and constructive criticism. All hardware design brainstorming, future designs, and revisions were evaluated with the team's design objectives in mind. Software was also built to prioritize ROV stability and system stability along with precision enabled by efficient PID loops and device communication.

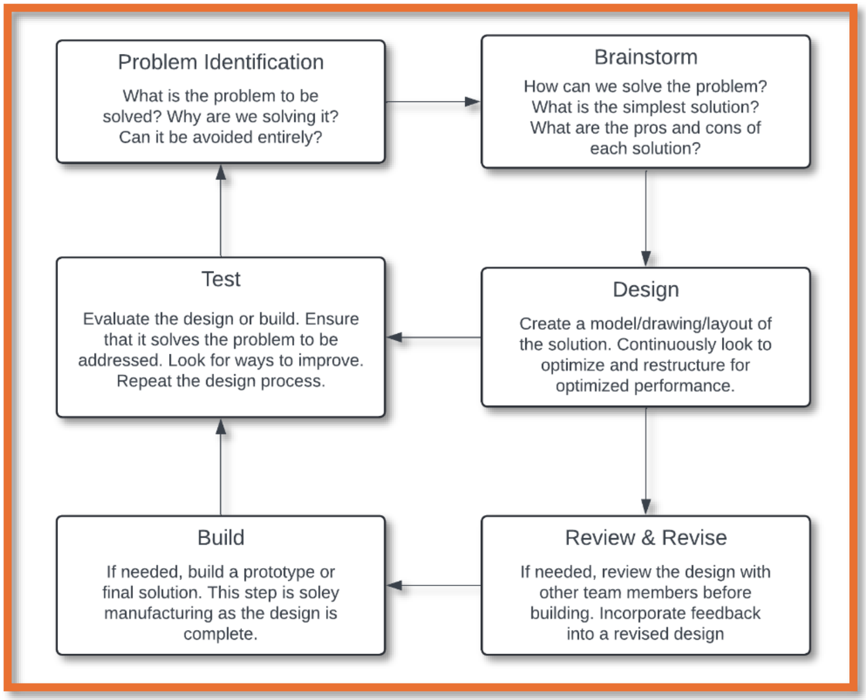

Figure 2: Coral Crusaders Design Flow by Vehd

Coral Crusaders' design flow (Figure 2) starts with identifying the problem that is to be solved. This includes the rationale behind the problem along with its criteria and restrictions. The problem definition is then taken and utilized to generate solutions (brainstorming) to the problem. During the brainstorming process the simplicity of solutions and pros/cons of each solution are evaluated. Brainstormed solutions are fit to the problem and one to two are chosen for design. Designed solutions are then tested, or, if a physical build is needed, reviewed and revised with relevant team members before manufacturing. Testing then informs future iterations of the solution with an emphasis placed on fully solving the problem with minimal downsides. This iterative design process ensures the efficacy and reliability of each solution within the ROV and float systems.

C. Sourcing Decisions

The sourcing of materials was largely determined by the decision to construct a new ROV from scratch, completely independent of last year's ROV. It was also governed by design objectives including improved speed, maneuverability, precision, and stability. Materials sourcing was also enabled by rigorous fundraising. This enabled the construction of a budget and fundraising goals around desired components rather than having available funds dictate the ROV's components.

One of the most substantial sourcing decisions was the choice to purchase six T200 thrusters from Blue Robotics. This decision was made to enable the speed and maneuverability of the ROV along with the reliability of the ROV. These six thrusters are also a long-term investment for Coral Crusaders as They will continue to be utilized in the coming years and so their continued reliability and performance is paramount. The utility of the T200 thruster is invaluable and their purchase was justified despite the $1,428 price tag.

Another important sourcing decision was the choice to purchase a watertight enclosure from Blue Robotics. Prior to the decision to source the enclosure from Blue Robotics, extensive research and testing was conducted on alternative enclosures. This included running water tests with a waterproof enclosure box bought online that had an IP68 rating. This rating indicates that a product can be submerged to a depth of 1m for 30 minutes at a time. This depth rating did not meet the ROV's requirements of being able to withstand 30 minutes or more at a depth of 5m. Due to this, the IP68 rated box was run underwater and run through all the stresses it would experience on the ROV, and it did not leak. However, given the level of care needed to maintain its watertight ability and the imperfections that would come with larger version, the waterproof box was simply not reliable. The Blue Robotics enclosure is preferable as it is reliable and rated for depths much deeper than required. These advantages mean that the enclosure will likely never leak, which is highly important given that if it were to leak an entire run or the entire robot would be gone.

The sourcing of the claw was also an important process for the team. As the competition date for regionals approached, Coral Crusaders chose to focus on driver training and extensive testing to guarantee points during the product demonstration. This led to the decision to reuse the pneumatic claw from last year's competition as it was versatile and easy to integrate with the ROV. This enabled greater experience piloting the ROV rather than developing a more advanced claw that could have failed during competition.

Finally, all metal components sourced for the ROV were either stainless steel or anodized aluminum with the exception of the ballast rods. Stainless steel and anodized aluminum were chosen for their excellent strength properties alongside their corrosion resistance which ensures the longevity of the ROV's components as they will not corrode. For the ballast rods, A36 low-carbon steel was preferred as stainless steel ballast was far too costly and A36 steel provides enough corrosion resistance with its low-carbon properties that with proper care it will not rust over time.

Mechanical Systems

Frame

Spooky Jobs's frame (Figure 3) is a custom design routed out of 3/8" ABS plastic with additional 3D printed parts. Its total size is 485 x 547 x 244 mm. A non-PVC frame was necessitated as T200 thrusters, and a Blue Robotics enclosure could be easily mounted on a custom designed frame. The overarching principle behind the frame was to separate the thrusters & electronics from the tooling of the robot. This was chosen to provide the maximum flexibility and modularity of the tooling system without interfering with the thrusters or electronics. To achieve this principle the frame was modeled in

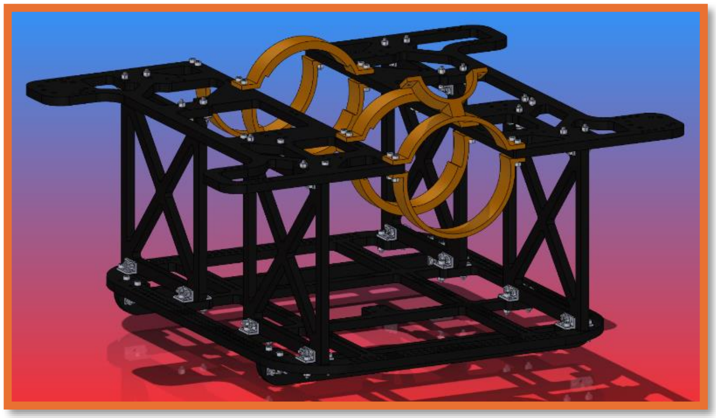

Figure 3: ROV Frame by Vehd

SolidWorks, and it underwent 7+ design cycles to ensure that it met the Coral Crusaders' standards and design objectives. This extensive design process ensured the frame did not need to be recut after the first try. The structural strength of the frame is ensured by the use of 3/8" ABS which has a minimum width of 3/8" across all parts and aluminum 3-hole goBILDA L-Beams with stainless steel M4 screws. To achieve the separation of the movement and tooling systems the frame was designed to provide a robust yet semi-permanent mounting system for the thrusters and enclosure. This was done as the thrusters and enclosure of the robot were likely never going to be changed after initial mounting and so modularity and adaptability were not concerns.

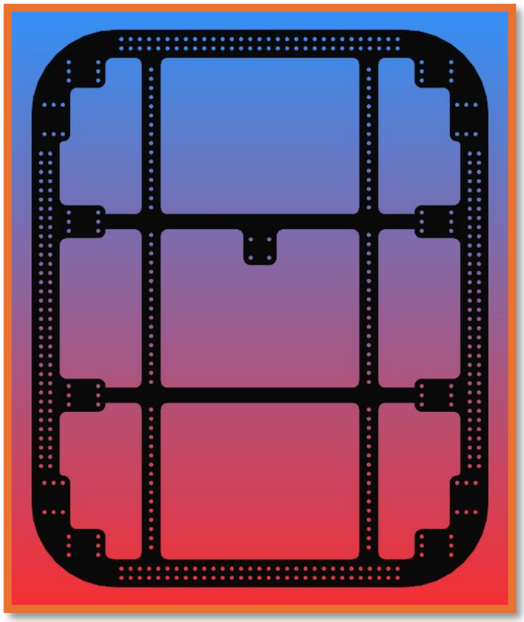

Figure 4: ROV Bottom Frame by Vehd

For tooling, however, modularity and adaptability were some of the greatest concerns. This was addressed by creating 120mm of space between the enclosure and the tooling platform (Figure 4) along with many M4 holes placed along the outside edge of the bottom frame to enable easy addition of future tooling. These holes have provided very useful as they have enabled the addition of the pneumatic claw and the temperature probe with minimal design needed.

Electronics Housing and Contents

Spooky Jobs's electronics are housed in a Blue Robotics watertight acrylic enclosure with an inner diameter of 100 mm and a length of 300 mm. This enclosure is rated to 100 m in depth and its transparency allows for quick visual inspections of electronics. Both aluminum endcaps (Figure 5) of the enclosure feature 10 x M10 holes which in addition to managing all the cables entering and exiting the robot, also leave sufficient space for future tooling endeavors. The separation of data and power endcaps not only allows for organized internal electronics, but also avoids the wire clusters associated with running a dozen wires through one holed endcap.

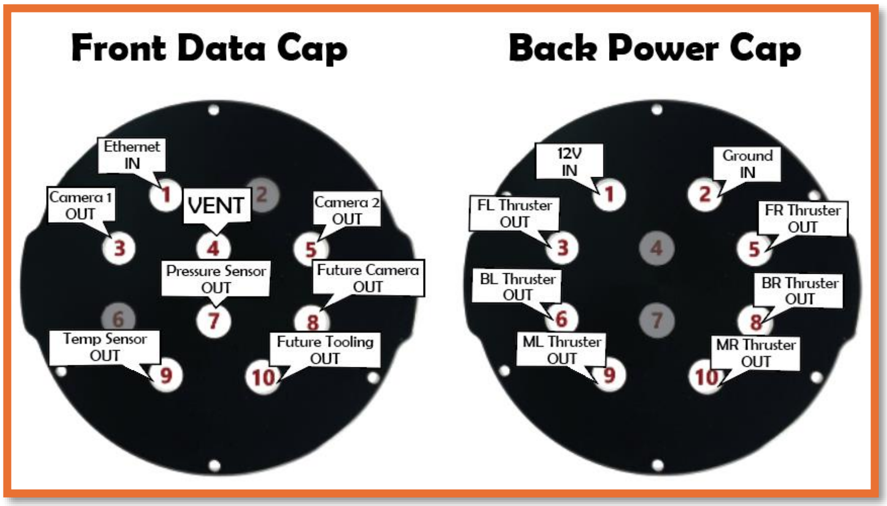

Figure 5: Endcap Configurations by Dylan

Blue Robotics WetLink penetrators are used to ensure watertight connections from the inside of the enclosure to the external tether, cameras, thrusters, and tooling. WetLink penetrators take seconds to install or uninstall while providing a secure high-pressure seal. This increases Spooky Jobs's serviceability in the field.

Additionally, the vent allows for easy pressure testing. Prior to deploying Spooky Jobs in the water, the enclosure can be vacuum tested with a hand pump to be deemed airtight. After decreasing the pressure in the enclosure to 38 cmHg and waiting for 15 minutes, if pressure doesn't change by more than 1.3 cmHg, then the ROV is ready to fly.

All enclosure electronics are securely fastened to a custom cut ABS tray. Designed in CAD, screw hole placements are optimized so that after components are mounted, there is sufficient space left for cable management. Self-adhesive cable tie mounts manage higher gauge wires that may be susceptible to pulling and breakage. Both sides of the tray are used for mounting and include terminal blocks to distribute power. The top side includes an ethernet switch and a Raspberry Pi 4B microprocessor. The bottom holds a 12v – 5v power buck converter, a Metro M4 microcontroller, and an internal PHT sensor and IMU.

Thrusters

All thrusters are placed on the top of the ROV. This takes advantage of the frame's design, where there are holes drilled into the entire bottom of the frame to allow for tooling. The vertical thrusters were placed with the front facing downwards, as more thrust is needed for descension than ascension as the ROV is slightly positively buoyant. The horizontal thrusters are each angled 45 degrees from the center to allow for equal omnidirectional movement. The vectored thrust that this configuration provides in addition to vertical thrusters arranged horizontally gives *Spooky Jobs* 5 degrees of freedom of movement – forward/backward translation, left/right translation, vertical translation, yaw, and roll.

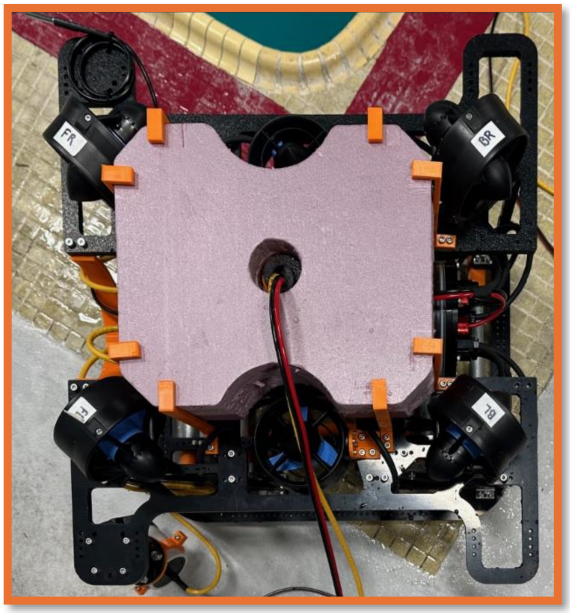

Figure 6: Thruster Config Photo by Rishi

Buoyancy

The buoyancy was calculated in SolidWorks by utilizing the full CAD model (Figure 8) of the ROV including all screws and hardware. Each part within the ROV assembly was either assigned a material (which included density information), or a predetermined weight that was either an estimate (for components like the electronics) or a calculated/weighed value for the cameras and 3D printed parts. These weights and densities allowed SolidWorks to make an exact calculation of the ROV's weight, after that a custom material was created for the buoyancy foam and the volume of the buoyancy foam was adjusted until the volume of the ROV was slightly (~200 g/cm^3) more than the weight of the ROV. This was to ensure a constant positive buoyant force on the ROV so if it were to stop functioning it would rise to the surface of the pool naturally. Two 3D printed cylinders were also added on the bottom of the ROV to enable the addition and removal of bismuth pellets to allow dynamic adjustment and trimming of the ROV's buoyancy. Bismuth was chosen as it has a relatively high density (9.747 g/cm^3), is non-toxic (unlike lead), non-corrosive, and is somewhat low-cost (~$55/kg) compared to other materials such as tungsten (~$187/kg).

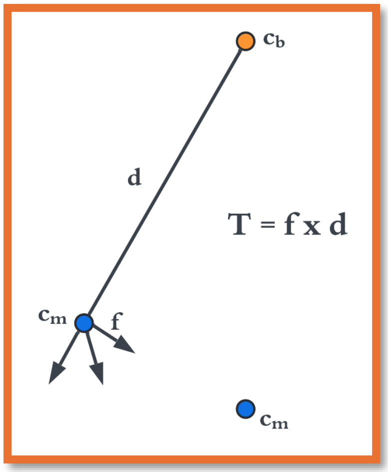

Figure 7: Righting moment diagram by Dylan

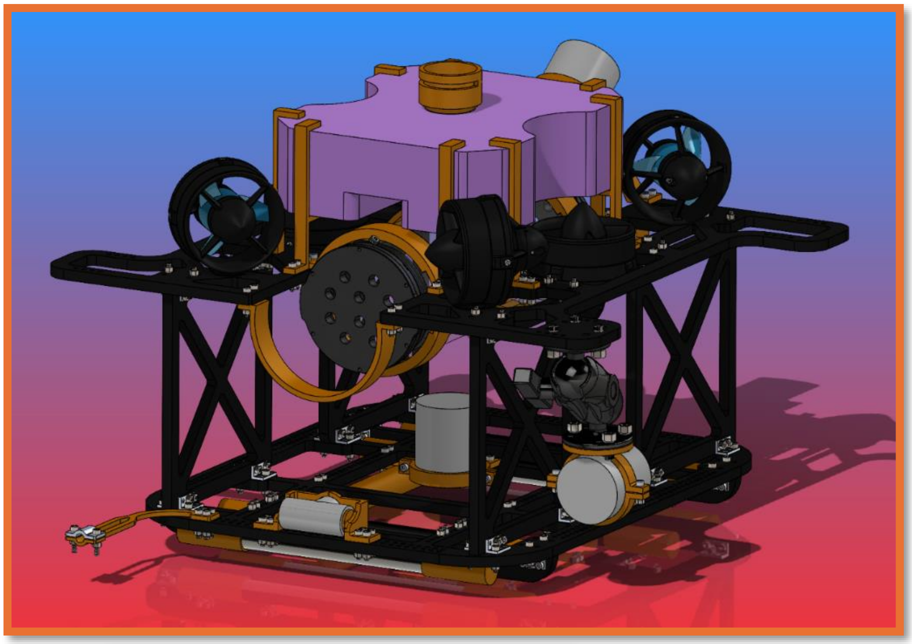

Figure 8: ROV CAD by Vehd

The buoyancy system of the ROV also plays an important role in the stability of the ROV. This is partly because the placement of the thrusters is 140 mm from the center of mass (COM) on the ROV. Due to this, anytime there is a thrust force from the vectored thrusters a torque force is created around the COM, causing the ROV to pitch forward/backward/sideways. This was addressed by distancing the COM and center of buoyancy (COB). To achieve this, four steel rods were placed on the base of the ROV each with a weight of 670 g for a total static ballast weight of 2.68 kg. This dropped the COM of the ROV significantly and with the addition of buoyancy foam on the top of the ROV (to compensate for the 2.68 kg of added weight) the distance between the COB and COM more than doubled to 95 mm. This increased distance between the COM and COB increased the righting force (T) that is created by a lateral displacement of the COB from the COM (Figure 7). This is because the righting force is proportional to the distance between the COB and COM and so as the distance between the two increases the righting force increases as well. The combination of this righting force and software-controlled acceleration creates a highly stable ROV that is resistant to pitching or yawing when accelerating forwards/backwards/sideways.

D. Electrical Systems

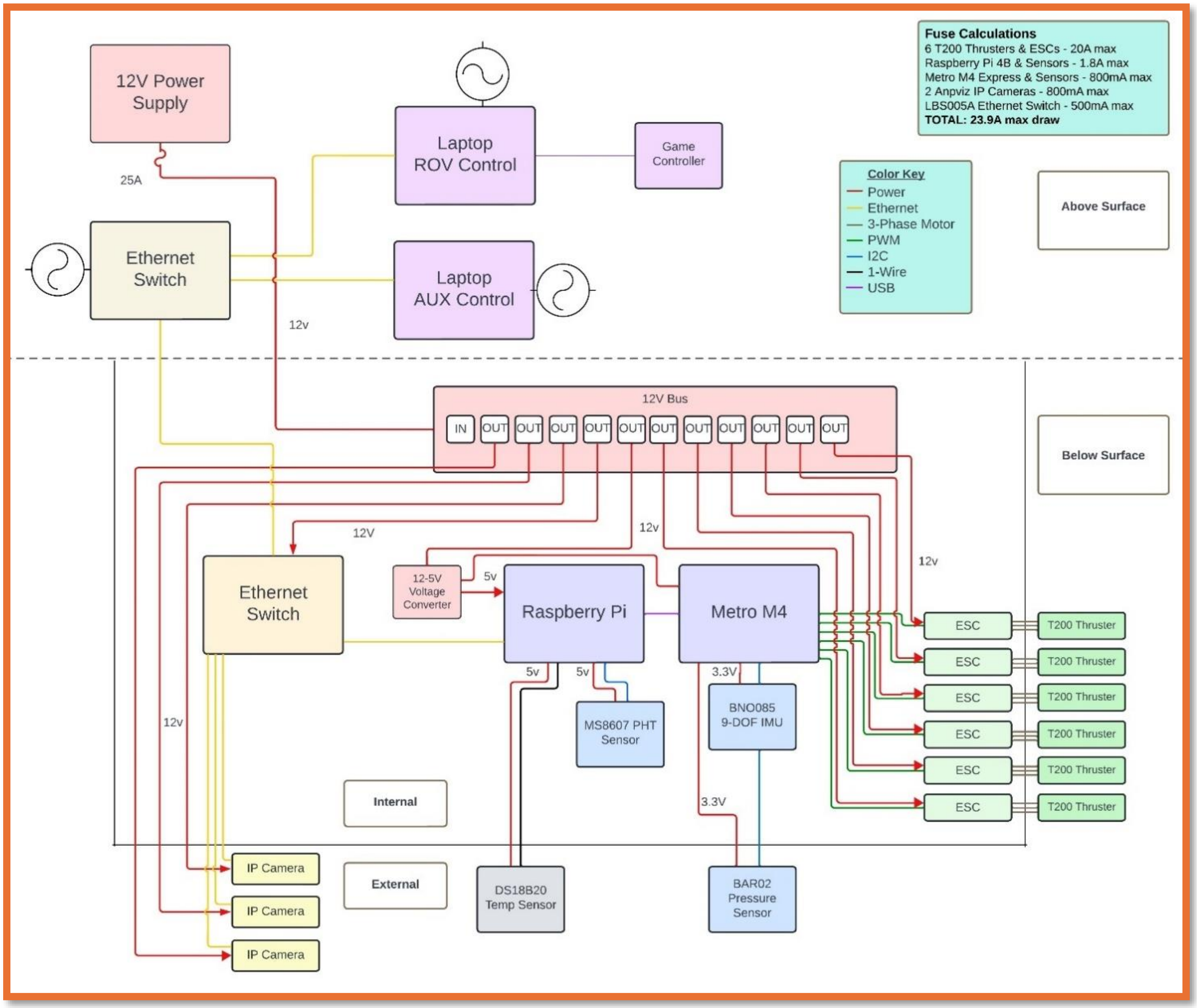

Figure 9: ROV System Integration Diagram by Dylan

ROV Electronics

Spooky Jobs' electrical system is based on the premise of expandability and serviceability, creating a wealth of future customizations. By running a CAT-6 ethernet cable from the surface to the Black Box ethernet switch on *Spooky Jobs*, communication and data can be received from the Raspberry Pi 4b and the two ethernet cameras. The compact Black Box with 5 ethernet ports allows for the easy addition or removal of ethernet cameras.

Another integral part of the electrical system is the inclusion of both a Raspberry Pi and a Metro M4. The Metro M4 has a powerful 32-bit ARM Cortex M4 core running at 120 MHz. It also supports floating point numbers and has 22x PWM outputs, making it the perfect microcontroller for operating 6 T200 thrusters and collecting continuous data from the pressure sensor and IMU. The Raspberry Pi, however, being a microprocessor, isn't specialized for the repeated tasks that the Metro M4 undertakes. Instead, the Raspberry Pi's purpose is for communication via ethernet, communication to and from Metro M4 via serial, and for taking single data points (eg. external temperature probe). Additionally, since the Metro M4 frees many repetitive tasks from the Raspberry Pi, in the future, the Raspberry Pi can be used specifically for the consuming task of video and data analysis. This configuration allows there to be countless expansions on the software side.

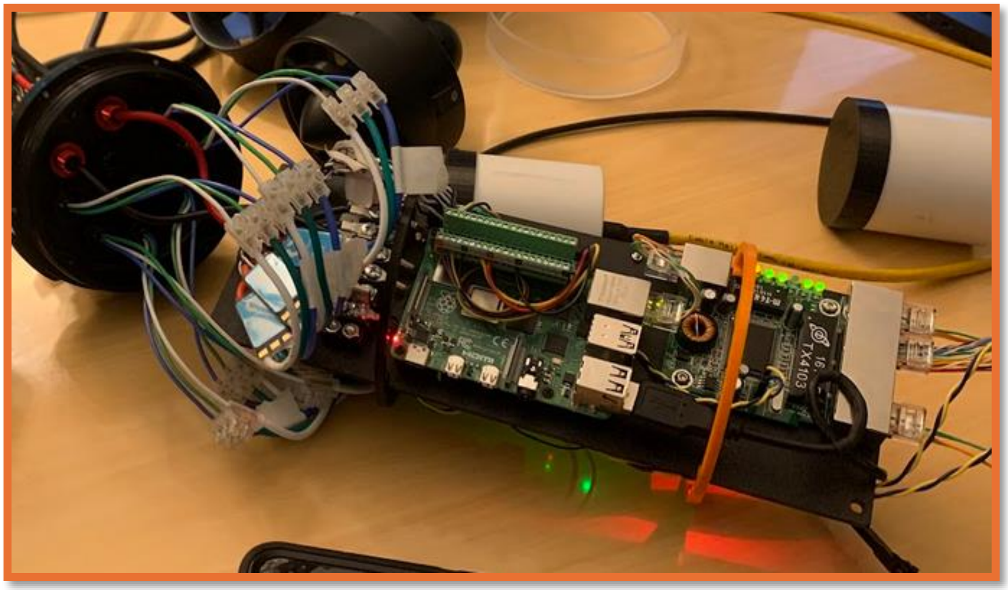

Figure 10: Ethernet Switch and Raspberry Pi Photo by Coach Mike

As for system power, the ethernet switch, ethernet cameras, and T200 thruster ESCs run off 12V from the surface. A 12V – 5V buck converter supplies 5V to both the Raspberry Pi and the Metro M4. All ESCs connect into a small perfboard which supplies ground connections and provides strain relief to the wires that then get screwed onto the Metro M4. Raspberry Pi and Metro M4 screw terminal hats provides for simple testing and serviceability.

Top-side Control System

For the top-side control system, the ROV's ethernet cable attaches to a surface Black Box ethernet switch which provides access to *Spooky Jobs*'s on-board electrical system on multiple laptops. One laptop can stream different camera views, while another can monitor positional and internal condition data, as well as take in game controller input from the Logitech F310.

A watt meter is attached downstream from the fuse to give an accurate read on the current draw of the electrical systems. These values affirm the functionality of the implemented current limiting program.

The ethernet switch, laptops, game controller, and power supply are all that is needed for the electrical top-side control system. This keeps top-side control flow as simple and streamlined as possible.

Tether

Spooky Jobs's tether features one CAT-6 ethernet cable, 12 AWG power cables, one pneumatic tube, and strands of 1 cm diameter foam backer rod. One of the biggest considerations for the tether was the gauge of the power wire, and the minimization of voltage drop. Firstly, 11m of tether was chosen to be used, as last year's PVC ROV utilized 14 m, which was excessive. Using the known supply voltage of MATE's power supply and the desired length of wire, the following voltage drop calculation table was made.

As shown in Table 1, using a 12 AWG power wire ensures a roughly 12 V output voltage for the ROV at a load of 20 A. This wire gauge gives the ideal balance between wire thickness and voltage drop.

Supply Voltage	14.1 V
Wire Length	11 m
Wire Gauge	12 AWG
Current Load	20 A
Voltage Drop	2.22 V
Output Voltage	11.88 V

Table 1: Tether Voltage Drop Calculations by Dylan

The CAT-6 ethernet cable transmits data signals from the Raspberry Pi and ethernet cameras between the laptop control and ROV. The 12 AWG power wires output 12 V to the ROV and have silicon sheathing which provides extra flexibility. The pneumatic tube serves to operate a piston valve which controls the gripper. To keep the tether neutrally to slightly positive buoyancy, strands of 1cm backer rod was added. Everything is then easily run through 11 m of split Techflex for organization.

The tether management protocol is simple and straightforward. Because the tether comes out vertically from the center of *Spooky Jobs*, it will stay out of the way during the ROV's rotational and translational movement. This means that the main job of the tether manager during deployment is to keep the right amount of slack on the tether so that the ROV has enough tether to roam while not creating entanglement hazards. For storage, the tether is always coiled in an over-under fashion. This guarantees that the cable rests in its natural coiled position and does not create loops within itself. Then in deployment, the tether can just be pulled out without worrying about entanglement.

E. Software

High Level Overview

There are three main pieces of software written for *Spooky Jobs*: topside compute, onboard compute, and a dedicated movement microcontroller (Metro M4). The topside software is written entirely in Python, with use of the inputs library to get gamepad data. The onboard software has its control flow written in Python, with a specialized C extension to format data for the Metro. The movement control software on the Metro is written entirely in C++. Communication between the topside computer and the onboard computer is done via a socket server hosted on the topside, which the Raspberry Pi connects to on initialization. Communication between the onboard computer and the movement microcontroller is done via serial pins.

Topside Software

The topside control software is a multithreaded program consisting of two execution threads. One thread parses input from the Logitech F310 gamepad. A separate thread is needed as gathering data from the gamepad is blocking and event driven. On each event, the thread crafts an NMEA 0183 (de facto standard for marine communications) compliant string containing the event, with a verification checksum. It then sends this string to the onboard Raspberry Pi using the socket connection. The frequency for this thread was chosen to be ~10hz after rounds of testing determined it provided a balance between ROV responsiveness and not overloading the topside/onboard computers or the network. The second thread checksum verifies socket input for NMEA formatted data coming from *Spooky Jobs*, such as depth, water temperature, internal pressure, humidity, and temperature, and other relevant debug statistics.

Onboard Software

The software onboard the Raspberry Pi is also a multithreaded program consisting of three execution threads. The first thread waits for socket input coming from topside control, checksum verifying each input and then placing the input into a global data map. A separate thread is needed for waiting for socket input because it is blocking. The second thread constantly polls the global data map at the same frequency topside control sends inputs to the ROV, ~10hz. A custom programmed C extension consumes the global data map and creates a NMEA payload, a raw byte buffer of the global data map structure. The buffer is passed back to Python where it is sent via serial to the Metro. The third thread gathers debug and sensor information from the Metro via serial. It then gathers data from sensors attached to the Pi, and packages all the collected information into an NMEA string and sends it to the topside computer via socket.

Movement Microcontroller

The microcontroller, the Metro M4, is dedicated specifically to thruster control and runs only one program in a standard Arduino setup->loop flow. The setup initializes the serial connection and other auxiliary structures. The loop then gathers data from serial input and sensors, processes it, and sets thruster powers accordingly.

Data Collection

The first part of the loop is data collection. The serial input buffer is checked, and if an NMEA string is found, memcpy() the known size of the byte buffer into the data structure. This provides the rationale behind creating sending a raw byte buffer - the Metro can memcpy() the received data directly into the same structure as was used to craft the buffer. Sending raw bytes was up to 5x faster (based on the frequency of global loop counter incrementing) than converting the inputs back from ASCII into integer values. Then, IMU and pressure sensor data is collected and processed into heading and depth.

Raw Thruster Power Calculations

Thruster power calculations are done by first calculating the thrust ratios necessary between all 6 thrusters to produce the desired movement based only on the topside gamepad inputs. Once the ratios are calculated, they are multiplied by gain constants chosen through hours of piloting and fine-tuning *Spooky Jobs* . The raw power values are then multiplied by a final, on-the-fly adjustable gain value.

Stability Settings

Custom industry standard PID (proportion, integral, derivative) depth and orientation hold controllers are implemented to increase precision. They calculate an error from a target and give an output based on the **P, I, and D** constants. The **P** part lowers power as the current value gets closer to the target, the **I** part adds to the output, increasing if it is not reaching the target, and the **D** part adds a damping effect to not overshoot. *Spooky Jobs'* fine-tuned hold controllers quickly correct, significantly increasing precision and efficiency.

The depth and orientation hold controllers take a target and a current value – for depth hold the target is desired depth and current depth, and desired heading and current heading for orientation hold. Both controllers output the power for vertical and horizontal thrusters respectively. Importantly, don't reset the integral portion of the controller for depth – the buoyancy of the ROV remains constant, as should the integral.

Power Limiting

The final step in the thruster power calculation loop is power limiting. Each Blue Robotics T200 thruster draws over 17A at max power. 6 thrusters draw significantly over the limit of 25A. To avoid exceeding the limit, dynamic current limiting is implemented in software. Blue Robotics provides a mapping from thruster power to power consumption. After each of the thruster powers are calculated in code, the final step is to limit the current. There are global (20A), vertical (7A), and horizontal (13A) amperage limits which allow the constant use of maximum current, increasing ease of use and power.

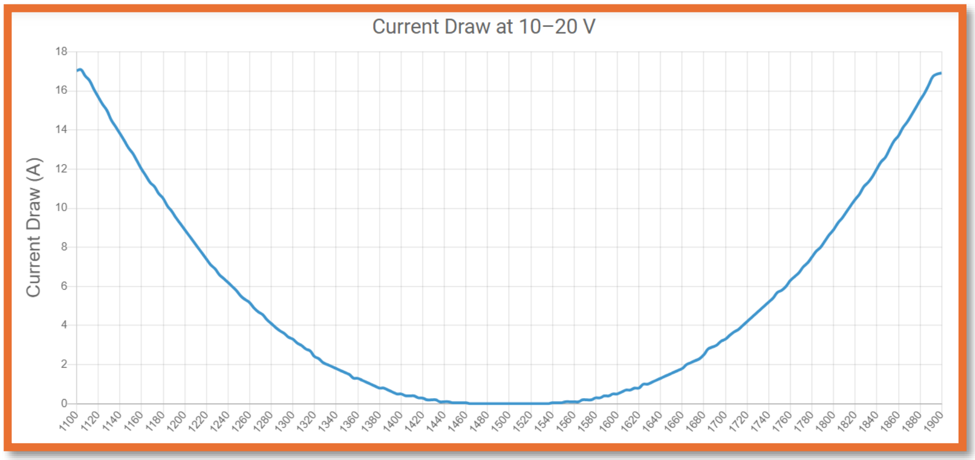

Figure 11: T200 Current Draw Chart by BlueRobotics

Data Display

From the Metro, all control, debug, and sensor data is sent back to the Raspberry Pi. The Raspberry Pi packages the Metro data with its own debug and sensor data and sends it all

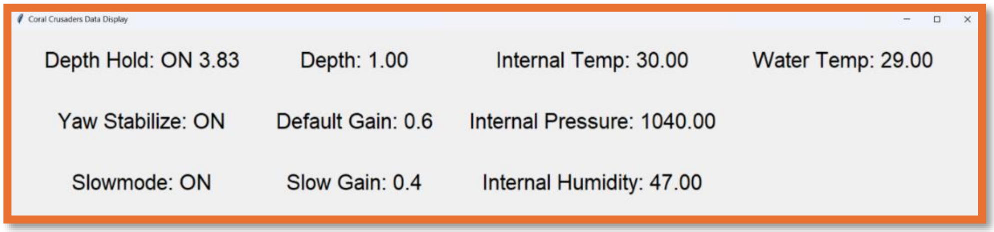

Figure 12: Coral Crusaders GUI Sample by Rishi

back to topside control. Sending all data is incredibly useful for debugging processes like current limiting, but only relevant data like depth, stability toggles, heading, enclosure climate, and water temperature is displayed (using tkinter) to the pilot. The rest is stored in data structures that can be accessed on request.

F. Ethernet Camera System

The vision system of Spooky Jobs features a set of two high-quality, low latency ethernet IP cameras for navigation and tooling. The video transmitted from these IP cameras is 4-megapixel quality and is displayed on one screen with adjustable settings for ease of access.

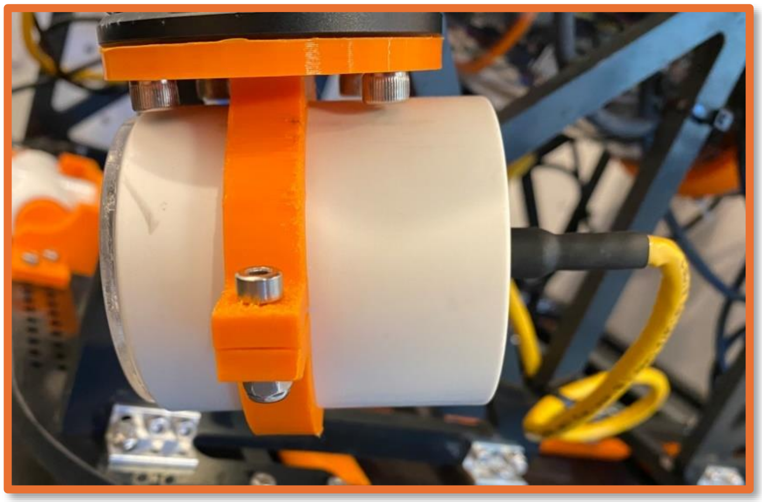

Figure 13: Ethernet Camera Photo by Vehd

One of the first priorities when designing the camera system this year was to replace the analog cameras used last year. While the analog cameras had some advantages like low latency, they also had several flaws like having to run through the tether and having low quality video steam. This year required a camera without the disadvantages of an analog camera while still preserving its strength. The best solution was found to be the Ethernet camera.

Spooky Jobs' ethernet camera system provides high quality 4K video stream affording the pilot precise bearing on their surroundings. It also is able to run its data to the surface in the same cable that other data is run through, preserving tether space. Finally, it still preserves a low latency of 100-200 milliseconds allowing for real time navigation.

The majority of the electronics concerning the ethernet camera system are located directly within the enclosure of the ROV itself. The data from each camera is directly linked to the Raspberry Pi through an ethernet switch. The stream from the cameras can then be sent directly to the surface through one cable along with the rest of the data from the ROV.

The source of the ethernet cameras was from an Anpviz 4MP PoE IP Bullet camera that was ordered off of Amazon. The commercial IP camera wasn't designed to remain submerged underwater for extended periods of time, so a custom camera enclosure needed to be designed to suit the team's design vision. During teardown, solely the camera board was extracted to be embedded in the custom enclosure.

The camera enclosure was built with two main goals in mind, waterproofing and compactness. The entire camera board is enclosed within a 2-inch radius 3-inch-long PVC pipe. The side that the camera wire runs out of is covered with a 3-D printed part is a sealed with a combination of a heat shrink, super glue, and epoxy.

The side that the camera records from is covered with a clear acrylic panel and sealed with super glue. To top it off the entire enclosure is protected from wear and tear when not in use by a 3-D printed lens cover.

The positions of the cameras were chosen purposefully to give the pilot a better grasp of their surroundings. One camera is located at the bottom to give the pilot bearings on their general location. The other camera is mounted on the side to give the pilot a view of tooling. This camera is adjustable so that the desired angle of view can be easily adjusted and reached.

G. Pneumatics

Spooky Jobs features a pneumatic gripper which is powered by 276 kPa (40 psi). Air is sent through a 0.635 cm pneumatic tube and is controlled by a valve in the pneumatic control box.

This pneumatics box is reused from last year. It contains two valves which control the two outputs. Last year, one output was used for a lift bag, of which is not needed this year. Therefore, the box has an extra output that is not currently being used. The box contains a regulator and release valve for safety purposes. See Figure 15 for the pneumatic SID.

Figure 14: Pneumatics Box Photo by Coach Mike

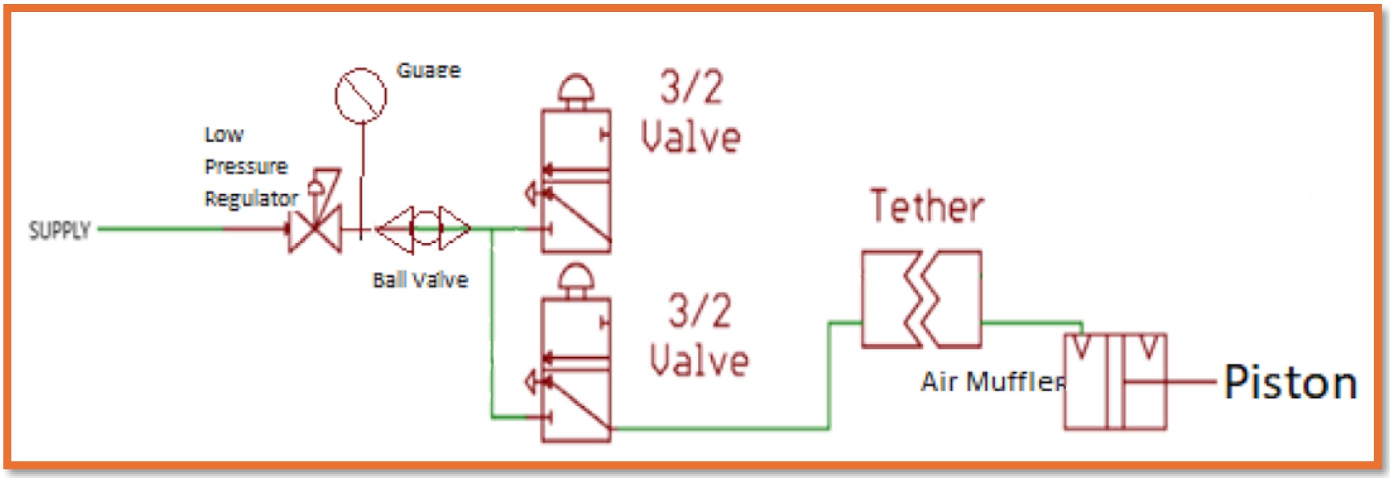

Figure 15: Pneumatic System Integration Diagram by Dhruv

H. Mission Tasks

Pneumatic Gripper

The pneumatic gripper is constructed from a spring-loaded grabber which is usually utilized by individuals who need extended reach. The claw can be shifted from its horizontal position to a vertical position depending on the task. It is powered by a 16mm bore 25mm stroke double-action air cylinder. The gripper closes when air is sent through the pneumatic tube. When pressure is relieved, the gripper springs back open. The benefit of using a pneumatic gripper is that it can be easily assembled onto any ROV build. The addition of a pneumatic tube to the tether is simple, and the biggest downside of using pneumatics is the possible tradeoff in gripper strength.

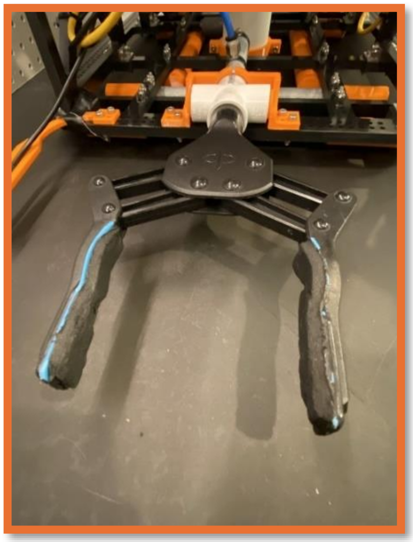

Figure 16: Pneumatic Gripper Photo by Vehd

Recovery Line Tool

Clipping a recovery line onto the bale was a difficult task, and specialized tooling extension was developed to add that functionality to *Spooky Jobs*. Using the pneumatic gripper, a grabbable s-biner clip system was designed and 3D-printed. Simply grabbing the clip with the gripper at the surface, pushing it into the hook on the bale, and releasing the clip was all that was necessary. This task now takes under 30 seconds and demonstrates the modularity and extensibility of the tooling and ROV.

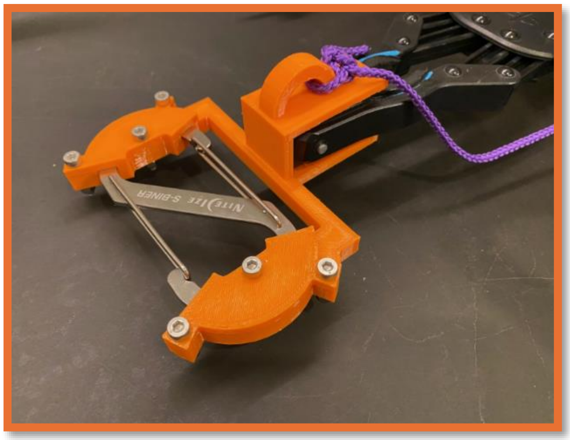

Figure 17: S-Biner Recovery Clip by Vehd

Temperature Probe Tool

To get the temperature of the water to verify SMART cable sensor readings, a DS18B20 waterproofed temperature sensor was used. A WetLink Penetrator was used to wire it through to the inside and connect it to the Raspberry Pi. One very important aspect of this sensor is that it uses the one wire protocol to transmit data. Only one enclosure penetrator is necessary so lots of space can be saved. The Raspberry Pi polls the temperature sensor at 5hz and transmits the data back to topside control for collection.

Profiling Float

Carrot (Figure 19), Coral Crusaders' profiling float, was developed to undertake the Mate Floats! task. Its goal is to complete two vertical profiles while taking pressure data, and then transfer it to the surface station.

Figure 18: Carrot Photo by Dylan

Figure 19: Buoyancy Engine Photo by Dylan

To accomplish this task, *Carrot* utilizes a 5 cm linear actuator and a 250 mL syringe (Figure 18) to control the volume of the float interior. By retracting in the plunger, the volume of the float is decreased, which increases the float's density. As it becomes denser than water, the float will start sinking. Contrarily, by extending the plunger, the float becomes less dense, and floats to the surface. However, for the slight change in buoyancy to cause a profile, the float must start out slightly positively buoyant, which means it requires a good amount of ballast. Inside the float, there is 230 cm^3 of room for lead shot ballast which will supply the 1.5 kg needed for the ideal buoyancy.

The enclosure consists of two halves of a Nalgene water bottle and 3D-printed connectors. These connectors thread together and squeeze an O-ring to provide sealing. The connectors can be wrapped tightly with self-

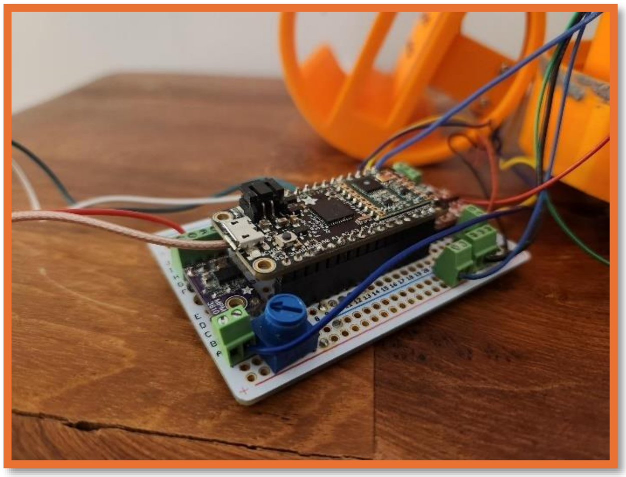

Figure 20: Float Perfboard Picture by Dylan

bonding silicon tape for greater watertightness. Connectors are attached to each half of the Nalgene bottle with silicone sealant.

The electronics in the float are assembled on a perfboard. The float utilizes a Feather 32u4 microcontroller with a built-in radio frequency module for surface communication. The RFM69 packet radio transmits time and pressure data to the surface station which has another Feather that receives the data. Then the station laptop reads the data via serial and automatically plots the data in Excel.

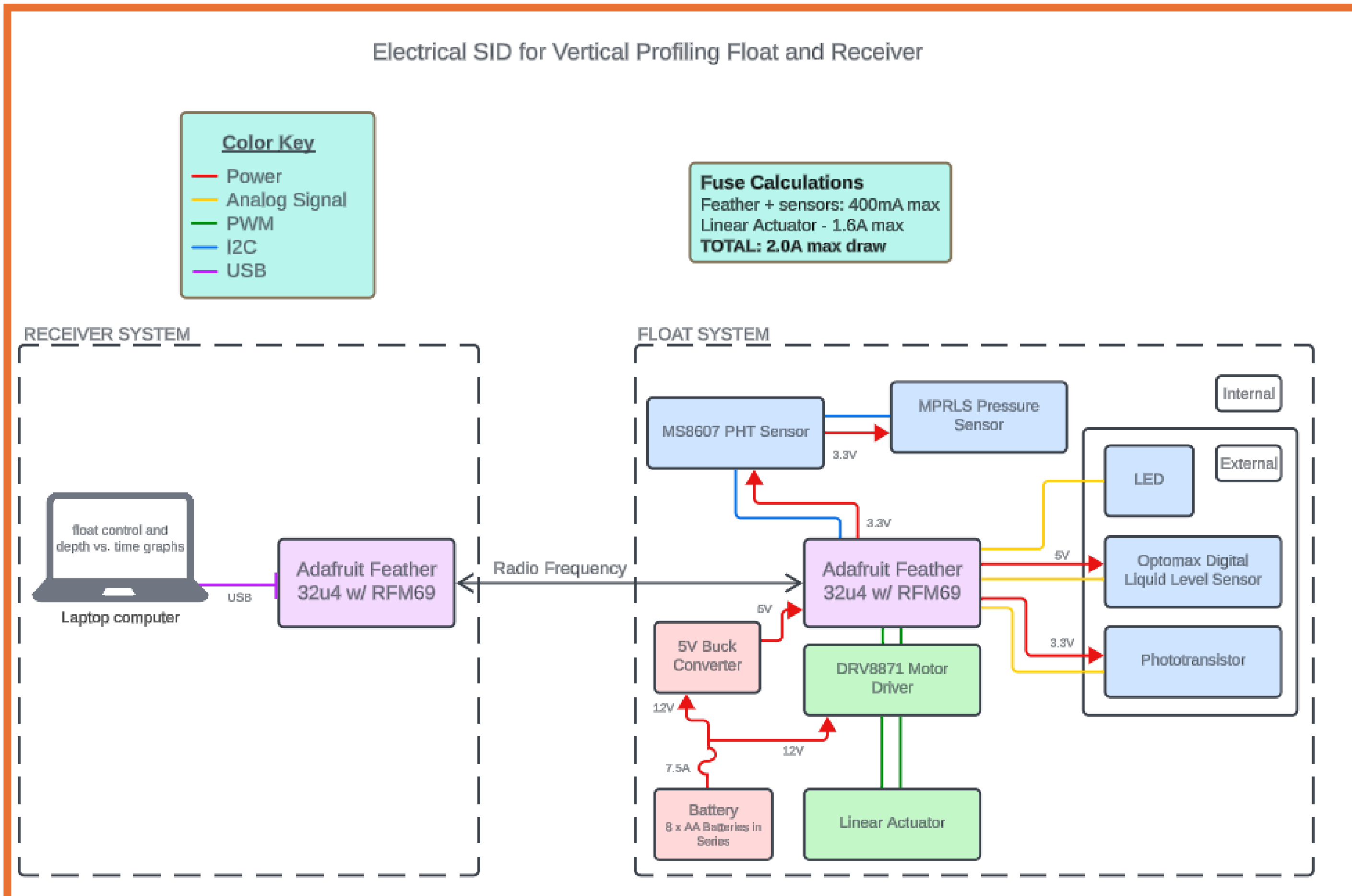

Figure 21: Float System Integration Diagram by Dylan

The feather controls 4 sensors - a phototransistor for bottom detection, a water level sensor for surface detection, a PHT sensor to monitor internal conditions, and a pressure sensor to collect depth data. A normally closed reed switch allows for float power to be switched on and off with an external magnet. By using a non-contact force for powering the float, there is no need to drill another point of leakage to install a physical switch.

The float system runs off 12V from 8AA batteries. This helps power the motor driver that runs the 5cm linear actuator for buoyancy. A 5v buck converter powers the Feather board and a 7.5amp fuse is wired 5cm from the battery to provide overcurrent protection.

I. Design Evolution

This year's ROV has been a massive step forward from Coral Crusaders' rookie year (last year). The ROV transitioned from a PVC frame to a custom ABS frame and incorporated a fully onboard and digital electronics system. Coral Crusader's weaknesses from last year informed this year's design and were made top priorities during the design process to ensure improved performance in the ROV.

The ROV has also made significant changes over the course of the season to better suit this year's missions. One such example was the addition of a static temperature tool, permanently attached to the ROV and wired into the electronics enclosure. This enables fast and accessible sampling of the temperature near the SMART repeater allowing the interchangeability of when we complete the SMART repeater task as well as preventing us from running an extra wire from the side of the pool. The modularity and adaptability of the tooling system on the ROV has also enabled multiple tooling and camera reconfigurations throughout the season to better suit our evolving list of mission priorities. This has provided the capability to relocate and manipulate ocean observing assets, deploy probiotic irrigation systems, determine the location of sturgeon spawning locations, and conduct vertical profiles of the ocean.

IV. Testing and Troubleshooting

Each individual mechanical and electrical component is ensured to be thoroughly tested prior to incorporation and execution in the ROV. When evaluating different components, two things are kept in mind – the quality of the component, and the level of difficulty of integrating that component into ROV design. For example, when prototyping the teardown board of both a Revotech and an Anpviz ethernet security camera, it was found that the Anpviz not only had less latency, but also had an integrated lens, and was easily removed from its housing case. Following the same logic, other sensors and microcontrollers were prototypes and experimented with to arrive with the setup that is on *Spooky Jobs* today.

Figure 22: Debugging Code Photo by Coach Mike

Once individual components were tested and narrowed down, a fully integrated bench test setup which mirrors the setup on the actual ROV could be run.

The Blue Robotics thrusters and enclosure were tested for quality prior to use even though it is clear Blue Robotics has a very high standard for quality. By running various code snippets for the motors, and pressure testing the enclosure, all their components were found to work flawlessly as anticipated, making the investment in reliable parts worth it.

Extensive time was spent at the pool with an emphasis on testing the maneuverability and vision of the robot. Because the thorough mechanical and electrical design choices turned out to be successful, it was a matter of repeated pool testing to inform iterative software changes to make flying *Spooky Jobs* as efficient as possible.

As for troubleshooting (Figure 22), problems start being debugged at a high level, listing out possible sources of error. Errors are narrowed down after testing those sources one by one. If it is an electrical problem, the handiest tool is the multimeter for test connections. If a problematic component has been found and shows no obvious issues, it can be placed under the microscope for further examination. Software debugging can be done without a connection to the ROV system. By manually inputting values, the variables of a program can be controlled to pinpoint the issue easier.

V. Safety

A. Safety Philosophy

Safety is of utmost importance, and numerous steps are taken to guarantee the safety of both team members and observers. Great care is taken to imbue each part of the design process with safety precautions to make work safer. During every stage of construction, special safety features are installed onto the ROV to ensure the well-being of everyone handling it. While in operation safety is the number 1 priority and extra care is taken to ensure the wellbeing of every person on deck.

B. Safety Protocol

Safety is kept in the forefront of Coral Crusaders' minds both during the operation of the ROV and during its construction. In lab environments, all members are required to wear goggles and proper lab attire, along with handling heavy equipment with care. A member seasoned with the type of equipment used is responsible for teaching other members on the proper handling of the equipment. The use of this equipment is constantly monitored by a properly trained team member. Every member is versed with the capabilities and dangers of pneumatic systems.

Figure 23: Organized Electronics Photo by Vehd

While the ROV is deployed, team members are constantly cognizant of any potential problems that may arise and are prepared to solve these problems. All potential loose wires and exposed electronics are properly secured to the table and kept far from any potential sources of moisture. Cables to the outlet are carefully laid under a mat to prevent accidental tripping. Communication between the tether manager and the control team is vital to prevent and respond to accidents. Following the end of a session, the ROV is thoroughly inspected for any issues and is wiped down to ensure that pool chlorine and moisture does not damage the ROV.

C. Vehicle Safety Features

One of the primary guiding principles while designing and constructing the ROV was safety while in use. This was heavily reflected in many of the safety features installed in the ROV.

The first of a large set of safety features is the fuse connecting to the main power supply. The max current draw was calculated to 23.9 A which works well with a 25 A fuse. A watt meter reads the current draw throughout the mission.

Any potential mishap in wiring was resolved through clean wire organization. All electronics within the enclosure were carefully positioned and mounted to ensure minimal wire stress while in use. Cable ties strain relief higher gauge wires with the risk of breakage. In addition, all exposed wires or solder joints such as those on the T200 ESC are protected by clear PVC heat shrink.

While in use there are numerous safety features employed to reduce the risk of harm. One of these features is a strained relieved tether. On the ROV side of the tether strain is relieved through multiple layers of sheathing and silicone tape that has been tested to hold the ROV in the air. The table-side tether is secured to the table using two clamps.

Spooky Jobs features the use of a pneumatic claw that specifically operates at 276 kPA (40 PSI). Along with a regulator and release valve, the pre-routed pneumatic box minimizes the possibility of accidents.

Thruster guards are 3-D printed, clip-on, and meet the IP-20 standard, ensuring that no fingers can be stuck in the thruster enclosure.

The result of machining the ABS frame was a product with many sharp edges. A great deal of care was taken to sand down the edges to prevent injury and the wires from coming loose.

D. Operations and Safety Checklist

Coral Crusaders utilizes operations and safety checklists (Appendix A) to enable the safety of members, clients, and spectators during the usage of *Spooky Jobs*.

VI. Accounting

A. Budget

Coral Crusaders is an unaffiliated team and is fully self-sponsored, receiving funding from friends, family, and other individual donors. Additionally, community resources are utilized, such as pools and local businesses that helped machine the ROV frame. At the beginning of the season, each team member paid a fee of $300.00 and collectively published a GoFundMe page. With this GoFundMe $5,000 was raised, and the initial budget goal was met. When it comes to making purchases, all purchases are discussed and approved before adding to the company's balance sheet.

B. Cost Accounting

This year the Coral Crusaders allocated most of its finances towards new Blue Robotics thrusters, an onboard electronics enclosure, a new control system, an IP camera system, and a new float build. An excel sheet was utilized to update and track team costs. The 2023-24 team Budget and Cost reports are shown in Appendix B and C. During the purchasing process, every part is researched thoroughly to ensure that it is reliable, safe, and cost effective. The reused pneumatic system and gripper helped reduce the overall cost of the ROV. By using these cost-effective strategies, a reliable and customizable ROV can be guaranteed.

Conclusion

A. Acknowledgements

Coral Crusaders would like to thank Mate II and the Marine Technology Society for putting on this competition and giving us the opportunity to showcase our ROV. We are also very grateful for the following for playing a large role in our success:

1. Our mentor, Mike Pesavento for his unwavering support, knowledge, and guidance which has been instrumental to our team's success.
2. Redmond and Juanita Pool for donating free pool time which has allowed for ROV testing and the gathering of necessary data for improvements.
3. Aaron at Pelagic LLC for machining our ROV's ABS frame for free.
4. Our kind individual donors for covering our team's budget.
5. Our families for their endless support.

B. References

https://bluerobotics.com/

https://www.britannica.com/science/bismuth

https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/

VII. Appendices

Appendix A: Operations and Safety Checklist

Pre-Power Checks	
Fuse is attached	
All thruster guards are properly attached	
Obstructions to the thrusters are cleared	
There is no exposed wiring	
Cables on the ground are covered with a mat	
Power source is secured	
Tether is secured to both the ROV and the table	
Pneumatic Checklist	
Verify that the pneumatic tube is properly connected to the ROV	
Verify that both knobs are up and no air is being sent to ROV	
Verify that the valve is off (red lever to the side)	
Ensure that PSI is below or at 40 (check both the gauge on compressor and box)	
Secure pneumatic box tube connections	
Pre-water	
Ensure enclosure is sealed and vacuum tested	
Verify that vision system is working	
Check that enclosure humidity is normal (below 50%)	
Check the strain on the tether	
Ensure that thrusters are rotating in desired directions	
Lower the ROV into the water with permission from the pilot	
In-water	
If humidity spikes shut off power to the system	
Check for large amounts of air bubbles	
Notify the pilot that they have control	
Check that ROV is responsive to control	
Recovery	
Ensure that the ROV is not moving	
Pick up the ROV and notify the pilot	

Appendix B: Budget

Income	Type	Description	Amount	
Funding	Donations	GoFundMe Fundraiser	$5,000	
Team Contributions	Cash	Member Contributions	$1,500	
Awards/Prizes	Check	MATE 2nd Place PNW Regionals Prize	$500	
Total Income			**$7,000**	
Expenses	**Type**	**Description**	**Projected Cost**	**Budgeted Value**
Mechanical	Purchased	Thusters	$1,530.00	$1,530
	Purchased	ROV and Float Build Components	$460.00	$460
	Purchased	Tools and Raw Materials	$440.00	$440
	Donated	Air Compressor	$150.00	N/A
Electrical	Purchased	Control System and Sensors	$1,020.00	$1,020
	Purchased	Power and Fusing Components	$295.00	$295
	Purchased	Camera System	$220.00	$220
	Purchased	Waterproof Enclosure and Cable Penetrators	$664.00	$664
	Purchased	Pilot Station and Tether	$160.00	$160
Pneumatics	Re-Used	Pneumatic Gripper System	$150.00	N/A
Pool Time	Donated	Pool time to test ROV	$2,048.00	N/A
MATE Fees	Purchased	Competition Fees	$250.00	$250
Competition Travel Expenses	Employee Paid Expense	Competition Transportation and Accommodations	$9,000.00	N/A
Total Projected Expenses			$16,387	**$5,039**
		Total Income	$7,000	
		Total Expenses	$5,039	
		Net Profit/Loss	**$1,961**	

Appendix C: Cost Accounting

Date	Type	Category	Expense	Source/ Notes	Amount	Running Balance
6/24/2023	Donated	Pneumatics	Air Compressor	Air compressor for pneumatics	$150	-
9/1/2023	Re-Used	Pneumatics	Pneumatic System	Pneumatic System with gripper	$150	-
12/18/2023	Purchased	Electrical	Arduino and Sensors	Float electronics, Raspberry Pi 4s, bench testing	$382.00	$382.00
1/15/2024	Purchased	Mechanical	Blue Robotics	Thrusters and support electronics, pressure sensor, bench testing	$850.86	$1,232.86
2/20/2024	Purchased	Electrical	Ethernet Switches	2x Blackbox Switch	$58.68	$1,291.54
2/21/2024	Purchased	Electrical	ROV Electrical	Ultrasonic and temperature sensors, enclosure and glands	$145.00	$1,436.54
2/22/2024	Purchased	Electrical	Adafruit Electronics	Competition build components	$292.81	$1,729.35
2/23/2024	Purchased	Electrical	IP Cameras	IP cameras and air wedge	$193.60	$1,922.95
3/3/2024	Purchased	Electrical	Float body	Float container, silicone hook-up wire, terminal blocks	$129.27	$2,052.22
3/5/2024	Purchased	Mechanical	Prop parts	Props and tooling	$45.65	$2,097.87
3/12/2024	Purchased	Electrical	Components	Float, ROV, and Camera components	$149.53	$2,247.40
3/18/2024	Purchased	Mechanical	Blue Robotics	Thrusters, Enclosure, Sensors, and Tools	$2,082.61	$4,330.01
3/21/2024	Purchased	Mechanical	Float builds	Camera and float build	$134.40	$4,464.41
3/24/2024	Purchased	Mechanical	Props and Float parts	Syringe and Linear Actuator	$94.98	$4,559.39
3/25/2024	Purchased	Mechanical	Tooling	Props and tooling	$322.64	$4,882.03
4/16/2024	Purchased	Mechanical	ROV Hardware	L-beams, Hardware	$344.21	$5,226.24
4/16/2024	Purchased	Electrical	Tether	Tether and power components	$205.22	$5,431.46
4/16/2024	Purchased	Electrical	Components	Last minute misc components	$136.30	$5,567.76
4/17/2024	Purchased	Mechanical	ROV Frame	ROV frame accessories	$186.95	$5,754.71
4/21/2024	Purchased	Mechanical	Tooling	Servos	$86.04	$5,840.75
4/22/2024	Purchased	Mechanical	Penetrators	Penetrators and DC-DC	$198.93	$6,039.68
4/23/2024	Purchased	Electrical	M4 Terminal Blocks	Spare parts	$210.77	$6,250.45
4/23/2024	Purchased	Electrical	Adafruit	PHT, DRV8871, STEMMA hub and wires	$110.51	$6,360.96
5/2/2024	Purchased	Mechanical	Blue Robotics	Spare Penetrators, Sealant, Vacuum Plugs	$136.80	$6,497.76
9/1/2023-5/9/2024	Donated	Time	Pool TIme	Free pool time to test ROV	$2,048.00	-
					Total Spent	**$6,497.76**