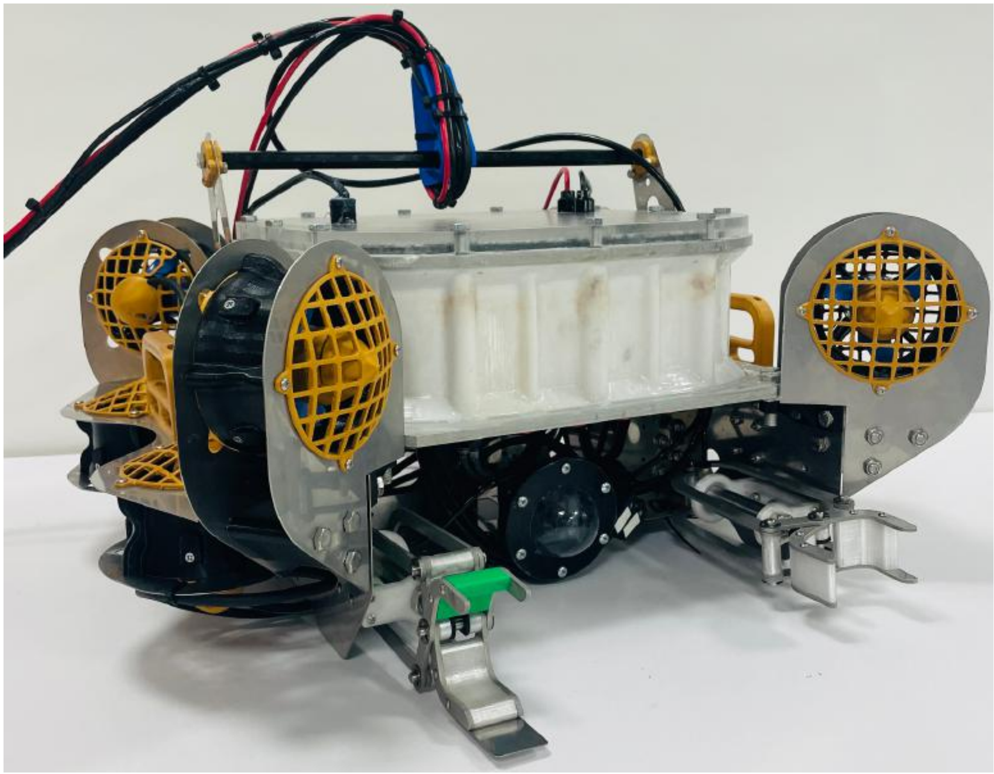
CWRUbotix

2023 Technical Documentation

UN Decade of the Ocean: MATE Inspires ESG

Case Western Reserve University
Cleveland, OH, USA



Tamatoa

Team Members

Project Leads

CEO & Team Lead	*Mechanical Lead*	*Hardware Lead*	*Software Lead*
Noah Mollerstuen	Julianna Carreras	Cole Mousa	Benjamin Poulin

Mechanical Team	**Hardware Team**	**Software Team**
Rucha Batchu	Tobias Cowles	Michael Carlstrom
Dean Chapman	Cole Judson	Ashraf Ibraheem
Eric Chen	Ben Kwiatkowski	Shawn Jung
Olivia Gatchall	Minh Phan	Georgia Martinez
Maxwell Rollins	Henry Odza	Richard Tsai
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Mentors

Jason Bradshaw, Ryan Karpuszka, Benjamin Voth, Robert Steward, Peter Koudelka, Adam Cordingley

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Abstract

CWRUbotix presents our latest ROV: *Tamatoa*. *Tamatoa* features a spacious electronics bay, fully custom-designed electronics (featuring a multiphase buck converter to provide maximum available power), a stainless steel frame, three manipulators and three cameras. These features allow it to perform the complex tasks needed to support marine renewable energy and maintain healthy waterways. Additionally, *Tamatoa* can perform some tasks autonomously using its three cameras and custom software.

In this document, we discuss the design of the robot's structure and manipulators, the design of all onboard electronics, and the software running on the robot. Additionally, this document explains many of the design decisions that led to this ROV design.

The members of CWRUbotix

Safety

Safety Philosophy

The safety of our team members is our highest priority, as well as the safety of the fellow design teams we share a space with in our university's makerspace, Sears think[box],. We believe that accidents are avoidable by following proper regulations from think[box] as well as within our organization. We follow industry-standard safety practices in our organization at all times. We believe that being prepared for accidents is a high priority, with first aid kits and fire extinguishers always within reach.

Safety Standards and Features

As we will demonstrate, *Tamatoa* meets all safety standards required by MATE. This includes both control requirements for the pneumatic and electrical systems (E-Stop, emergency pressure relief valve, fuses, etc.) and physical requirements of the ROV itself (thruster shrouds/propeller guards, cable management, etc.). Both physical and electrical protections are put in place for the safety of our team and to ensure our robot is able to overcome any faults encountered.

Project Management

Company Overview

CWRUbotix is an entirely student-run organization from Case Western Reserve University. The team is split into three sub-teams, each with a sub-team lead. The team lead serves as the head project manager and supports technical development at a system level. The mechanical, software, and hardware leads in turn manage the members, workload, and technical development for their respective sub-system. Our CEO and team lead, Noah Mollerstuen, is responsible for the overall project management of the design, build, and testing of the robot. He also interfaces with our executive board members to complete the proper paperwork and obtain needed materials. Our mechanical lead, Julianna Carreras, is responsible for the design of all physical parts of the robot. Our hardware lead, Cole Mousa, is responsible for the development of all electrical aspects of the robot. Our software lead, Benjamin Poulin, is responsible for the development of all software elements needed to control our robot. The remaining members of the team support their respective leads and perform valuable work to help design the robot.

Project Management Methodology

CWRUbotix employs a stage-gate systems engineering approach to plan, document, and support the development of its robots. By employing this methodology throughout the project lifecycle, we ensure that our system meets all customer and derived requirements, stays on track for critical deadlines, and undergoes detailed external design reviews at several phases throughout the system's development.

Project Phases and Design Reviews

Included below is a description of the stages of the ROV project. Each of these phases culminates in a deliverable which serves to review and finalize the work done in that phase - usually, this is a deliverable such as a design review or operation of the ROV for competition.

Phase	Key Objectives	Method of Review
Phase A - Prototyping Phase	Create subsystems, define system-level architecture	Preliminary Design Review
Phase B - Preliminary Design	Define all requirements and concept of operations, design and construct prototype systems	Preliminary Design Review
Phase C - Detailed Design	Complete design work for all systems at a final level of detail. Have working proof of concepts.	Critical Design Review
Phase D - Assembly and Fabrication	Complete the assembly and fabrication of the system.	Release for Manufacturing Reviews

Phase E - Integration and Testing	Test and evaluate the performance of the system.	Completing testing objectives
Phase F - Operation	Successfully operate the system to meet the requirements of the product demonstration.	Performance during product demonstration

Table 1: Project Phases

Timeline Management

The same phases from the previous section serve as the guide to the chronological progression of the project in our Gantt Chart. In this chart, the phases are divided further into smaller tasks, and these tasks are ordered appropriately and provided an expected number of weeks to complete. The full Gantt Chart is included in the Appendix.

Project Costing and Budget

As one of a few competitive robotics teams under the CWRUbotix student organization, the overarching club maintains detailed spreadsheets on budgeting, funding sources, and purchases. All ROV costs are grouped together, but we also pre-allocate money for having a new member "bootcamp" and for lab supplies used by all teams. We estimate costs based on previous year's spending documentation, and our elected treasurer manages spending and allocations, while purchases are managed by our university's mechanical engineering department.

Budget Item	Total Budgeted	Spent	Balance
Boot Camp	$500.00	$454.10	$45.90
Lab Supplies	$855.72	$572.14	$283.58
MATE ROV	$7,731.56	$5,697.61	$2,033.95
ROV Travel	$11,881.73	$9,888.20	$1,993.53
Total	$20,969.01	$16,612.05	$4,356.95

Table 2: ROV Budget

The majority of the ROV is built from scratch each year, so we must budget for buying parts for the whole robot, as well as spares and prototypes. All purchase requests are stored in an expansive Google Drive. These purchases are also copied into a spreadsheet, which is used to accurately track our spending and balance.

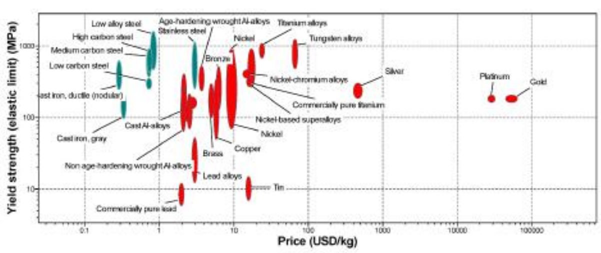
The full project budget, broken into categories and including both the budgeted and spent amounts, is included in the Appendix. The total cost of constructing the project sums to $7,731.56, including the control station, supporting electronics and float.

Mechanical

Frame

Structural Design

Tamatoa's frame is similar to last year's *CWRUstacean*, with modifications made to support a bottom-facing hook. The frame is manufactured from 22 ga (0.762 mm) 304 Stainless Steel sheet metal. When choosing the material for the frame, the initial trade studies considered various metals and polymers as well as a variety of construction methods. From our previous experience we knew that understanding the buoyancy of the ROV was paramount. We aimed for a neutrally buoyant design that, if anything, was slightly negatively buoyant so movement would be easier. We have previous experience using 6061 Aluminum sheet, but we found that the persistent problem of galvanic corrosion was difficult to overcome. Additionally, aluminum bolts cross-thread very easily. Since we aimed to minimize the size of the ROV, we came to the conclusion that we needed a more dense material than 6061 to maintain our target buoyancy (2.7 vs 8 g/cm^3).



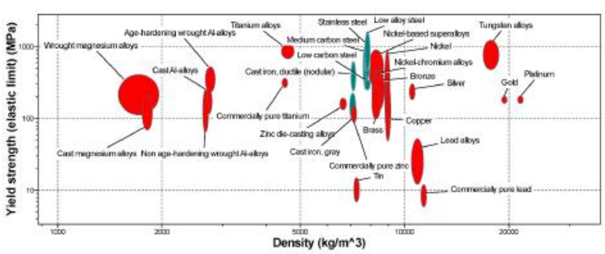


Fig. 1: Metal materials considered for the frame are compared in cost and strength (top) and in strength and density (bottom) using CES EduPack.

After selecting 304 Stainless Steel, the method of manufacturing the different segments of the frame was straight forward using an OMAX 5555 WaterJet Cutter.

Fig. 2: Set-up and aftermath of Waterjetting

By utilizing a sheet metal design for the frame we provided ourselves the flexibility of modular construction. The components of the frame were attached to each other using gussets. To achieve maximum compactness in the design we utilized additive manufacturing to be able to include complex geometries and modularity for our gussets. To enhance their tensile strength, we printed the gussets using Gizmo Dorks PETG filament. To make replacement and redesign of gussets simple and uniform we used standard #6-32 stainless steel fasteners whenever possible. Additionally, we made sure that the design was symmetric in both the *X* and *Y* axes to eliminate any potential moments and thereby simplify buoyancy design.

Thruster Selection & Configuration

Due to our robust power architecture (See Electrical- Power Conversion and Distribution), we have opted for eight total T200 thrusters from Blue Robotics - four vertical and four horizontal. Our four vertical thrusters are located near each corner of the frame, allowing the robot to translate vertically, pitch, and roll. The four horizontally oriented thrusters are located on 45° angles at each of the frame corners, allowing the ROV to translate horizontally in both axes and to yaw. Combined, the ROV can move with 6 degrees of freedom.

Utilizing off-the-shelf thrusters saves us considerable resources which are better spent elsewhere, as custom thruster design and manufacturing would be costly and exceedingly difficult, and the available products fit our requirements perfectly.

Electronics Bay - Mechanical

The Electronics Bay (E-Bay) houses the majority of the electronics (see Electronics Bay - Electrical) on board the robot in a waterproof enclosure. The design of the E-Bay this year was the same as our previous year's model – square-ish and large. This design was created in order to make it easier to layout and fit the electronics. The E-Bay is designed in the shape of a "squircle," a shape between a square and a circle, to approach a near square layout, while still having rounded sides and corners that better withstand water pressure. The final E-Bay design measures 345 mm x 345 mm at the outermost point of the walls, leaving a 280 mm x 280 mm squircle interior for the electronics. The interior has 100 mm of height, large enough to fit some of the larger electronics such as the MMPSU.

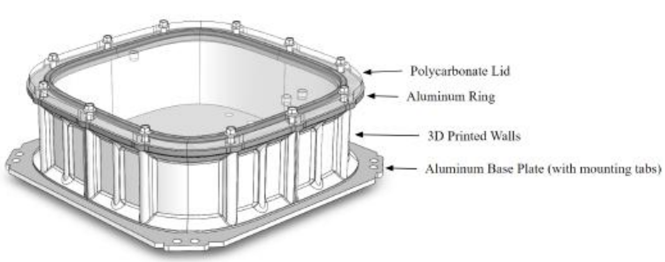


Fig. 3: E-Bay Model Featuring Squircle Shape

The E-Bay design is built on a bottom plate of aluminum. Aluminum was chosen for its high thermal conductivity so that it would act as a heat sink for the thruster speed controllers, which produce considerable heat. An open channel underneath the E-Bay was deliberately designed into the frame to allow for water flow across the surface of the bottom plate to aid in heat dissipation. The aluminum plate includes tabs to attach the E-Bay to the frame, and was manufactured using the water jet cutter.

The walls of the E-Bay are 3D-printed out of polycarbonate on a Stratasys Fortus 400mc industrial Fused Deposition Modeling (FDM) printer. In previous years, our custom E-Bay design had been machined out of a single block of aluminum. This technique was dismissed due to the complex machining process and high costs. Another idea was to machine out a block of plastic, but we had difficulties sourcing raw material with the required 100 mm of height at reasonable costs. For these reasons, we decided to 3D print the walls and construct the E-Bay from multiple parts and materials. To save material, the walls are 4 mm thick with columns added for the bolts. To confirm the strength of the E-bay and determine the minimum thickness of the walls, we performed finite element analysis (FEA) using SolidWorks' Simulation package. FEA allows us to place a defined pressure over all external faces and simulate how those faces would experience water pressure. In accordance with a safety factor of 2.5, simulations were performed with a pressure at 10 m depth, corresponding to approximately 100 kPa. The results of these simulations are shown in Fig. 4.

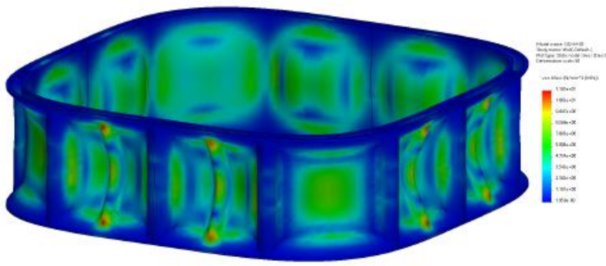


Fig. 4: FEA Stress Analysis

Stratasys Polycarbonate filament has a yield strength of around 60 MPa, so the maximum stresses on the model in the simulation above at around 11.8 MPa are well within the limit.

The top lid of the E-Bay is constructed of a clear polycarbonate sheet, allowing operators to see into the E-Bay and diagnose any problems, such as a leak, quickly without having to remove the lid. The polycarbonate lid was machined on a ShopBot router table.

To waterproof the E-Bay, the bottom aluminum plate is permanently attached to the walls with epoxy. The aluminum plate was aligned to the walls by using aluminum dowels inserted and epoxied into holes machined in the plate and holes printed in the E-Bay walls - these dowels also serve to reinforce the walls. The walls of the E-Bay are also painted with epoxy to fill any gaps between the layers resulting from the 3D printing process. An aluminum ring is epoxied to the top edge of the 3D printed walls to add additional stability and to provide a smooth surface for the o-ring to seal against. This o-ring rests in a groove machined into the polycarbonate top lid. This lid is then fastened against the top surface with screws that thread into heat-set inserts within the walls. The full layout can be seen in the following cross section in Fig. 5.

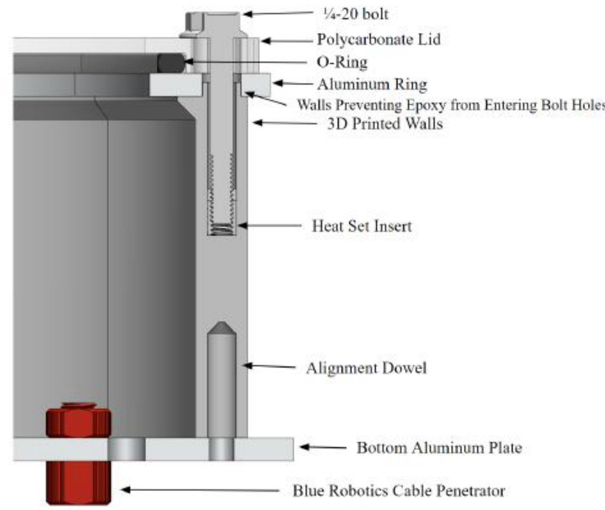


Fig. 5: E-Bay Wall Cross Section

The E-Bay includes 12 Blue Robotics potted cable penetrators through the bottom aluminum plate and three similar penetrators through the polycarbonate lid. These lid penetrators are for the tether, including the two power lines and ethernet. The cable penetrators in the bottom lid lead to the thrusters, cameras, solenoids, lights, and other devices scattered across the robot.

Buoyancy

Along with a large E-Bay (approx. 150 N of buoyant force) came concerns about buoyancy. As we were designing the robot, we made sure to account for the weight in water of each component and ensured that the ROV was approximately neutrally buoyant. Ultimately, with the addition of slightly thicker metal for our manipulators along with fasteners, we found when testing the robot that it was still slightly negatively buoyant. Additionally, due to the lack of counterweight on the back of *Tamatoa* to account for our forward-facing manipulators, the ROV tended to tilt forward when placed into the water. To account for this along with the slight negative buoyancy, we added approximately 800 cm^3 (0.80 kgf) of closed cell foam underneath the E-Bay and moved it such that the foam was more forward to account for the previously mentioned tilt. This made *Tamatoa* neutrally buoyant in the water and fairly balanced.

Payload and Tools

Manipulators

The manipulators we have designed to perform this year's tasks were based on our previously designed Linkage Claw with two main variations: picking up and putting down vertical props (*Vertical Linkage Claw*) and picking up and placing down horizontally oriented props (*Horizontal Linkage Claw*). We also incorporated a bottom facing hook in the center of *Tamatoa* in order to recover the container from the bottom of the reservoir. The hook is positioned directly below the center of mass of the ROV so the weight of the container does not induce any torque while it is lifted. The following table shows our initial outline of tasks and the manipulators.

	Task	Manipulator
Marine Renewable Energy	Position a floating solar panel array	Vertical Linkage Claw
	Moor the panel array to 3 anchor points	Vertical Linkage Claw
	Connect solar panel array to the power grid	Vertical Linkage Claw
	Remove biofouling	Linkage Claw (Any Variation)
Offshore Aquaculture and Blue Carbon	Position the simulated UV light over the diseased area	Horizontal Linkage Claw
	Place a tent over the diseased area of coral, insert syringe and inject fluid into the tent	Linkage Claw (Any Variation)
	Install a Eco-Mooring system	Vertical Linkage Claw
	Transport the fry to safe release area	Horizontal Linkage Claw
	Recover a container from the bottom of the reservoir	Hook
Floats	Build and deploy custom float	Horizontal Linkage Claw

Table 3: Task Outline

Linkage Claw

The Linkage Claw is a design first featured on *CWRUstacean (2022)* which has had slight modifications to improve its performance in competition. The Linkage Claw is able to manipulate up to 2” PVC with the additional advantage of being able to pick up non-PVC props. The focus of the Linkage Claw design is to allow for less precise aiming by the ROV’s human pilot, as it features a wide area in which an object can be placed and still be successfully captured. The linkage mechanism itself is inspired by toy claw grabber arms, and modified to fit our pneumatic actuators and PVC pipe.

The linkage mechanism of the Linkage Claw was Waterjet cut out of 3.175mm (⅛") 304 Stainless Steel for rigidity. The spacers as well as the mounting bracket were 3D printed with MatterHackers RYNO engineered PETG filament. The two variations of the Linkage Claw on *Tamatoa* sport the same basic linkage mechanism described above; however, their mounting bracket has simply been rotated 90 degrees. Additionally, to aid with grabbing onto non-PVC objects, there is a plate attached to the bottom arm of the Horizontal Linkage Claw to provide more surface contact. Additionally, this 'scoop' aids with picking up objects resting on the pool floor.

Fig. 6. Vertical (back) and Horizontal (front) Linkage Claw

These two variations are mounted at the front of *Tamatoa*, with the vertical variation on the left-hand side of the drive camera view and the horizontal variation on the right-hand side of the drive camera view.

Hook

Tamatoa has one bottom-facing hook in order to pick up the heavy container on the bottom of the reservoir. This hook consists of two hook plates of Waterjet 3.175mm (⅛") 304 Stainless Steel with multiple spacers placed between to strengthen the structure. Our construction ensures that the hook is more than able to pick up the maximum weight of the container of up to 120 N (~12.23 kg).

Camera Enclosures

This year's ROV has two monocular (single lens) cameras: one fish-eyed forward-facing camera and one bottom-facing camera. These cameras are placed so that the front linkage claws are in view of the main driving camera and the bottom facing camera has a view of the bottom hook. All single cameras are enclosed in 3D printed GizmoDorks PETG housings with clear vacuum-formed PETG fronts. These front panels are convex to avoid blocking the view of the fish-eyed camera.

On the back of *Tamatoa*, there is a RealSense camera which is utilized for computer vision tasks. It is housed in a 5.72 cm (2.25") OD, 12.7 cm (5") long clear tube, which allows for the stereo camera to use its full field of view. This tube has two 3D printed PETG end caps that each have two o-rings on them to prevent water from getting inside the camera enclosure. The camera itself is mounted to a machined 6061 Aluminum cylindrical rod which sticks out of the side of the enclosure to act as a heat sink.

Additionally, this allows for the adjustment of the vertical angle of the camera, with it usually sitting at 45 degrees downward. All camera enclosures utilize Blue Robotics Wetlinks cable penetrators.

Vertical Profiling Float - Mechanical

The main body of our vertical profiling float is made out of 60 cm long, 10 cm OD high-pressure hard polycarbonate tubing. The main buoyancy engine consists of a 300 cm^3 polypropylene syringe attached to two plunger rods with a T8 brass nut. The nut is driven by an 8mm lead screw attached to a motor. In order to account for the great amount of buoyant force from the air contained around the main syringe, most of the less complex parts of our vertical profiling float were made with 6061 aluminum including the four ⅜'' (9.53 mm) support rods, support plates, and plunger rods. The support rods also allow us to add on any needed ballast in the form of extra rings around the float. The endcaps were 3D printed with MatterHackers RYNO engineered PETG filament with a hole on the back end to allow for an antennae used to communicate with the surface laptop (See Vertical Profiling Float - Electrical and Vertical Profiling Float - Software).

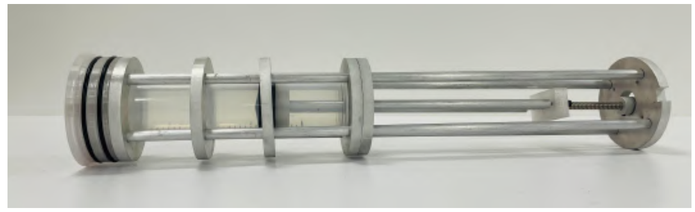


Fig. 7: Float Internal Assembly

Our process flow diagram is also shown below in Fig. 8. In summary, the profiling float's profiles are based on fixed, experimentally-derived timing to minimize the sensing electronics needed on board, which would otherwise add considerable complexity. The float has a total volume of 5097±150 cm^3, and so its dry mass is 5.097±0.150 kg in order to achieve neutral buoyancy in water. The buoyancy engine thus provides 0.150 kgf, or about 1.47 N, in either direction to either ascend or descend in its vertical profiles.

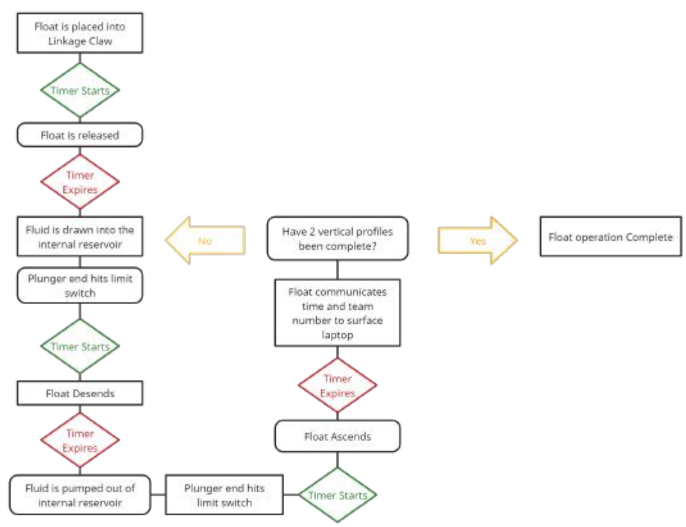


Fig. 8: Profiling Float Process Flow Diagram

Fry Cage

Our fry cage is made out of 6mm acrylic plastic that was laser cut and engraved on the Epilog

Fusion Pro 48 and further bonded together with Scigrip 3 acrylic solvent cement. To make things as simple as possible, this fry cage is manually activated and separate from *Tamatoa.* This allows the ROV to perform other tasks while waiting for the fry to acclimate. The main mechanism for opening and closing the fry cage is a magnet which keeps the door on the bottom face of the fry cage closed unless pulled by a vertical piece of PVC connected to the door. In order to deploy this cage without activating the door, there is a separate horizontal piece of PVC which is used as an attachment point when deploying.

Fig. 9. Northern Redbelly Dace Fry Cage

Electrical

Subsystem Overview

The system's overall electronic design emphasizes cost efficiency, space efficiency, and modularity. These emphases were chosen because they enable us to stay within our budget, while also allowing for ease of troubleshooting and enabling future expansion and improvement. Our system is powered from the standard MATE supply and is controlled via a surface laptop which sends control information across a Cat6A ethernet cable integrated into our tether to our control electronics. These connections are first made at our control station, and are then sent down the tether to the robot. The power connection is fused with a 30 A in-line fuse before entering the control station. Power is sent across two marine-grade 10 AWG wires with a 30 A fuse in-line, which is integrated into our tether per safety requirements. All of our electronics, with exception to sensors and cameras, are mounted and housed in a watertight electronics bay, which is centered on the frame of the robot. Sensors and cameras have their own custom air-filled housings. Block diagrams providing a visual overview of the electrical subsystem are provided in the Appendix.

Control Station

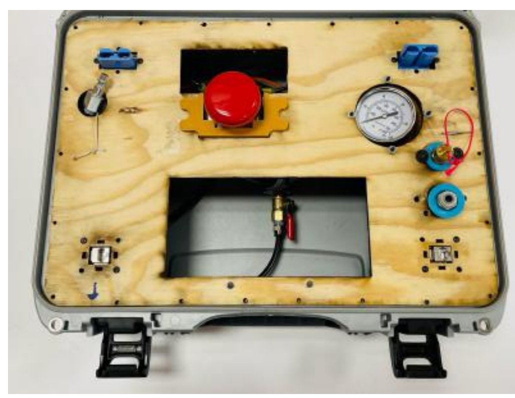


Fig. 10: Top-Down View of Control Station

From an electrical perspective, the control station is very simple. It is supplied by a 48 V line from the surface power supply, fused at 30 A. This power line has an emergency stop button on the +48 V cable, which then goes to an output connector that connects to the tether.

Beyond this, there is an Ethernet passthrough with the input on the left of the control station and the output on the right. This allows for the tether and surface computer to easily connect and disconnect their Ethernet cables. There is also a screen in the top lid of the control station with a single USB-C cable that can connect to our surface computer to act as an extra screen.

Electronics Bay - Electrical

All of the electronics of our robot, aside from the cameras and other sensors, were designed in such a way that they would fit into our watertight electronics bay. The E-Bay, as described in earlier sections of this document, provides a safe environment for our electronics to be placed in and to dissipate heat to the surrounding environment. Waterproof penetrators were used for all connections that needed to enter or exit the E-Bay. The main connections entering are the 48 V tether power and Cat6A ethernet tether cable. The connections exiting are those that go to each of the thrusters, the USB cables to connect to the cameras, the cables connecting to the solenoids, and the cable connecting to the LED used to irradiate the diseased coral. Inside the E-Bay itself, there are a few main components: our DC-DC power supply, our motherboard with its attached daughterboards, the Pixhawk flight controller, and the ESCs for the thrusters. These components are described in detail below. Additionally, a system block diagram detailing the relationship between all these components is available in the Appendix. The layout of the electronics in the E-Bay can be seen in Fig. 11.

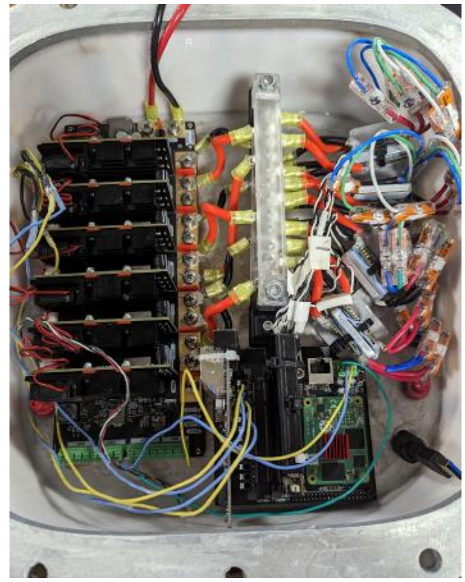


Fig. 11: Electronics Bay with Electronics

Power Conversion and Distribution

The 48 V power from the tether is received by the Modular Multiphase Power Supply Unit (MMPSU), a 6 phase 2.4 kW DC-DC buck converter designed by Repowered Electronics- an electronics company founded by CWRUbotix alumni. MMPSU provides the main 12 V rail which is used by all of the ESCs/thrusters, as well as 5 V and 12 V auxiliary rails for our control circuitry. The 12 V main rail is connected to individual ESCs using bus bars, and the 5 V and 12V auxiliary rails directly connect to the motherboard using standard connectors. All wiring used for power delivery is sized according to the maximum current that will pass through each power rail. For the main 12 V rail, 10 AWG wire was used, as a current of up to 30 A is expected. For the connection from the auxiliary rails, only a maximum of 5 A is expected, so 20 AWG wire is used. MMPSU was chosen over an in-house solution as it provided adequate power delivery for our solution while being compact and efficient. It would take a significant amount of effort to design and build an in-house solution capable of providing the necessary ~1.5 kW of power needed to run the robot. For this reason MMPSU was purchased and integrated into our design. An image of MMPSU can be seen below in Fig. 12.

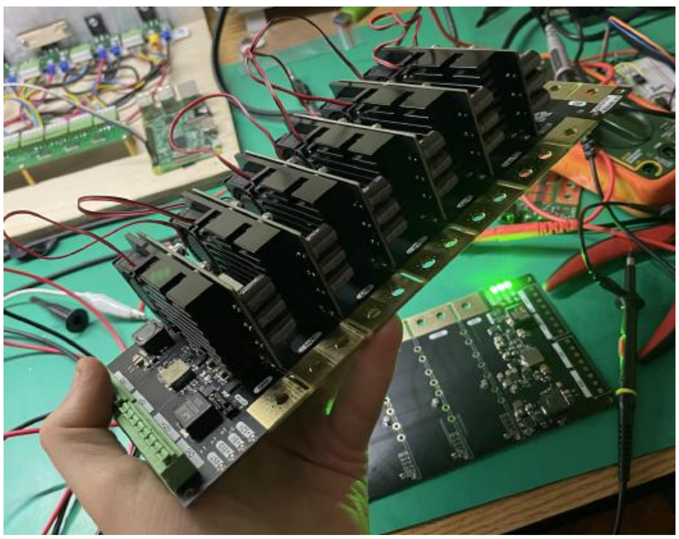


Fig. 12: The Completed MMPSU

Control Electronics

Motherboard

The core component of our electronics system is our custom-designed motherboard. This board serves to connect the surface computer to the main data-handler and general computer for our robot: a Raspberry Pi Compute Module 4. We chose this device as our main computer because of its high-speed operation, robust ecosystem, and integrated IO. We use the included PCIe x1 lane with a USB controller card to provide four high-speed USB 3.0 connections, which were used for our cameras. We use the onboard USB 2.0 to connect to our flight computer, and the onboard Gigabit Ethernet to talk to the surface computer. The motherboard does a small amount of power conversion, 5V to 3.3V, in order to power all the necessary components. It also has back-up serial connectors, and expansion slots that are used to connect to our daughterboards. We chose to design this board in-house, as we would be able to include all the features we needed for our design while keeping the cost and size of the board down, as well as minimizing the cable runs needed in our E-Bay. The layout of the motherboard can be seen below in Fig. 13.

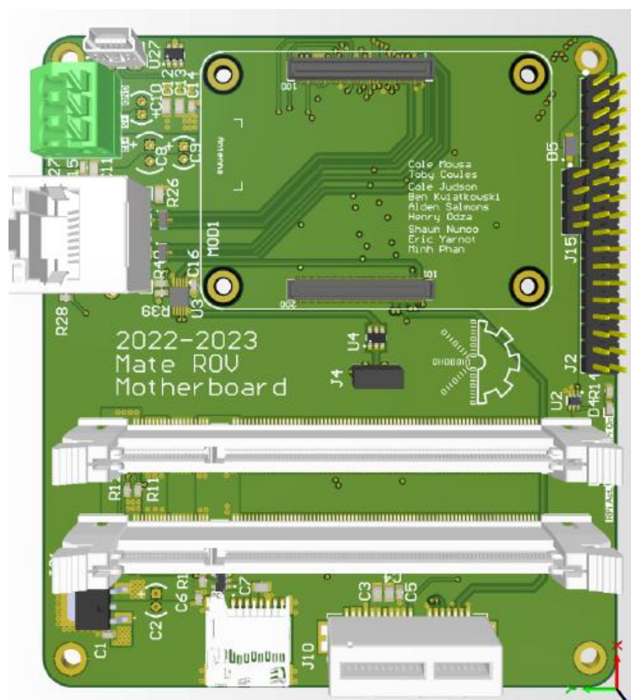


Fig. 13: Motherboard Design

Relay Daughterboard

In addition to the motherboard, we also designed a custom relay daughterboard. This board contains six solid-state relays which are used to turn on and off external devices - such as lights and solenoids. This daughterboard connects directly to the motherboard through the use of a SODIMM slot. The relay board can be seen below in Fig. 14.

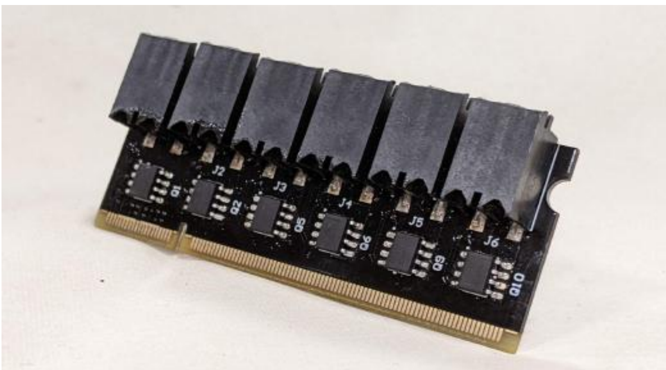


Fig. 14: Relay Daughterboard

Pixhawk Flight Controller

Tamatoa's main flight computer is an off-the-shelf Pixhawk 1. The flight computer gives instructions to the ESCs, which control the thrusters. The Pixhawk 1 is a standard flight computer that provides all the needed features to efficiently run our robot. While we investigated the viability of a custom Pixhawk solution, we ultimately decided to integrate an off-the-shelf model as a daughterboard by using a male USB 2.0 Micro B on our motherboard. This solution provides many of the benefits of a custom solution without incurring the costs of producing a custom board.

Vertical Profiling Float - Electrical

The electronics of the float were designed to be as simple as possible. An Arduino Nano controls a small brushed DC motor which powers the buoyancy engine. Two limit switches are placed on either side of the syringe in order to provide feedback when the syringe reaches either end of its movement range. Additionally, we utilized an I^{2}C RTC module and an SPI 900Mhz transceiver module from Adafruit in order to fulfill the transmission requirements. The clock and transceiver were both chosen for their ease of implementation and the transceivers' use of the 900Mhz band allows for legal unlicensed broadcasting. The transceiver communicates with a corresponding Arduino on the surface as the float completes vertical profiles. A simple H-bridge board is used to switch the direction of the brushed motor and to provide speed control. The entire electronics stack is powered by 8 AA batteries in series.

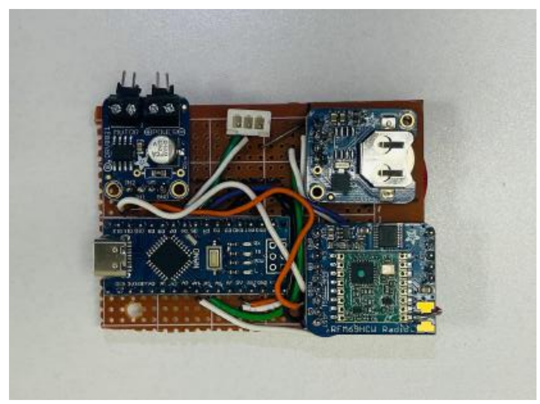


Fig. 15: Float Electronics

Tether Design

Competition Requirements

Tamatoa's tether was designed to conform to the requirements set forth by the MATE competition. The tether has strain relief both on the robot itself and on the control station. This ensures that any forces on the tether will not damage the tether connectors. The tether is approximately 10 m long, allowing the ROV to reach all tasks in the pool. The tether consists of two power cables, an Ethernet cable, and a pneumatic line. The power cables connect the robot to 48V DC, as required. On the surface side of the tether, Anderson Powerpole connectors are used to connect to the control station.

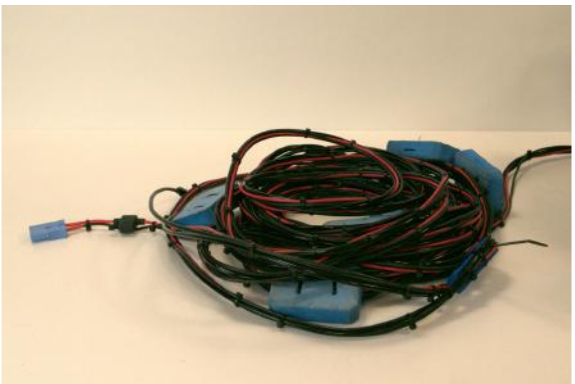


Fig. 16: Coiled up tether

Tether Management Protocol

Our tether will be managed mainly through the use of flotation foam placed at various points along the tether. This will keep the tether out of the way of the robot as it performs tasks. If the tether does get in the way, it will be the job of the tether manager to manipulate the tether from the surface to keep it out of the way of the ROV.

Software

Software Architecture

Tamatoa's software architecture leverages Robot Operating System 2 (ROS 2), a system for facilitating communication between multiple processes called "nodes." This year our design philosophy followed model-view-controller principles, aiming to separate all of our logic from the graphical user interface (GUI) and move it into our ROS network. Our network is split between nodes running on the surface computer and nodes running on the ROV. It comprises task selection nodes, which handle switching between autonomous and manual control modes, hardware interaction nodes, which interface with actuators and sensors, and GUI communication nodes, which allow our GUI to update and query these other nodes.

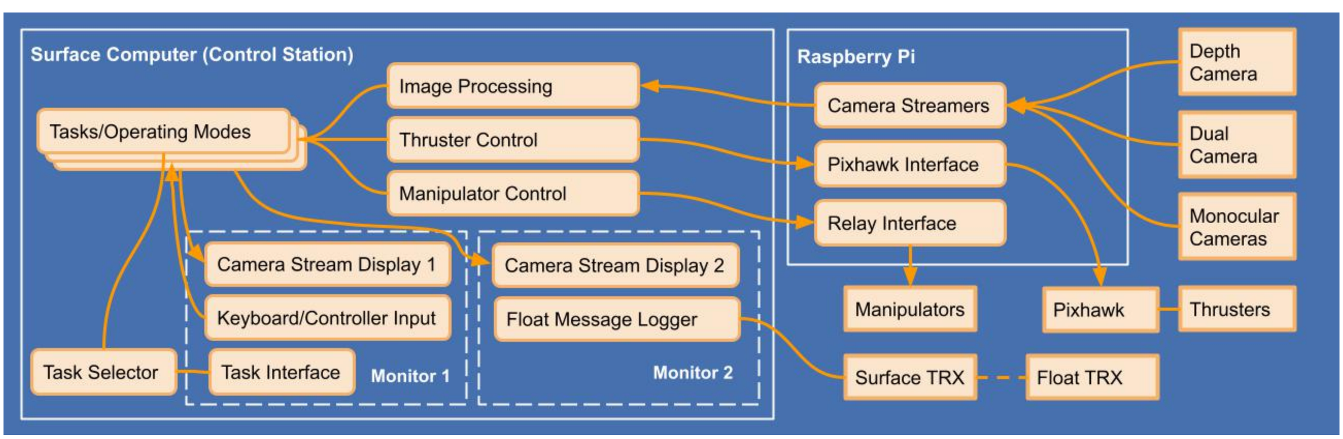


Fig. 17: Software Block Diagram

Surface Computer

GUI

The GUI is written with PyQt5 and comprises a pilot GUI used by the driver and a copilot GUI with ancillary information.

Pilot

The pilot GUI contains three camera streams: the front camera, the bottom camera, and a depth camera. These streams are received over the ROS network and decoded with the ROS OpenCV Bridge. This GUI also contains a button to arm and disarm the ROV. The pilot's computer runs remote controller nodes in the background, which listen for inputs from the keyboard or a PlayStation controller and relay those inputs to the appropriate hardware interface nodes on the ROV.

Copilot

The copilot GUI is divided into multiple tabs. The primary tab primarily serves to facilitate switching between robot operating modes, like autonomous docking and manual driving. This tab includes a series of buttons for different operating modes, which request operating mode changes from the Task Selector node. The primary tab also logs debugging information and displays the time remaining in the product demonstration. The secondary tab contains two grids of buttons representing the seagrass bed before and after 3 months. Clicking these buttons toggles their colors between green and white and displays a count of how many squares changed. The tab also has a video feed of the bottom camera which can be paused when the "after" grid is in view.

Autonomous Docking

One node on the surface computer is dedicated to managing autonomous docking of the ROV. This node applies OpenCV filtering to individual frames streamed by the camera interfacing nodes and locates the center of the largest clump of red pixels. It then issues commands to thruster controlling nodes to steer the ROV toward that clump of red pixels, thereby driving into the docking station.

Coral Modelling

To model the coral head, the ROV is equipped with an Intel RealSense D415 depth camera. In addition to the color of each pixel, the camera can infer its distance from the camera (depth) by combining data from three separate image sensors. This data is streamed to the surface computer, which uses the RTAB-Map ROS library to estimate the movements of the ROV and create a cohesive map of the ROV's environment. The operator can view this map in 3d and use it to measure the coral head.

Fig. 18: Intel RealSense D415 Depth Camera

ROV

The Pi Compute Module 4 on the ROV runs an Ubuntu server. A single main ROS node for the Pi runs when the ROV boots using Systemd and custom udev rules. As seen in *Fig. 17*, the Pi communicates with three device types. The first device is the Pixhawk, which controls thruster motion in six degrees of freedom. We use Pymavlink to communicate from a ROS node on the Pi to the Pixhawk. The second device is an I^2C relay interface which controls our manipulators. We use WiringPi to command relays from a ROS node. The final device type is the ROV cameras, which are streamed over the ROS network via Video4Linux2 and the ROS OpenCV Bridge.

Vertical Profiling Float - Software

The float interacts with the rest of the software subsystem via serial commands to an Arduino radio transceiver. An Arduino Nano tethered to the surface computer via a USB cable receives commands from a ROS node over serial, then broadcasts these commands to the Arduino on the float over radio using the RadioHead RF69 library. The Arduino on the float listens for a command to submerge, then begins performing automatic vertical profiles. At the top of each profile, the float Arduino broadcasts our team number and the time according to its RTC module. The control station Arduino receives this information and communicates it to the surface computer via serial.

System Integration Diagrams

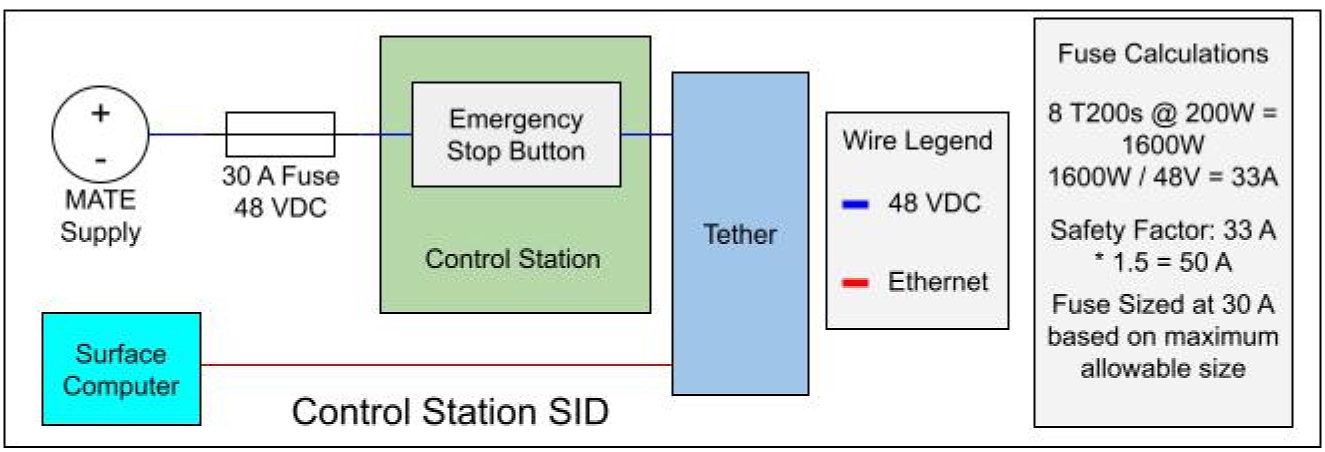


Fig. 19: Control Station Electrical SID

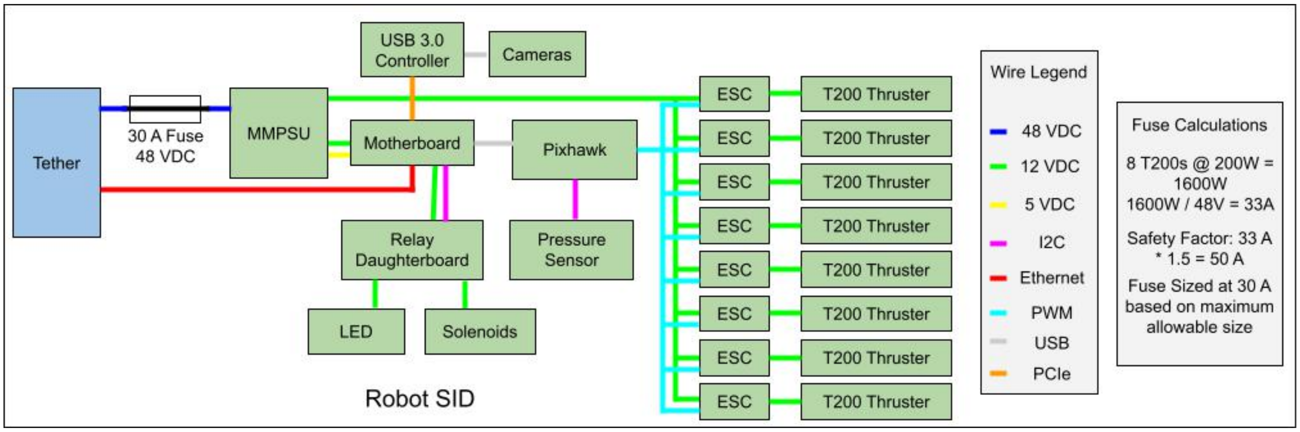


Fig. 20: ROV Electrical SID

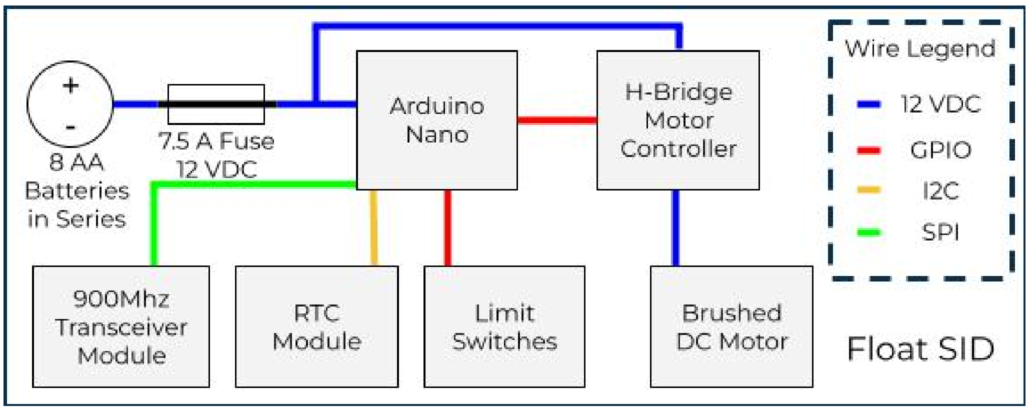


Fig. 21: Float SID

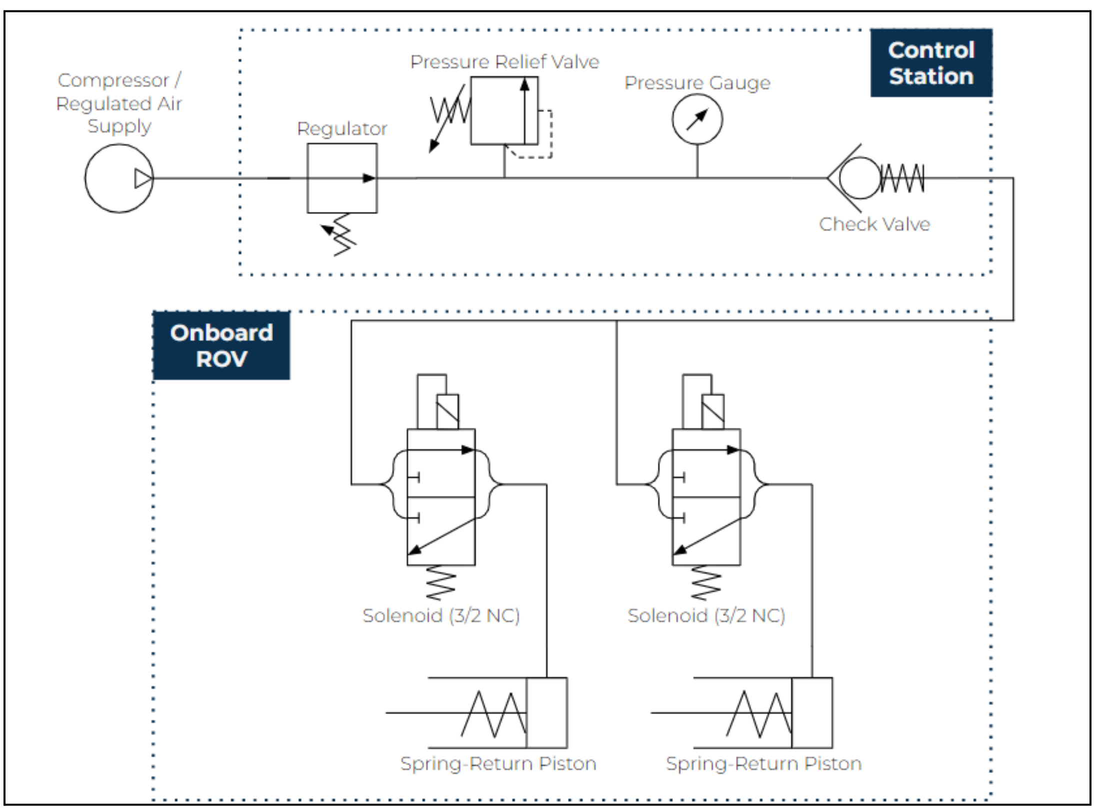


Fig. 22: ROV Pneumatic System SID

Appendix

Safety Checklists

Pre-Dive

- Verify power is off
- Inspect E-Bay to check it is properly sealed
- Verify that tether has strain relief on ROV
- Check that there are no objects/wires near thruster guards and actuators
- Verify electrical and pneumatic connections are secure
- Turn on power in control station
- Wait for surface computer to connect to ROV
- Verify all camera streams displayed on surface computer
- Check that area around ROV is clear
- Operator calls “Arming” and arms the ROV
- Perform a thruster test by sending movement controls
- Verify all thrusters are functioning
- Actuate each of the manipulators
- Disarm the ROV

Launch

- Verify ROV is disarmed
- Inspect E-Bay to check it is properly sealed
- Two crew members grab ROV from either side and put ROV into water
- Check no bubbles are escaping from the E-Bay
- If there are bubbles, follow Leak Detected procedure
- If there are no bubbles, crew calls “Ready to arm”
- Operator calls “Arming” and arms the ROV

Recovery

- Operator pilots the ROV to the surface
- Operator disarms ROV and calls “Disarmed”
- Crew grabs ROV and sets it on the poolside
- Operator turns power off from the control station
- Visually check for water in E-Bay

Leak Detected

- Operator or crew calls “Leak”
- Hit the emergency stop button on the control station
- Use tether to hoist ROV to poolside
- Crew grabs ROV and sets it on the poolside
- Visually check for water in E-Bay
- If water exists in E-Bay, remove lid from E-Bay and dry all components
- Check for corrosion on all electronics
- Ensure all entry points are watertight
- After drying, test full system to ensure complete functionality

Mission Layout and Planning

	On Dive (ROV takes with)		At Depth (ROV performs in pool)		For Recovery (ROV returns with)	
	Subsystem	**Prop**	**Subsystem**	**Task**	**Subsystem**	**Prop**
1	Vertical Claw	Solar Panel	Horizontal Claw	Deploy Float	Hook	Heavy Container
	Horizontal Claw	Float	Vertical Claw	Position Solar Panel		
			Bottom Camera	Monitor Seagrass Recovery		
			Bottom Camera	Count Frogs in Transect		
2	Horizontal Claw	Fry Cage	Front Camera	Inspect Fry Release Sites		
			Horizontal Claw	Deploy Fry Cage		
			Front Camera	Inspect Buoy Rope		
			Vertical Claw	Release Fry		
			Depth Camera	Model Coral Head		
3	Horizontal Claw	Coral Tent	Horizontal Claw	Deploy Coral Tent		
			Coral LED	Irradiate Diseased Coral		
			Cameras	Autonomous Docking		

Table 4: Mission Planning

		Preliminary Cost Estimate			Approach / Requirements			
Product Demonstration	Points	Development	Competition	Points per cost	Software	Hardware	Mechanical	Manipulator / Sensor
TASK 1: Marine Renewable Energy	70							
Install a floating solar panel array								
Position a solar panel array amongst floating wind turbines	*10*	2	3	2.0		Camera that can look up	Resistance to entanglement, surface manipulator	Front vertical gripper, cam tilted up
- Moor the panel array to three anchor points	*15*	4	5	1.7			Caribiner manipulator	Front vertical gripper
- Remove the power port cover	*5*	2	2	1.3				Bottom gripper or front vertical gripper
- Install the power line connector into the power port	*10*	2	2	2.5				Front horizontal gripper?
Remove biofouling from the foundation and mooring lines of floating wind turbines								
1-2 turbines cleared	*5*	1	2	1.7			Surface manipulator, make sure manip closes all the way for pipe cleaners	Passive surface manip?
3-5	*10*	1	3	2.5				
6	*15*	2	4	2.5				
Pilot into "resident ROV" docking station (press button in both cases)								
Autonomously	*15*	3	2	3.0	Red button docker			Forward facing cam
Manually	*10*	1	2	3.3				Forward facing cam
TASK 2: Healthy Environments from the Mountains to the Sea	170							
2A: Coral Reefs and Blue Carbon	90							
Create a 3D model of a diseased coral head								
Autonomously	*30*	5	3	3.8	3D capture, SLAM, dual cam measurements → 3D	Dual cam facing forward or down		Stereo or depth cam tilted 45° down
Manually	*20*	3	3	3.3	Dual cam measurements?		Ruler for manual measurements?	Stereo or depth cam tilted 45° down
Identify reef organisms using eDNA								
Collect a water sample from above the coral head	*10*	4	4			Camera on the manipulator	Sharp sucking manipulator, pump to surface/to liquid storage	Syringe manip with sharp end
- Use the eDNA data to identify coral reef fish species	*5*	1	1	1.5				None
Administer Rx to diseased corals								
With simulated UV light	*10*	2	2	2.5		Need to be able to see what we're landing on	1" diameter occluding light source casing, green LED on bottom of robit	Cover with led powered from ROV
Place a tent over the diseased area of coral	*10*	2	2	2.5				?
- Insert a syringe filled with "probiotic" into a port	*5*	2	2	1.3				Front vertical gripper
- Inject a "probiotic" fluid into the tent	*5*	4	3	0.7			Syringe pressing manipulator	Syringe manip?
Monitor and protect seagrass habitat								
Compare images to determine the recovery of a seagrass bed from an anchor scar	*5*	1	1	2.5	Take image & move to 2nd monitor			Bottom cam
Install an Eco-Mooring system	*10*	1	2	3.3				Front vertical gripper
2B: Inland Lakes and Waterways	80							
Reintroduce endangered native Northern Redbelly Dace fry								
Search two potential sites for invasive predatory fish species to determine which one is safe for release	*10*	2	2	2.5		Back camera?		Front cam

Table 5: Sample of Task Analysis

Budget

CWRUbotix 2023 Budget (USD)					
Budget Category	**Item Category**	**Type**	**Amount**	**Total Purchased**	**Budget Allocated**
Electrical	Power Electronics	Purchased	$40.83	$1,953.87	$2,000
	Control Electronics (Boards, Parts)	Purchased	$405.78		
	Small Electronics (OEM Components)	Purchased	$704.86		
	Thrusters (T200 Cores)	Purchased	$802.40		
Mechanical: Components	Pneumatic System Components	Purchased	$0.00	$2,138.32	$2,500
	Fasteners and Mechanical Hardware	Purchased	$1,136.99		
	Waterproofing (O-Rings, Penetrators)	Purchased	$126.54		
	Float Components	Purchased	$72.39		
Mechanical: Raw Material	Stainless Steel Stock	Purchased	$298.54	$621.56	$800
	Aluminum Stock	Purchased	$142.11		
	3D Printer Filament	Purchased	$137.70		
	Watertight Enclosures	Purchased	$43.21		
	Float Stock (Tube, Rods)	Purchased	$0.00		
Manufacturing	Waterjet Time	Purchased	$100.00	$184.86	$200.00
	Epoxy	Purchased	$84.86		
Software (Controls, Sensors, Supporting Resources)	Control Station (Electronics)	Purchased	$403.62	$418.57	$500.00
	Cameras, Sensors	Purchased	$0.00		
	Testing Hardware and Supplies	Purchased	$14.95		
	Controllers and Control Laptop	Purchased	$0.00		
Miscellaneous	Prop Mockups (PVC Pipe, etc)	Purchased	$279.74	$820.69	$1,000.00
	Pelican Case for ROV Transport	Purchased	$540.95		
Total Construction Expenses				**$6,137.87**	**$7,000**
Lodging and Travel (Internationals)	Flights	Purchased	$5,950.14	$11,179.78	$12,000
	Housing	Purchased	$2,229.64		
	Team Meals	Purchased	$2,000.00		
	Rental Cars and Gas	Purchased	$1,000.00		
Total Lodging and Travel Expenses				**$11,179.78**	**$12,000**
Cash Income	Case Alumni Association Grant	Income	$10,000.00	$19,102.28	
	University Student Government Funding	Income	$1,722.52		
	Gene Haas Foundation Grant(s)	Income	$4,879.76		
	think[box] Student Project Fund	Income	$2,500.00		
Total Cash Income for 2023				**$19,102.28**	
				Expenses	$17,317.65
				Cash Income	$19,102.28
				Rollover	$1,784.63

Table 6: Project Operating Budget

Gantt Chart

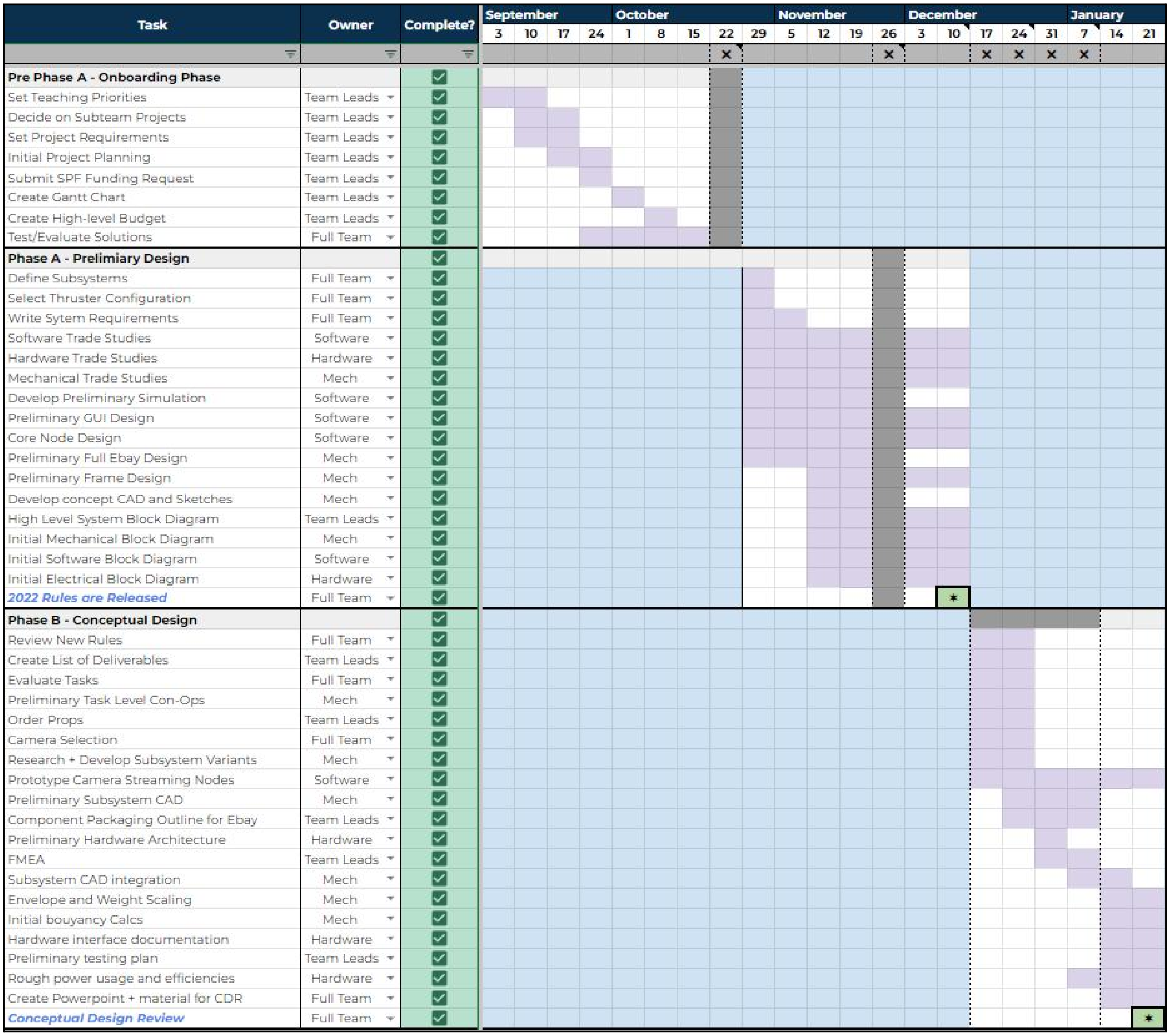


Fig. 23: Project Gantt Chart, Phases Pre-A through B (cont. next page)

Included in the partial Gantt chart in Fig. 23 are the first three phases, including the pre-season Research and Development phase where we prototype potentially useful solutions, and the first two design phases where we work to design the competition ROV. The remaining phases are included on the following page: the final phase of ROV design, as well as the phases for manufacturing, testing, and operating the ROV.

Tasks are broken down into general responsibilities and are marked when they are completed. Note that each phase ends in either a design review or a deliverable, indicated by a green star. Weeks begin on Saturdays, when we have our weekly full team meetings. Areas shaded in gray designate breaks from the university classes.

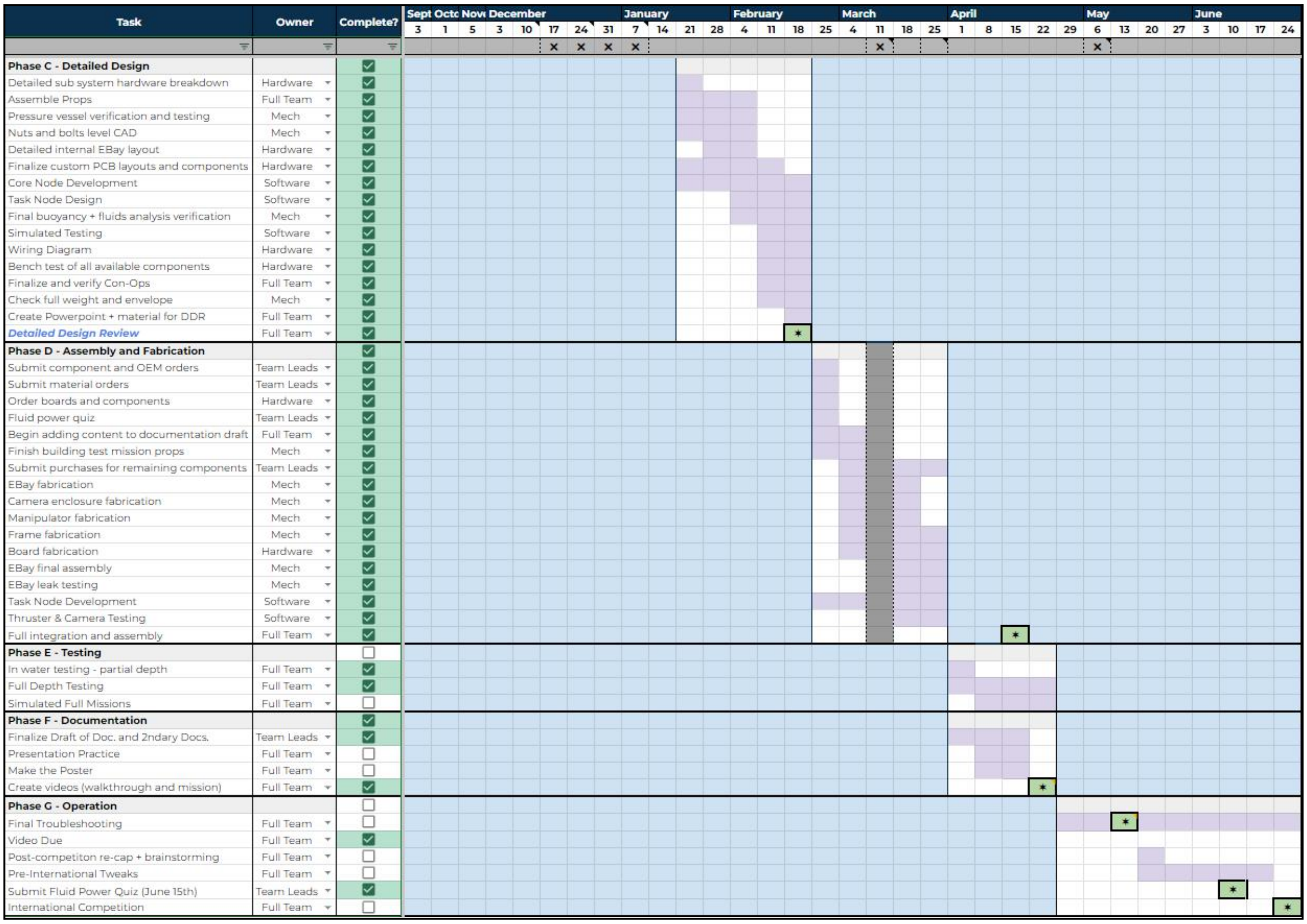


Fig. 24: Project Gantt Chart, Phases C through F (cont. from previous page)

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