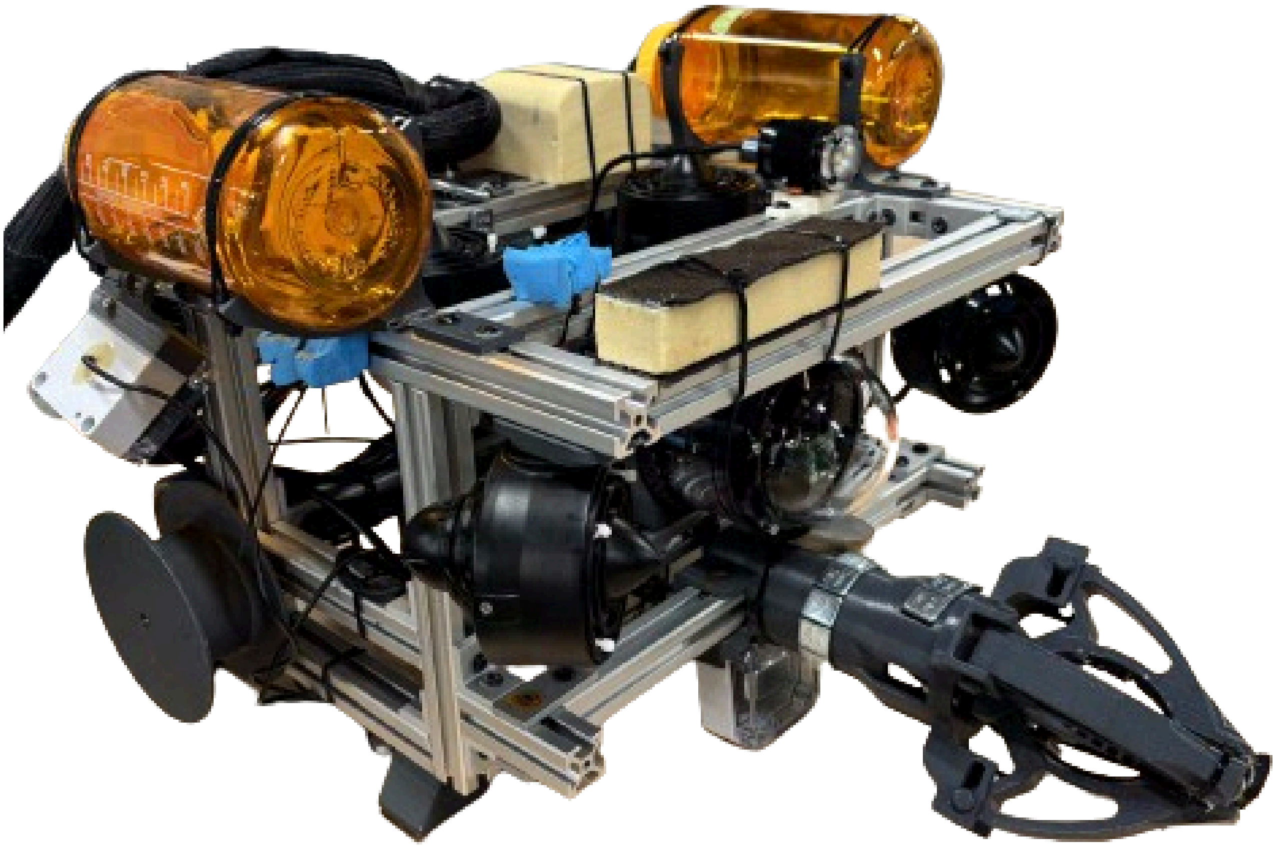

Sugar Hill, Georgia, USA

COMPANY MEMBERS: 9th-12th Grade
orange name indicates a returning member/mentor

- Makenna Reilly: Founder, Project Supervisor
- Violet Brockmann: CEO, CFO, Lead Manufacturer
- Sarah Redstrom: Lead Mechanical Engineer, Lead Tether Manager
- Camila Crespo: Lead Electrical Engineer, Social Media Manager, Asst. Tether Manager
- Sophia Clingan: Mechanical Engineer, Pilot
- Estrella Lozano: Lead Programmer, Lead Profiling Float Technician, Safety Officer
- Ava Farrell: Mechanical Engineer, Copilot
- Anjika Shah: Lead Prop Technician
- Michael Reilly: Mentor

INTRODUCTION

ABSTRACT

SeaCow Robotics is a company comprised of eight talented young women with access to a large makerspace, allowing for in-house prototyping and manufacturing of many of the robot's components. Our mission is to create a unique and successful product while providing a safe space for girls to explore and develop their STEM passions. Moo Shoo, our fourth underwater Remotely Operated Vehicle (ROV), is designed to contribute to three of the UN Sustainable Development Goals. These goals focus on expanding the Global Observing System, protecting biodiversity, and addressing climate change. To efficiently achieve these goals, Moo Shoo utilizes a wide range of tools and subsystems, minimizing the need for frequent resurfacing. This document outlines Moo Shoo's design, prototyping, manufacturing, and testing process, emphasizing its contributions to various UN Sustainable Development Goals.

Figure 1: 2024 SeaCow Robotics Employees - Makenna Reilly

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TEAMWORK

COMPANY ORGANIZATION & ASSIGNMENTS

SeaCow Robotics is an 8-person company divided into the following sub-teams, with each member belonging to at least one: mechanical, electrical, software, and manufacturing. In the fall, team members explore all four subteams to find which one(s) they are drawn to, and will be concentrating their time and work in that field.

Leads of each subteam are most often, but not always, returning members and have the role of outlining tasks within their discipline, delegating those tasks to members of their subteam, and teaching others how to complete those tasks. The CEO collaborates with the Project Supervisor to update the detailed plan of tasks daily and the calendar of season goals weekly to manage team progression. They also serve the role of being the public face of the SeaCows Robotics, leading the team at outreach events. The Project Supervisor, along with helping the CEO manage team progress, helps any members who are struggling with a technical or team management issue. All members have access to both the detailed plan and seasonal calendar, and are tasked with bringing up concerns/necessary changes at bi-weekly meetings.

SeaCow Robotics expanded by 60% between the 2023 and 2024 season, giving members more opportunities to specialize in what they are most passionate about. However, this also means that the majority of team members are new members, so all returning members have an increased responsibility of guiding their coworkers.

SCHEDULING & PROJECT MANAGEMENT

In August 2023, the returning members of SeaCow Robotics met to discuss the timeline for the design, manufacturing, and assembly of Moo Shoo, along with the recruitment and training of new members. A large portion of this time was spent reflecting on weaknesses in previous robots, and how they could be remedied to make a robust, reusable robot. At this initial meeting, a Gantt chart for the 23-24 season was made, including all tasks necessary to make the base for Moo Shoo. This base robot includes only basic driving systems, cameras, and a multi-purpose gripper. This Gantt chart was updated and reviewed regularly.

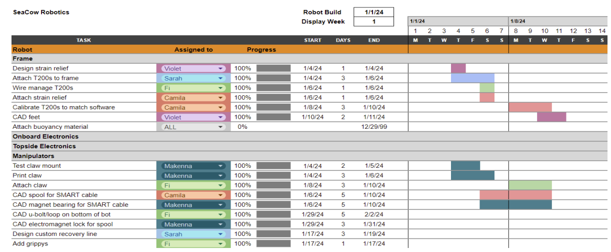

Figure 2: Gantt chart used for initial project management

After the 2024 RFP was released, all team members met to brainstorm ideas for mission-specific manipulators and revise the Gantt chart made earlier in the season. The team quickly realized that the lack of capability for notifications on the Gantt chart made it less likely to be followed and checked daily, so SeaCow Robotics made the decision to switch to Trello and Google Calendar. Through Trello, larger tasks were broken into many smaller tasks and assigned members and due dates. In Google Calendar, broader goals were able to be tracked, ensuring that the pace of development was on track for competition in May.

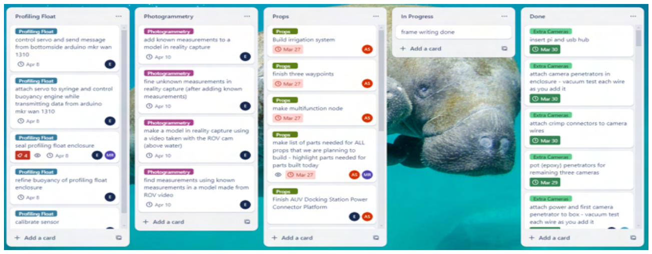

Figure 3: Trello used for project management after RFP release

COLLABORATIVE WORKSPACE

With a variety of challenging mission objectives, it is vital that all employees have access to the workspaces of all other subteams so that members can seamlessly transition from working in their subteams to integrating components with the robot. All documentation, research, and company documents are available in the company Google Drive, which is shared with new members during the onboarding process. By investing time to organize this Drive well, new members can add/edit any document without fear of misplacing their work or undoing someone else's.

All 3D CAD is done in a shared OnShape folder, which allows optimal collaboration. When a subteam begins the design of a mission-specific manipulator, such as the recovery line used in task *1.1 Release the multi-function node,* they simply create a new part studio in context of the main assembly, allowing them to predict interaction with other parts of the robot without affecting them. Once the part is ready, they then insert it into the assembly. When a subteam wants to make a change to an existing part of the robot, they create a branch. In this branch, they can make any changes they choose without affecting the existing robot design, giving them full creative freedom.

Main communication outside of work time was done through the Discord app, which provided an organized way to communicate logistics information, set up in-person meetings, and discuss technical information/strategy. The organization and security that can be achieved with this app made it the ideal solution for SeaCow Robotics.

When problems arise in other day-to-day operations, members go through the chain of command to make sure that none of their peers have already experienced and solved the same problem before reaching out elsewhere for help. They first ask their respective lead, then the other leads, then the CEO, then the Project Supervisor. If no one has experience with a specific problem being encountered, members are trained to use resources like online forums and Chat-GPT to brainstorm solutions. If the problem is not solved within the next day, other members will assist in finding a solution.

DESIGN RATIONALE

DESIGN EVOLUTION

Moo Shoo is the fourth ROV produced by SeaCow Robotics, incorporating concepts from the previous three years. This robot builds upon the successful components of its predecessors, such as vectored thruster orientation and a linearly actuated claw, while improving on past weaknesses like our camera systems.

In the 2024 season, nearly all employees have a background in robotics, gained through participation in activities like SeaCow Robotics, FIRST Lego League, VEX IQ, or FIRST Robotics Competition. This collective experience expedited the company's ability to create a water-ready ROV. This extra time proved invaluable for issue identification, design refinement, and understanding the competition.

A primary goal in Moo Shoo's design is to eliminate the need for resurfacing between tasks. A modular design allows the simultaneous use of multiple tools, streamlining task completion without resurfacing. Efficiency is furthered through extensive exploration of the Ardusub system, initially used in 2023. This system enhances accuracy and speed during task completion and surface travel. Leveraging additional features enhances Moo Shoo's UI capabilities, aiding employee understanding of ROV operations.

Safety remains paramount throughout the 2024 season, guiding design, manufacturing, assembly, and testing. Balancing safety with empowering new team members is achieved through safety protocols and adherence to task-specific requirements.

MECHANICAL DESIGN & MANUFACTURING PROCESS

SeaCow Robotics chose to design a new ROV for the 2024 competition, drawing from principles and techniques honed in the creation of past robots rather than recycling major components. Employing familiar methods and systems enabled swift and confident design decisions.

The mechanical design phase commenced in August, post Longmont, Colorado Championship Event. A team of SeaCow Robotics mechanical and control systems engineers met to outline Moo Shoo's major components, aiming for an easily adaptable and versatile base for future customizability to competition tasks. Recognizing the need for an advanced camera system and a more modular ROV design to facilitate the pilot's and tether manager's tasks, the team embarked on refining the initial iterations.

Early design iterations prioritized thruster placement for orientation, omitting the need for pitching of the ROV, given the camera's pitch capability inside the enclosure. Moo Shoo's design took place in OnShape, a computer-aided design (CAD) software facilitating collaborative editing from anywhere with internet access. Numerous iterations of the main frame design were undertaken, with the final version addressing issues encountered in 2023, such as customization challenges, frame fragility, and a faulty camera system.

The frame, crafted from T-slot aluminum for its simplicity and customizability, featured custom T-slot aluminum bars sourced from Automation Direct. This allowed precise control over the design and expedited frame assembly, enabling early hands-on involvement of employees in the season. Additionally, several frame components were 3D printed using a Stratsys 3D printer, facilitating the fabrication of custom parts for various requirements, including thruster mounts, parts of the claw mechanism, and more.

MECHANICAL COMPONENTS

FRAME

Switching to T-slot aluminum for the frame of the ROV provided modularity, customizability, and complete confidence in the tolerances designed for connecting the parts due to where the T-slot aluminum was sourced from. This frame is much less buoyant than the 2023 ROV, however with inspiration from other 2023 World Championship teams, accommodation was relatively simple.

The modular design is meant to provide more space for the additional cameras and tools, and ease of handling of the ROV. This design also provides many opportunities to mount various tools to minimize surfacing, along with handles to ensure the safety of SeaCow Robotics employees when handling Moo Shoo.

The electronics enclosures are located in the center of the frame which allows the main camera to achieve a clear view of the claw, objects in front of the ROV, and the surface. Thrusters are mounted at 30° angles on 3D printed mounts to secure the T200s. This angle was chosen over 45° angles because it increases the forward thrust of Moo Shoo by up to 25% at the sacrifice of strafe thrust, which was successful in the 2023 season.

Two 32oz Nalgene water bottles are mounted at the top of the frame to raise the center of buoyancy, adding more stability to the ROV. The frame of the robot has ballast and buoyancy added to make up for the differences in mass, raising the stability of the robot.

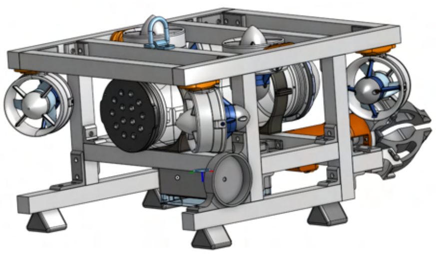

Figure 4: CAD of frame

PRIMARY ELECTRONICS ENCLOSURE

The Primary Electronics Enclosure (PEE) houses the electronics for all basic ROV functions including driving, the primary camera, power level monitoring, and depth sensing. SeaCow Robotics chose to re-use the enclosure and most electronics from the 2022-2023 season in order to save valuable time and money, only modifying the 12V to 5V converter and one penetrator into the enclosure. These changes are detailed in the Bottomside Electronics subsection of the Electrical Systems Section. Making an entirely new PEE would've allowed consolidation of the two underwater electronics enclosures, but the cost to make this upgrade would've been at least $400, compared to the $50 spent on the Secondary Electronics Enclosure (SEE).

A 100mm Acrylic Enclosure from Blue Robotics was used to house these electronics, providing plenty of room to safely organize the components but resulting in a difficult frame design process, as employees had to work around this large tube. To accomplish this integration, the enclosure mounts were integrated as supports into the frame design, allowing the frame to be more vertically compact. This idea was modified from a similar one in SeaCow Robotics' 2023 robot.

SECONDARY ELECTRONICS ENCLOSURE

After deciding to upgrade to a USB camera system from an analog camera system, SeaCow Robotics was met with the decision to either upgrade their existing underwater electronics enclosure to include the components needed to accommodate the streaming of 4 extra cameras or add an entirely new enclosure. As mentioned in the previous section, employees decided to add a secondary enclosure due to the cost difference between the two options.

In order to save funds, make the mounting process easier, and integrate the camera system faster, the company decided to buy a rectangular submersible housing from McMaster for $30, compared to a $150 75mm housing from Blue Robotics. Employees then installed penetrators into this enclosure and vacuum tested it to ensure a seal, providing a simple housing for camera electronics. Originally, employees decided to order the smallest enclosure that the electronics could fit in, and directly epoxy wires through the enclosure walls, instead of using penetrators, to save space. After struggling to form a seal using this method, employees upgraded to a larger enclosure and outfitted it with a full set of potted penetrators. The details of these electronics can also be found in the Bottomside Electronics subsection of the Electrical Systems section.

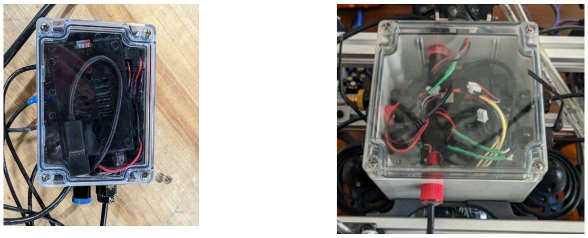

Figure 5: Comparison of original (left) vs. updated (right) camera electronics enclosures - Makenna Reilly

THRUSTERS

Moo Shoo is equipped with six T200 thrusters in a vectored orientation. The four horizontal thrusters in this orientation allow all horizontal degrees of freedom. This allows the pilot maximum freedom in movement, increasing efficiency.

Vertical thrusters are mounted on the left and right side of the robot, which allows a larger electronics enclosure at the sacrifice of pitching. Returning employees decided that pitching was deemed unnecessary due to the main camera servo.

Since the Ardusub system is used on Moo Shoo, it was also important to choose a thruster orientation that was able to work with this software. The vectored thruster orientation used on Moo Shoo matches a default thruster orientation in the piloting software, which made it easy to get the thrusters up and running quickly.

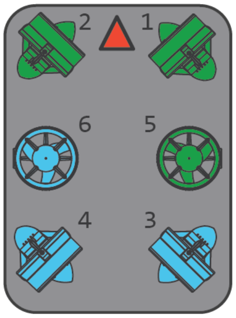

Fig. 6: Vectored ROV configuration - Ardusub Gitbook

These six thrusters provide speed, but they also draw a large amount of current. This current is limited by the main 25A fuse, and through the Ardusub software. The RC3_MAX, RC3_MIN, and RC3_TRIM parameters limit the current drawn by all of the thrusters to 2A by limiting the maximum and minimum PWM values. This provides an extra layer of safety in compliance with MATE ROV Competition regulations.

RC3_MAX	1684 PWM	RC max PWM
RC3_MIN	1316 PWM	RC min PWM
RC3_REVERSED	Normal	RC reversed
RC3_TRIM	1316 PWM	RC trim PWM

Fig. 7: Current-limiting parameters in QGroundControl

These thrusters are also a massive monetary investment at $200/thruster, bringing the total expense of thrusters onboard to $1200. Fortunately, SeaCow Robotics employees in 2022 deemed this an important investment for the long term success of the company, and proper care of these thrusters has helped maintain them for the future.

CAMERAS

Moo Shoo utilizes five digital cameras, including one Raspberry Pi Camera and four Microsoft Lifecam HD-3000s. Upgrading to using five digital cameras instead of one digital and two analog cameras improved ease of navigation and task completion for the pilot, photogrammetry capabilities, and camera replaceability. The Microsoft Lifecam HD-3000s were chosen for their ease of integration into a webcam streaming software. Originally, the company chose to use Megapixel SuperMini USB cameras for their low relative cost and $14 per camera and small size, making manufacturing and assembly of custom enclosures simpler and replacement less expensive. However, these cameras came with little to no documentation and were too complex to integrate into a streaming software within the time allotted to them.

The Raspberry Pi Camera, located on a servo inside the larger electronics enclosure, provides the pilot with a clear view of the claw for tasks that require this manipulator such as *1.1 Release the multi-function node.* Due to its ability to pitch, it is also helpful in navigating back to the 1 meter square representing a ship's internal launch bay.

Digital Camera 1 is mounted on the topside of the robot with a view of the u-bolt and hook on the bottom side and provides a view of robot payloads such as the power connector from the

AUV docking station used in task *2.1 Deploy SMART cable*.

Digital Camera 2 provides a view of the right side of the robot, where the side mounted manipulators are located. This camera is vital, as it allows the pilot to see the custom recovery line used in task *1.1* and our spool used to hold one half of the SMART cable in task *2.1*.

Digital Camera 3 is mounted underneath the claw, and provides another angle for navigation and tasks involving the use of the claw.

Digital Camera 4 is mounted on the left side of the robot, and is used for navigation and photogrammetry in task *3.3 3D Coral Modeling.* As the pilot completes a survey of the coral restoration area, screenshots are taken from Digital Camera 4 and uploaded to the Capturing Reality app, which then makes a 3D model of the area.

Originally, the four Megapixel USB cameras were housed in custom enclosures, made by CNC routing a block of PVC and securing a laser-cut acrylic top with epoxy. This resulted in a robust, easily manufacturable enclosure that the employees were able to repeat for each of their cameras and a few spares. When switching to Microsoft Lifecam HD-3000s, the decision was made to house them in pre-made enclosures from McMaster in order to save time and make the camera system more easily recreatable by other teams, using the guide posted on the SeaCow Robotics website. While this was $30 more expensive than making our own enclosures, it saved more than 3 hours of company time, making the investment pay off when considering a possible rate of $10/hour. The electronics for these cameras are housed in an enclosure from McMaster, which holds a Raspberry Pi 3B+, 5V power from the main enclosure, and custom USB jumper cables to connect each camera to a port on the Pi. This enclosure is outfitted with a Blue Robotics Vent in order to test the seal before submersion. Since camera power is provided from a 5V source inside the main electronics enclosure, the only wire added to the tether for four extra cameras is one ethernet cable.

Figure 8: Comparison of original (left) vs. updated (right) camera enclosures - Makenna Reilly

BUOYANCY/BALLAST

When the employees simplified the design process by not CAD-ing the T-slot aluminum exactly, opting for basic rectangles instead, they couldn't assign materials to the parts, hindering accurate buoyancy calculations. Initially, they added syntactic foam rectangles around the top of Moo Shoo and ballasts (laser cut 9.5mm 316 Stainless Steel in 200g circles) to the claw. These measures, based on prior experience, aimed to counteract the compressed air within the pneumatic cylinder powering the claw.

From there they discovered that Moo Shoo was much heavier–despite the air in the claw, tube enclosure, and camera splitter enclosure–than in previous years when constructed from HDPE. To address this, they temporarily used plastic water bottles available at the time, proving effective in the short term. For a more permanent solution, they ordered Nalgene bottles while still relying on large pieces of syntactic foam used on TAUrus two years ago.

Given the imbalance in weight distribution due to components like the cameras and electromagnet on the right side, the employees made further adjustments by incorporating wheel weights, pull buoys, and smaller pieces of syntactic foam. Additionally, employees opted against using pool noodles to maintain consistent buoyancy at lower depths where they compress.

ELECTRICAL SYSTEMS

TOPSIDE CONTROL SYSTEM

To save funds, SeaCow Robotics decided to re-use the 2023 topside control box. Ava was tasked with preparing the topside control box for this year's ROV. This included removing the existing wiring, and taking measurements to design plugs in CAD for the holes left behind. Another employee, Camila, was tasked with examining the changes and making adjustments to make sure it could properly function.

This case features a laser-cut acrylic sheet positioned over the components, allowing the company to mount switches onto it, providing visibility of all topside electronic elements, and serving as a protective barrier for both the electronics and employees.

Contained within the extra-large case are electrical components essential for the topside control box's functionality: a double bus bar, one main power switch, a pneumatic switch controlling the claw, a pneumatic solenoid, a pressure relief, a pressure regulator with gauge, and an electromagnet switch. Penetrators into the topside control box include a 9-pin receptacle, three quick-disconnect pneumatic fittings, an Ethernet receptacle, an Anderson Powerpole receptacle, and an ROV power receptacle.

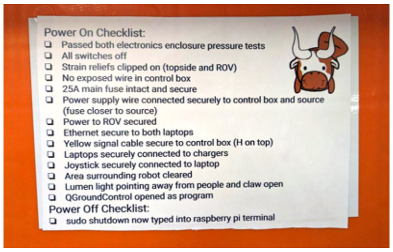

Fig. 9: Pre and Post Power Checklist in Topside Control Box - Makenna Reilly

The 9-pin receptacle facilitates signal transmission to the ROV and aligns with two pneumatic connectors and the power to ROV connector on the same side of the topside control box, reducing tripping hazards. Meanwhile, the Anderson Powerpole and Ethernet penetrators are rear-mounted, linking the topside control box to the laptop and power source. The camera Ethernet from the tether passes through a strain relief before connecting to the camera laptop.

Safety considerations are essential in the topside control system's design, and seen in several features. A strain relief is integrated into the tether's topside via a carabiner that prevents the pulling of wires. Furthermore, a pre and post-power checklist is permanently attached to the lid of the topside control box (as depicted in Fig. 9), this lessens the risk of accidentally powering the robot prematurely, safeguarding both the system integrity and employees from potential harm.

TETHER

The tether is made up of one signal wire, two power wires for main power, two power wires for the electromagnet, two pneumatic tubes, ethernet for the new camera system, and two camera wires. Additionally, the company added a 19mm buoyant backer rod to eliminate the need for bulky pool noodles taped around the tether. All of these elements are surrounded by a split tether loom that holds them together in an organized and safe fashion.

The main signal wire is a Blue Robotics Fathom X tether, which was chosen due to its compatibility with Blue Robotics penetrators. Since the underwater enclosure used on MooShoo is produced by the same company, extra time does not have to be used to waterproof it. This wire is also neutrally buoyant, which minimizes the buoyancy calculations needed to be done for the tether.

The two main power wires are 8 AWG silicone wires in red and black. These wires, although negatively buoyant, are extremely flexible and provide maximum range of motion for the tether which makes piloting much easier. The penetrators for these wires are potted, meaning they have an epoxy seal instead of a compression seal. These penetrators are reused from SeaCow Robotics' 2022 robot, and utilize a semi-flexible epoxy which allows the extremely flexible silicone to bond to it more securely when properly prepped. Prepping the silicone wires included intensely sanding them and cleaning them with abrasive alcohol. This was vital in ensuring a secure and long-lasting seal that can be trusted.

The two pneumatic tubes are polyurethane, 1⁄4" OD, 0.156" ID tubes which are filled with pressurized air regulated to 40 PSI. The pressurized air inside these tubes makes them buoyant, which helps to offset the negative buoyancy provided by the heavy silicone power wires previously described. These tubes connect to pneumatic fittings inside the claw providing the air necessary to operate the pneumatic actuator.

The "dummy camera" wires are RCA video cables. Since the cameras chosen are completely potted with epoxy already, the only waterproofing needed to be done was with the RCA connectors on the robot side. These were waterproofed by encasing the connectors in epoxy, fully protecting them from water at the expense of greater weight. These cables are only slightly negatively buoyant, which means that less buoyancy must be added to bring the tether to neutral buoyancy.

The strain relief on the robot side of the tether is provided by a carabiner attached to a dynamic mount on the top and center of Moo Shoo. This placement ensures that the slightly positively buoyant tether rises straight up from the ROV when submerged, minimizing the tether's effect on the motion and ease of driving of the ROV. The carabiner used for strain relief on the robot also provides a secure grab-point for employees to safely lift the robot out of the water without risk of back injury. The strain relief on the topside control box is done similarly with a carabiner that is attached to the tether loom and a built-in hole on the control box.

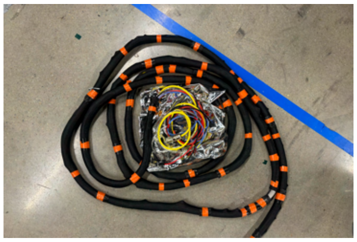

Fig. 10: Tether - Camila Crespo

BOTTOMSIDE ELECTRONICS

As mentioned earlier, SeaCow Robotics chose to re-use the main electrical/control systems design from the 2023 season. This decision was made due to the success the company had previously using the Ardusub control system with compatible hardware. This system includes a Raspberry Pi 3B, Pixhawk 1, Blue Robotics ESCs, a Power Sense Module, a 12V → 5V converter, and related accessories. All of the electronics just mentioned are housed in the (PEE). With this hardware, which is recommended by Ardusub, SeaCow Robotics is able to have basic vehicle functionality including, driving, one camera, a gimbal for that camera, and a light with zero code. This saved immense time, at the cost of a more expensive control system. However, this system is highly reusable, and the company does not see it becoming obsolete any time soon.

While most of the PEE remained unchanged from 2023-2024, one more branch was added to the 12V → 5V converter to accommodate the new camera system. This was done by soldering two new wires to the existing wires on the 5V end and adding a Dupont connector so that any 5V component could be attached. A penetrator with a 2 conductor cable was added to the enclosure, with a compatible Dupont connector, which then traveled to the Secondary Electronics Enclosure, providing 5V 2A to the Raspberry Pi 3B+.

The SEE includes a Raspberry Pi 3B+, 4 USB connectors for the USB cameras, a 5V power cable attached to a Micro USB pigtail, and an ethernet cable that goes to the surface. The SEE allows access to the stream of our new cameras. The programming for the SEE is in the software section.

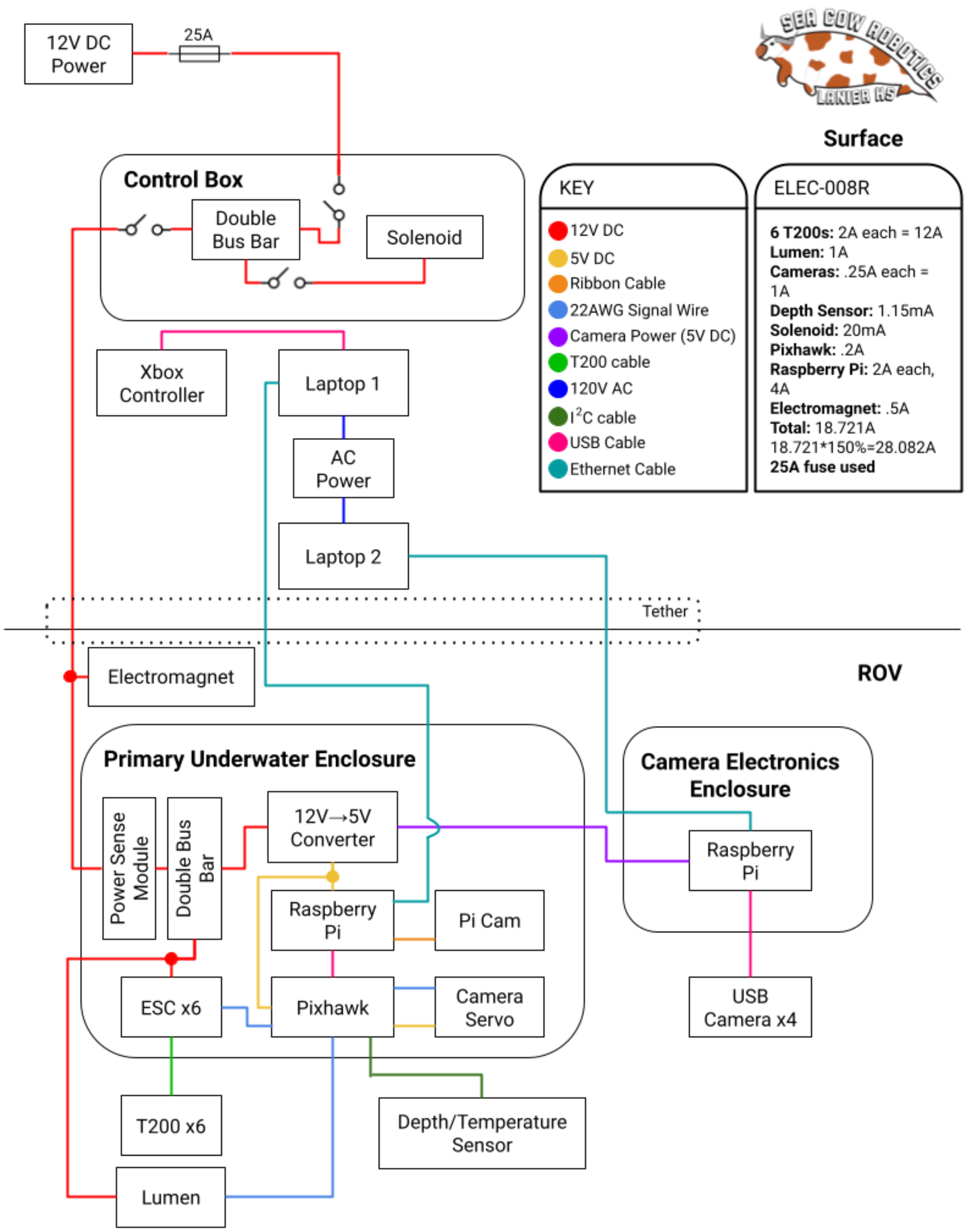

Figure 11: Electrical SID

PNEUMATICS

The only use of Moo Shoo on pneumatics is to actuate the claw. The pneumatic system consists of a connection to the MATE supplied air source, a pressure release valve, a regulator set to 2.75 Bar with an accompanying gauge, a solenoid valve, and a double action pneumatic actuator. All constituents within the system adhere to the MATE regulations, with max ratings of 6.9 Bar or higher. Power for the solenoid comes from the double bus bar housed within the topside control box, operated via a switch integrated into the laser-cut acrylic panel. This switch enables swift activation of the claw by our copilot as necessary.

Contained within the topside control unit, the pressure relief valve, regulator, and solenoid are separated from electrical wiring. These components are securely fastened using zip ties to the acrylic plate and bottom of the control box. Accessibility to the pressure relief valve is ensured, allowing any employee to promptly access it for safety purposes at any given moment.

Despite the inclusion of two pneumatic lines descending to the robot, resulting in a heavier and less flexible tether, it effectively mitigates the negative buoyancy induced by the two 8AWG silicone power wires. Consequently, in conjunction with the backer rod as detailed in the Tether section, the tether achieves a slight positive buoyancy. The pressurized air enclosed within the claw-controlling cylinder significantly influences the robot's overall buoyancy and center of buoyancy, thus requiring wheel weights and 200g ballasts to be attached to the claw.

All symbols utilized within the SID adhere to ANSI standards. As shown in Fig. 12, this SID does not anticipate the presence of a relief valve and regulator on the compressor, although these features are commonly present. This design choice facilitates compatibility with a wide array of air supplies, allowing Moo Shoo to be demonstrated at many locations.

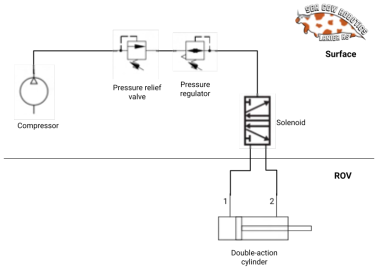

Fig. 12: Pneumatic SID

SOFTWARE

The majority of hands-on coding that was done for Moo Shoo was done for non-ROV systems. Among these, the profiling float is a notable example of needing intensive coding efforts for functions such as temperature, pressure, depth, and altitude measurement. The profiling float includes an Arduino MKR WAN 1310 for buoyancy engine control and communication with another board housed in the topside control box. Both components were programmed using Arduino's custom language, which is based on C++.

While Photogrammetry for task *3.3 3D Coral Modeling* has had a larger software demand in the past, the decision to switch to using Reality Capture, a photogrammetry app has negated much of this work. This app removes the need for employee software development, as it creates a 3D model from pictures without direct code. This app also has saved money, since, by using known measurements, the need for a stereoscopic camera which can be quite expensive is removed. The USB cameras used to capture the images for this task have proved to be a software challenge, but the company eventually landed on a low latency streamer called Pi Improved Camera Streaming (PICS) that also requires no software development. The brainstorming process to land on this software is described later in this section.

PROFILING FLOAT

The profiling float is one of our non-ROV devices that works in conjunction with Moo Shoo to complete task 4 MATE Floats! Information on the design and electrical elements of this device can be found in the Tooling section of this document. The Arduino is used to control a servo which operates the syringe inside the float. It uses a limit switch to stop the servo when the lead screw has reached its maximum/minimum and a timer to control how long the syringe holds each position.

Communication between the float and the surface is done using an Arduino MKR WAN 1310 which has LoRa capabilities. The time is calibrated by measuring the second since the profiling float was turned on then uploaded to the onboard Arduino each time it is used. Currently, the team number is represented by RN30, but this can easily be changed. Once the Arduino is turned on, the time is automatically updated and sent to the receiver board inside of the topside control box.

The code uses both the LoRa, MS5837 and Time libraries made by Arduino to minimize code needed. There is also a one-second delay between each time the on-board Arduino sends data to not overwhelm the user on the receiving end while still providing an accurate time.

```
//Send packet
LoRa.beginPacket();
LoRa.print("time: ");
LoRa.print(hour());
LoRa.print(":");
LoRa.print(minute());
LoRa.print(":");
LoRa.print(second());
LoRa.println(" team number: RN30");

sensor.read();

LoRa.print(sensor.pressure());
LoRa.println(" mbar");

LoRa.print(sensor.temperature());
LoRa.println(" deg C");

LoRa.print(sensor.depth());
LoRa.println(" m");

LoRa.print(sensor.altitude());
LoRa.println(" m above mean sea level");

LoRa.endPacket();


counter++;
delay(1000);
```

Fig. 13: Excerpt from the LoRa sender showing the packet

The sender for the sender includes a packet which includes the time, the current pressure, temperature, depth and altitude which these variables are then graphed to make it easier to see the change.

The code for the receiver is more compact and consists of a check to make sure that it is receiving the correct size and type of packet, printing the information it receives from the sender, and adding a personalized tag for SeaCow Robotics. The information received is displayed in the serial monitor the Arduino IDE of the laptop connected to the topside control box which can easily be read without pilot distraction.

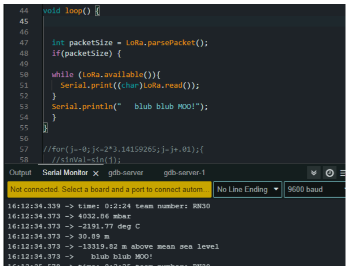

Fig. 14: Excerpt from LoRa receiver and example of serial monitor output

USB CAMERA STREAMING

Initially the Motion package was used to access the camera. However using this program made it difficult to configure the cheaper cameras being used. With these problems the employees upgraded cameras to Microsoft LifeCam HD-3000s, which is detailed more in the Cameras section. The employees also changed to a new package called PICS, which allowed the SeaCows to quickly deploy a low latency streaming system. The PICS setup required the SeaCows employees to install the libjpeg library, clone PICS from github, and then compile PICS. This setup was much quicker than Motion and resulted in a much lower latency. The employees tested the latency by using a stopwatch in front of the new cameras, taking a picture including both the video feed and the live stopwatch, and comparing both times. With the new system, there was a 400 ms latency, compared to the ~1.5s latency with Motion.

TOOLING

PNEUMATIC CLAW

The pneumatic claw serves as the primary manipulator aboard Moo Shoo, and is the sole pneumatic device on the robot. Further details regarding the pneumatic system can be found in the preceding Pneumatics section. Adopting a four-finger configuration, the claw was designed for its versatility in grasping a diverse array of objects. Pneumatics were favored as the actuation method for the claw due to their ease of creating linear motion.

Prior interactions of the SeaCow Robotics ROVs encountered efficiency limitations attributable to the constrained size of the primary manipulator,requiring precise maneuvering by the pilot for accurate positioning. This challenge was addressed in the design of Moo Shoo's claw, engineered to achieve a maximum opening width of 19 cm.

Additionally, Moo Shoo's claw boasts considerable strength. Leveraging a double-action pneumatic cylinder operated at the MATE provided maximum of 2.75 Bar, it securely grasps objects without the risk of damaging the 3D printed claw or compromising the integrity of the object. This mitigates instances of dropped objects after acquiring them, thereby minimizing the need for the pilot to reposition the robot for retrieval. Nonetheless, to further diminish the likelihood of dropped objects, tool chest grip material was glued onto into the claw's fingers.

Addressing operational challenges encountered during task execution, the integration of magnets into two claw fingers significantly enhanced effectiveness in tasks involving the manipulation of metal pins to untangle ropes in task *1.1 Release the multi-function node*.

The decision to fabricate the claw as a fully 3D printed assembly , omitting traditional steel pins, presented a difficult conversation. Ultimately, this approach yielded substantial reductions in cost, weight, and system complexity. Notably, the adoption of steel pins would have inflated the claw's cost to approximately $200, while the fully 3D printed assembly, inclusive of the pneumatic actuator, carries an approximate cost of $50. Furthermore, this design facilitates expedited claw replacement in the event of breakage.

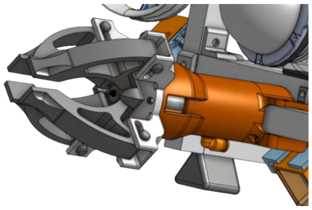

Fig. 15: Pneumatic Claw - Camila Crespo

Rigorous testing protocols were undertaken to validate the reliability of this system within the context of SeaCow Robotics. This testing included finding optimal tolerances between pins and slots, testing fillet radii to minimize pin breakage, and finding an appropriate wall thickness to ensure assembly durability. Insights from these tests informed refinements to the claw design, ensuring robustness and operational effectiveness.

SPOOL

The electromagnet used for the spool was chosen for its compact height (10mm), incredible strength (200N), and low amperage draw (0.5A). It also doubles as a support bracket for the frame of the robot, saving space and money that would've been spent buying unique brackets that fit around the electromagnet. SeaCow Robotics has previous experience waterproofing electromagnets, so employees used the same method of epoxy flooding the electromagnet casing as they did in 2023.

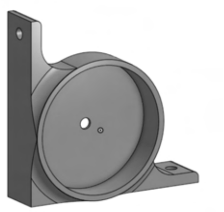

Figure 16: CAD of electromagnet mount/frame support bracket

Task *2.1 Deploy SMART cable* involves laying a cable, deploying a repeater, and returning the other end of the cable to the surface. Since half of the cable must not be laid until the repeater is deployed, SeaCow Robotics created a custom spool, which controls the release of the second half of this wire. This design was inspired by the 3D printers used regularly since they control when/how the filament is released. The original prototype of this mechanism followed the 3D printer model more closely, using a servo to hold in place and/or unwind the cable. However, this was expensive, bulky, and difficult to make modular.

Instead, employees prototyped a spool held in place and/or allowed to spin freely using a combination of electro and permanent magnets. The custom 3D-printed spool has an inlaid permanent magnet in the center, holding the spool onto the side of the robot, and ring shim along the outside edge, providing a surface for the electromagnet to hold. A custom mount on the side of the robot encases another permanent magnet which holds the spool onto the robot and has enough tolerance (.75mm) for it to spin freely when the electromagnet is disengaged. A screw protrudes through the center of this magnet and acts as the axel for the spool to spin freely on. Originally this screw was 3D printed, but employees found that it was too fragile to withstand reasonable stress during transport. The ring shim along the outside edge provides a surface for the electromagnet to grip when powered, preventing the spool from spinning freely and releasing the cable when the first half is being laid and the repeater is being deployed.

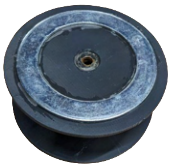

Figure 17: 3D printed spool with inlaid magnet and ring shim - Makenna Reilly

To save space, money, and time, the electromagnet used for the spool mechanism is the same as the one used for the Recovery Line, which is detailed in the next section.

RECOVERY LINE

In the 2023 MATE competition, one of the tasks involved mooring a solar panel array to three anchor points, with the connection point simulated by a carabiner pushed into a u-bolt. This proved to be a challenging task. So, when a similar task arose this year, the team opted to create their own solution, since that was an option. Sarah, tasked with planning, CAD-ing, 3D-printing, and constructing the homemade recovery line, spearheaded its development.

The first challenge encountered was devising a mechanism to keep the line open until it needed to be closed at a specific time. Sarah initially considered pneumatic solutions but ultimately opted for an electromagnet due to its simplicity. The plan involved one fixed finger and one rotating finger, held back by a string tied through a large metal washer. This assembly would be controlled by an electromagnet. When turned off, it would release the tension created by a rubber band around the two fingers, allowing the line to close.

Originally, a separate tether was planned to be used to connect the recovery line's electromagnet to the surface, similar to the approach taken the previous year with the fish fry container. However, it was later decided to use the same electromagnet as the one for the spool. The spool, attached to a long bolt, could be removed, necessitating a hole in the body of the recovery line. Additionally, a ring magnet within the mount of the bolt and a metal nut epoxied to the end of the recovery line was utilized to hold the recovery line in place for added stability. Corrugated plastic side flaps were also added to prevent rotation.

Once closed around the U-bolt, Moo Shoo would strafe to the left to release the recovery line. Velcro was also added to the connecting ends of the fingers to ensure a secure hold when pulled off by Moo Shoo.

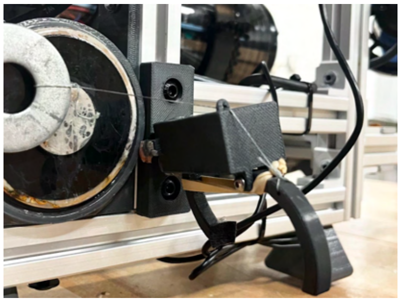

Figure 18: Recovery Line - Sarah Redstrom

PROFILING FLOAT

Our profiling float used in *Task 4 MATE Floats!* uses an extremely simple buoyancy engine consisting of a syringe, a lead screw connected to a servo, and a bladder. When in use, water is contained in the bladder-syringe system and shifts between the two to change the buoyancy of the float. When the majority of the water is inside the syringe which is inside the main body of the float, the float sinks. When the majority of the water is in the bladder, the float rises.

Figure 19: Profiling Float - Camila Crespo

As previously mentioned, the main computers inside the profiling float are an Arduino MKR WAN 1310. These computers use a limit switch, servo, antenna, depth/pressure sensor, and a I2C converter to connect the sensor to the arduino to control the buoyancy of the float and transmit data back to the surface side of the pool. Information on this code can be found in the

Software section. The electronics are intentionally simple to save space inside the enclosure and minimize current draw, as seen in the fuse calculations.

A 3” blue robotics tube is used for the body of the profiling float due to its small but adequate size to fit all of the components safely in addition to its availability since it was used by SeaCow Robotics in 2022. The 4 AAA batteries are secured in their own container which is then wrapped in electrical tape to prevent any batteries getting loose from vibrations in transportation. All other electronics are also wrapped in electrical tape to prevent any wires from becoming loose inside the container and causing a danger to the electronics and SeaCow Robotics employees. More information on the float can be found in the non-ROV Design Document.

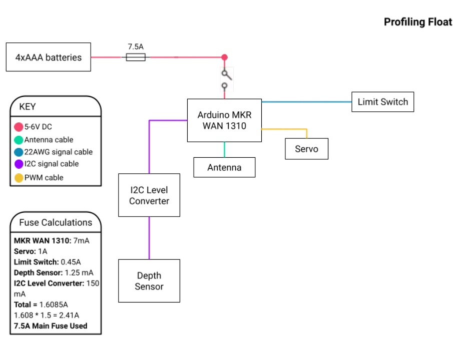

Figure 20: Profiling Float SID

U-BOLT

To complement the hooks on both the SMART Cable Repeater and the AUV Docking Station Power Connector in *Task 2.1*, a U-bolt attachment to Moo Shoo was necessary. Sarah used a previous sketch for sliding the hooves into the T-slot aluminum. However, the tolerance levels and fillets were too little, resulting in difficulty sliding it into the T-slot aluminum due to significant resistance. Another challenge arose when it was discovered that the plate where the bolts went through was not flush when slid into the T-slot aluminum, leaving a significant gap and preventing the attachment from being tightened in place on either side. Once these initial issues were resolved, two holes were indented into the piece for the U-bolt to fit into, to be epoxied in place. However, the nut and bolt holes for securely locking the piece in place were too close to the slide-in component, making it impossible for the nuts to fit. After addressing these issues, the newly mounted U-bolt would enable Moo Shoo to securely hold the SMART Cable Repeater and the Power Connector involved in *Task 2.1*.

HOOK

Task 3.1 involves positioning the probiotic irrigation system in its designated location. The system is modeled by a PVC box that does have some grab points for the claw, but the company aims to keep the claw available for tasks that absolutely require its use. A large U-bolt on top of the box offers a potential solution. To achieve this, the company decided to add a hook underneath Moo Shoo, near the back right.

Sarah took on the task of designing and 3D printing the hook’s attachment. She utilized the sketch for the hooves (as used for the U-bolt) and then based the further design on the purchased metal hook. As there was no existing 3D model of the hook, CAD-ing the attachment proved difficult. The plan was to secure the hook to the attachment using a bolt and nut. Despite using a caliper, Sarah enlarged the holes found in the back piece of the hook to accommodate any potential measurement errors. Additionally, two holes were added to the piece to allow a nut and bolt to completely secure the hook-attachment assembly to the T-slot aluminum.

Initially, the hook resembled a T-shape with small fillets in the perpendicular corners. However, due to low tolerance on the sliding component, the struggle to move and remove the piece led to breakage. To prevent this from happening again, larger fillets were added to reinforce the structure. With the hook successfully mounted onto the robot, the pilot can now easily scoop up the irrigation system, freeing the claw for other tasks and minimizing trips to the surface, thereby optimizing efficiency.

Figure 21: 3D printed mount and hook - Sarah Redstrom

MAGNETS

In order to pull the metallic pin in task *1.1 Release the multi-function node,* two small rare-earth magnets are attached to opposite sides of the claw. Rare-earth magnets were chosen due to their impressive strength to size ratio when compared to other types of magnets that we've used in the past. This allows the magnets to be mounted on the claw without interfering with accomplishment of other tasks. While rare-earth magnets can get expensive, the ones chosen for this task were reasonable at $1.90 per magnet.

Originally, the magnet was located in the center of the claw, but was unreliable since the metallic pin was sometimes pushed too far in for the magnet to achieve contact with the pin. Employees then chose to move magnets to the claw fingers. In testing, the company experienced issues with the claw getting stuck closed as the magnets were attracted to each other. Instead of a redesign, the magnets were simply flipped so that like poles were facing each other, preventing the claw from being stuck closed.

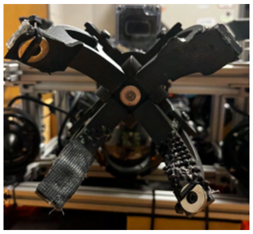

Figure 22: Open claw with magnets - Sarah Redstrom

TROUBLESHOOTING & TESTING

SeaCow Robotics tests new and old components throughout the design process. Using CAD software, employees are able to design attachments for the robot and test it online before using material to make it. After prototyping, each new component is tested thoroughly out of water before being tested in the water, in order to ensure safety and efficiency.

One example of the SeaCows Robotics troubleshooting process was a new employee assigned the task of utilizing CAD software to design plugs for the topside control box. While three of the four plugs were successfully printed and fitted into the topside control box, one plug turned out undersized due to inaccurate measurements.The employee remeasured and adjusted the CAD accordingly, learning from her mistakes. With the acquired measurements, Ava, a recent addition to the company, learned about the design process under the mentorship of returning employees. Following adjustments made to the original CAD design, the plug was accurately printed, thus finalizing the topside control box assembly.

SAFETY

COMPANY SAFETY PHILOSOPHY

Safety is paramount at SeaCows Robotics. All employees must adhere to MATE and SeaCow Robotics safety protocols continuously to foster an environment conducive to learning and growth, uninterrupted by accidents. Our mission is to develop an exceptional product while nurturing a safe space for girls to explore and nurture their STEM interests. Employees are required to follow safety procedures, including wearing personal protective equipment, using tools only in designated areas, and working under the supervision of employees educated on the equipment.

LAB PROTOCOLS

The manufacturing process of Moo Shoo entails several procedures with inherent risks, including the use of a CNC router to cut PVC bars, epoxy application for camera enclosures, assembly of the T-slot aluminum frame, and soldering of electrical wiring for the camera system. To ensure the safety of personnel, each step is overseen, with new trainees receiving comprehensive guidance from experienced colleagues and constant supervision from mentors during hazardous tasks.

Assembly of the T-slot aluminum frame presents a moderate level of risk due to the sharpness of the metal components. Every employee exercises caution, prioritizing safety in the handling of these materials, particularly around their edges, to prevent any potential injuries. Prior to commencing work, thorough consultations of JSA and safety protocols are conducted. Additionally, a resource, such as a booklet authored by a former SeaCow Robotics Manufacturing Lead, containing checklists for CNC router operations, is provided alongside the equipment.

During operation of the CNC router, strict safety measures are enforced, mandating the use of safety glasses by all employees and the presence of two individuals at the router table. One team member monitors the material to prevent issues such as lifting or melting, while the other oversees the CNC routing program, addressing any anomalies in cut depth or unexpected patterns. Both individuals maintain access to an immediate emergency stop button to ensure swift intervention in case of emergencies.

Epoxy application for Moo Shoo is conducted within an isolated and well-ventilated environment to prevent disturbances to the epoxy process and to guarantee the safety of all personnel involved. Given the utilization of various epoxy types, including Gorilla 5-minute, g-flex, and e-zlam, for sealing camera enclosures and securing components such as u-bolts and electromagnets, employees are mandated to adhere strictly to instructions provided on the epoxy containers and to utilize all recommended protective gear.

Soldering operations take place in an exposed and adequately ventilated area within the workspace, facilitating fumes emitted during the melting of solder and flux. Each trainee receives supervision from at least one experienced colleague, ensuring the correct temperature settings for materials, incorporating periodic breaks to mitigate fume exposure, and maintaining safe distances from hot solder to prevent burns.

During water testing procedures, employees undergo a checklist to verify the secure attachment of all electrical wires to the control box before activating the power source for the ROV, thus ensuring operational safety at all stages of the manufacturing process.

TRAINING

Training is a crucial phase within the underwater robotics process. At the beginning of the semester, the SeaCows welcomed five new members, each with limited to no prior experience in the field. Throughout the training period, challenges arose as these individuals dealt with unfamiliarity regarding appropriate tools, CAD software, and various other programs within the process. The veteran members of the team had patience, building a supportive environment that contributed to skill development. As time progressed, the training gradually became more manageable and natural for all employees.

The training curriculum contained a diverse pool of skills, including collaborative brainstorming, prototype development, rigorous testing procedures, mechanical manipulation of robotic components, utilization of a Raspberry Pi, and proficiency in Arduino programming for wireless communication.

Upon successful completion of the training program, new employees attained full qualification status, granting them ability to undertake a wide spectrum of tasks independently. However, for safety reasons, tasks deemed hazardous such as soldering or CNC routing, continued to be supervised by more experienced employees.

VEHICLE SAFETY FEATURES

MATE ROV Competition safety requirements were considered in all aspects of designing, manufacturing, and building Moo Shoo. Some of the elements on our robot that have the potential to be more dangerous are the underwater enclosure, the pneumatics, and the machined edges on the frame and all manipulators.

The danger caused by the underwater electronics enclosure is minimized by doing frequent vacuum checks and inspecting o-rings/epoxy seals before each dive. The vacuum check is done after any time the enclosure is opened and before the first submersion of the day. This check allows employees to see the rate at which air enters the enclosure when brought to the vacuum pressure of -0.5 Bar, simulating submersion and water entering the enclosure. If the pressure goes down to above -0.45 Bar after 15 minutes, the enclosure is deemed unsafe for use and requires maintenance.

Every employee is required to review and understand the Fluid Power information provided by MATE and work with another experienced SeaCow Robotics employee before working on any pneumatics. When pressurized, no employee is permitted to manipulate any pneumatic components except the pneumatic regulator to change the output pressure or the pressure relief valve to remove pressure from the system. All other pneumatic components are concealed in cases or enclosures to minimize this risk.
All sharp edges on our robot have been sanded down to minimize the risk of injury when manipulating it.

All of the 3D-printed components have rounded edges and the flush cut zip ties have been sanded down. Our robot also includes the required safety components including strain relief on the robot and topside control box, thruster guards fitting the IP20 standard, a fuse within 30 cm of the main power connection, a single connection to the main power supply, clearly separated AC and DC power lines, and more.

OPERATIONAL & SAFETY CHECKLISTS

In all ROV operations, employees are required to follow all safety checklists and recommendations in Appendix 1, the safety checklist inside the control box which can be seen in the Topside Control Systems section, and the recommendations in the JSAs.

ACCOUNTING

BUDGET

In August, SeaCow Robotics had a meeting to determine the amount of funds left over from the previous year, and determine how much budget each category (Frame, Manipulators, Cameras, etc.) would be given in the 2023-2024 season to support our goals. This budget can be found in Appendix 2. Since no prototyping had been done at this point, the budget is a higher level document, only allocating large chunks of funds to each category that the company wanted to invest in to improve Moo Shoo. While the company wasn't anticipating receiving many donated parts, unlimited free pool time was offered by Swim Atlanta and The Water Tower, allowing SeaCow Robotics to focus their funds on project development.

Team travel expenses took up a large portion of our budget. Two team hotel rooms at $200/night, 5 meals for each employee at an estimated $13/meal, gas money for two cars to travel at an estimated $0.85/L for 800 km, and other miscellaneous expenses totaled around $1000. From there, company leaders decided on team priorities for robot development, and allocated funds accordingly. As live, exact project spending was totaled in the Ordering Sheet, the higher level Project Costing document was updated with approximated totals, and the actual vs. approximated spending was updated in the Budget. All of these documents can be found in Appendix 2. As you can see, much more than was budgeted was spent on cameras, but with the surplus of funds from the previous year, the team decided that the development of a robust camera system was paramount for the development of the company in subsequent years, and spent what was needed to make a reusable, modular system.

COST ACCOUNTING

As expenditures were made, they were tracked live in the SeaCow Robotics Ordering Sheet. This document tracked all expenses that the company made and their status (ordered, received). An overestimate of these costs, sorted by category, was then moved into the larger Project Costing document to track whether or not the budget was being met by category. An overestimate was used in order to account for costs that the Ordering Sheet may have missed, such as higher than expected shipping fees. This document also includes the distinction between new, reused, and donated items. While no parts were donated this year, pool time was donated by Swim Atlanta and The Water Tower, which was given an estimated value of $20/hour and accounted for as income in the Budget.

CONCLUSION

ACKNOWLEDGEMENTS

MATE II for providing the opportunity to support women in STEM and demonstrate our passion and skills
Lanier High School for supporting this team
State Farm for providing team funding
Nordson Corporation for providing team funding
Georgia Tech for providing a mentor
Swim Atlanta for allowing pool access
Gwinnett County Public Schools for funding the LHS makerspace
National Science Foundation for supporting MATE
The Water Tower for giving a space to publicly display and demonstrate our mission/robots
The International Science and Engineering Fair for providing a space to display our mission/robots
Blue Trail Engineering for providing discounted products
Jesuit High School Robotics for providing documentation format inspiration

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APPENDIX

Pre-Pool Procedure

Visually inspect underwater electronics enclosure
Unscrew vent plug from end cap
Insert vacuum pump connection into penetrator
Bring underwater enclosure to 15inHg vacuum
Wait 15 minutes
Passed for pool if pressure is >13.5inHg

Power Up Procedure

Follow Pre-Power checklist
Turn power supply switch on
Turn main power switch on
Listen for two noise sequences on ESCs
If both sequences are not heard, power down
Wait for blue light on Pixhawk
Proceed with test

Pre-First Dive Systems Check

Complete power up procedure
Inspect penetrators and o-rings for damage
Press pneumatics switch and verify claw moves
Attempt rotating main camera
Attempt dimming and brightening light
Arm ROV
Test all thruster movements briefly (<10s per)
Disarm ROV
Proceed with dive

Launch Procedure

Submerge ROV and rotate
After rotation hold under and watch for bubbles
If any extra bubbles rise, execute leak procedure
If no extra bubbles rise, CEO calls ready
If ROV is in safe orientation, tether managers call ready
If QGroundControl is running without issues, pilot calls ready
Pilot arms ROV and begins task

Communication Loss Troubleshooting

Follow Raspberry Pi shutdown procedure
Turn off main power switch
Turn off power supply switch
Wait 10 seconds
Complete Power Up Procedure
If communication is restored, continue test
If no communication, move ROV to safe area and begin continuity tests

In-water Leak Detection

Power down
Inspect enclosure for obvious damage/leaks
Observe color of leak detection packet
If packet is blue, there is no leak, continue with test
If packet is pink, there is a leak
Dry off exterior of ROV and move to its container
Remove vent plug and place in safe space
Disassemble demonstration station and move to workspace
Identify cause of leak

2. BUDGET AND PROJECT COSTING

Expense	Category	Additional Details	Cost	New/Reused?
Thrusters	Frame	6 Blue Robotics T200s	$1,200.00	Reused
Main Electronics Enclosure	Frame	Raspberry Pi 3B, Pixhawk, Power Sense Module, ESCs, etc.	$700.00	Reused
Frame Materials	Frame	80/20, T-nuts, bolts, aluminum brackets, etc.	$250.00	New
Camera Electronics & Enclosure	Cameras	USB cameras, secondary underwater enclosure, penetrators, etc.	$600.00	New
New Buoyancy & Ballast	Frame	Nalgene bottles, backer rod	$75.00	New
Exisisting Buoyancy & Ballast	Frame	syntactic foam, wheel weights	$250.00	Reused
Tether Materials	Tether	8AWG silicone wire, fathom X cable, pneumatic tubing, etc.	$240.00	Reused
Manipulator Materials	Manipulators	magnets, 3D printed tools, ring shim, rubber bands, etc.	$120.00	New
Profiling Float Upgrades	Profiling Float	I2C Level Converter, Arduino MKR WAN 1310, connectors, etc.	$120.00	New
Exisiting Profiling Float Materials	Profiling Float	SeaGlide syringe hardware and PCB, Arduino MKR WAN 1310	$100.00	Reused
Team Shirts	Misc.	10 custom hawaiian shirts	$200.00	New
Marketing Display Materials	Misc.	project board, custom printed poster, custom printed stickers	$50.00	New
Travel to Regional Event	Misc.	2 team hotel rooms (one night), gas money, 5 team meals, etc.	$1,000.00	New
Topside Control System Materials	Topside Control System	weatherproof case, cable penetrators, acrylic sheet, etc.	$150.00	Reused
Total Project Cost:	$5,055.00			
Total Project Cost - Reused:	$2,415.00			
Total ROV Cost:	$3,585.00			
Total ROV Cost - Reused:	$1,045.00			

Figure 23: Snippet of Project Costing Document

Category	Additonal Details	Allotted Funds	Actual Spending	Under Budget?
	Expenses			
Frame	80/20 aluminum, nuts/bolts, buoyancy/ballast	$350.00	$325.00	☑
Cameras	USB cameras, camera enclosures, electronics enclosures	$200.00	$600.00	☐
Manipulators	custom 3D printed manipulators, magnets, nuts/bolts	$150.00	$120.00	☑
Profiling Float	Arduino, DF13 connectors, I2C level converter, etc.	$130.00	$120.00	☑
Misc.	travel fees, competition entry fees, t-shirts, marketing materials	$1,400.00	$1,250.00	☑
	Income			
Income	State Farm Grant, GoFundMe	$5,000.00	-	-
Donation	40 hours of Swim Atlanta pool time (estimated $20/hr value)	$800.00	-	-
Donation	10 hours of The Water Tower pool time (estimated $20/hr value)	$200.00	-	-
Total Alotted Funds:	$2,230.00			
Total Spending:	$2,415.00			
Amt. Over Budget:	$185.00			
Remaining Funds:	$2,585.00			

Figure 24:Snippet of Budget Document

Ordered?	Received?	Vendor	Item Name	Additional Specs	Item Quantity	Unit Price	Total Price	Link
☑	☑	Automation Direct	T-slotted rail - 11.581"		2	$2.78	$5.56	https://www.autom
☑	☑	Automation Direct	T-slotted rail - 16.954"		2	$4.07	$8.14	https://www.autom
☑	☑	Automation Direct	T-slotted rail - 13.264"		7	$3.18	$22.28	https://www.autom
☑	☑	Automation Direct	T-slotted rail - 7.523"		2	$1.81	$3.61	https://www.autom
☑	☑	Automation Direct	T-slotted rail - 6.074"		3	$1.46	$4.37	https://www.autom
☑	☑	Automation Direct	T-slotted rail - 8.523"		2	$2.05	$4.09	https://www.autom
☑	☑	Automation Direct	T-slot corner bracker		30	$2.50	$75.00	https://www.autom
☑	☑	Automation Direct	T-slot t-nut (single, pack of 10)		8	$5.50	$44.00	https://www.autom
☑	☑	Automation Direct	T-slot bolts (pack of 10)		8	$4.25	$34.00	https://www.autom
☑	☑	McMaster	m3-45 bolt		1	$3.88	$3.88	https://www.mcma
☑	☑	McMaster	Acrylic Sheet		1	$4.38	$4.38	https://www.mcma
☑	☑	Amazon	USB Camera		4	$13.25	$53.00	https://www.amaz
☑	☑	Amazon	Ring magnet		1	$18.99	$18.99	https://www.amaz
☑	☑	Amazon	USB hub 3.0 4 port with power adapter		1	$20.49	$20.49	https://www.amaz
☑	☑	amazon	usb to ethernet		1	$13.59	$13.59	https://www.amaz
☑	☑	amazon	usba-usba female-female		1	$5.99	$5.99	https://www.amaz
☑	☑	amazon	18awg 2 conductor cable		1	$12.99	$12.99	https://www.amaz
☑	☑	amazon	g-flex epoxy		1	$31.14	$31.14	https://www.amaz
☑	☑	amazon	10ml disposable syringes		1	$7.99	$7.99	https://www.amaz
☑	☑	amazon	electromagnet		1	$15.99	$15.99	https://www.amaz
☑	☑	Amazon	electromagnet		1	$16.49	$16.49	https://www.amaz
☑	☑	Automation Direct	T-slot t-nut (single, pack of 10)		4	$5.50	$22.00	https://www.autom
☑	☑	Automation Direct	T-slot bolts (pack of 10)		4	$4.25	$17.00	https://www.autom
☑	☑	Mcmaster	ring shim		1	$4.37	$4.37	https://www.mcma
☑	☑	Mcmaster	PVC bar		1	$15.23	$15.23	https://www.mcma
☑	☑	Mcmaster	304 Stainless Steel U-Bolt	1/4"-20 Thread Size, 1-1/8" ID, 2	1	$3.94	$3.94	https://www.mcma
☑	☑	Mcmaster	USB splitter enclosure		1	$21.67	$21.67	https://www.mcma
☑	☑	amazon	50ft ethernet		1	$12.58	$12.58	https://www.amaz
☑	☑	Robot Shop	I^2C Level Converter		1	$25.00	$25.00	https://www.robots
☑	☑	Digikey	DF13 crimp sockets		20	$0.10	$2.00	https://www.digike
☑	☑	Digikey	DF13 connector female		5	$0.18	$0.90	https://www.digike
☑	☑	Blue Robotics	M10-4.5mm-LC Penetrator		1	$12.00	$12.00	https://bluerobotics
☑	☑	amazon	backer rod	1/4" - 100ft.	1	$13.34	$13.34	https://www.amaz
☑	☑	amazon	50ft USB		1	$21.90	$21.90	https://www.amaz
☑	☑	amazon	usb camera		2	$14.11	$28.22	https://www.amaz

Figure 25: Snippet of Ordering Sheet