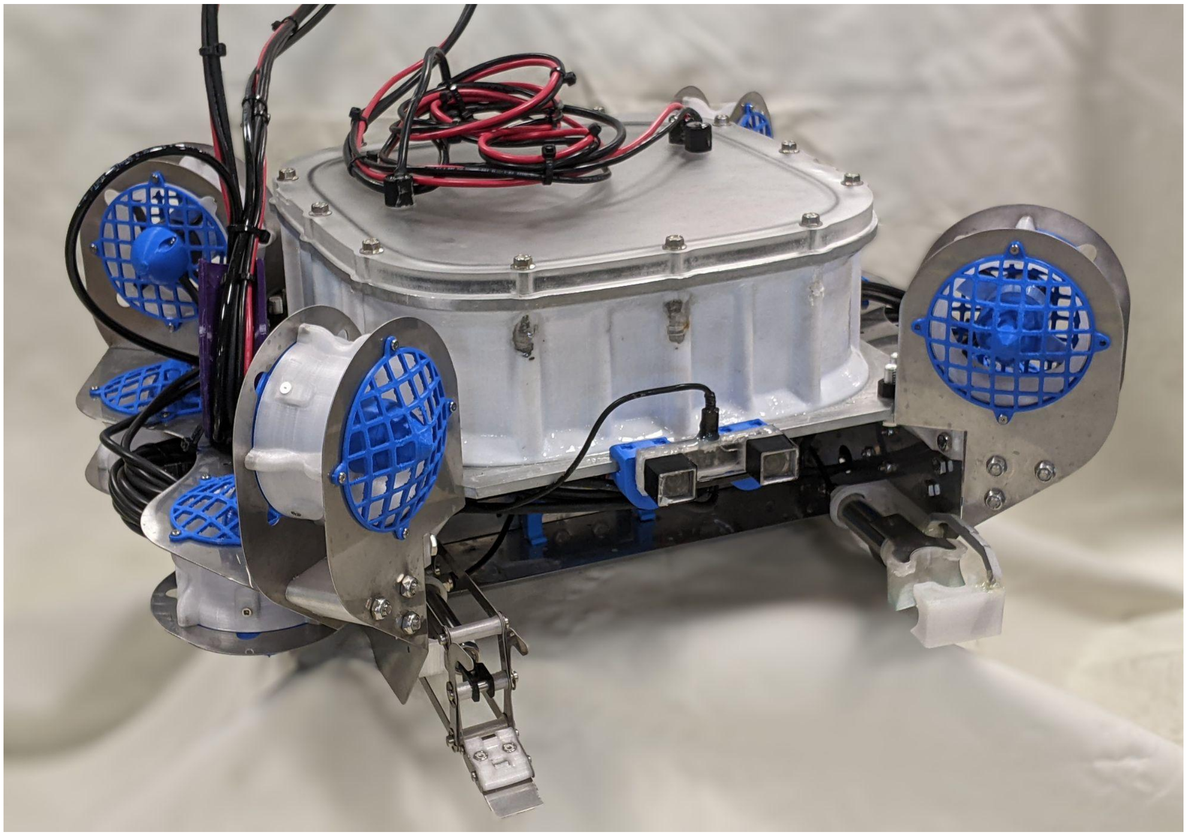
CWRUbotix

2022 Technical Documentation

UN Decade of the Ocean: MATE Inspires ESG

Case Western Reserve University
Cleveland, OH, USA



CWRUstacean

Team Members

Project Leads:

Benjamin Voth	Cole Mousa	Gershon Gilman	Ryan Karpuszka
(Team Lead/Mentor/CEO)	(Hardware Lead)	(Mechanical Lead)	(Software Lead)

Hardware Team:	**Mechanical Team:**	**Software Team:**
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Introduction

Abstract

This year we designed and built the *CWRUstacean*. Some of the interesting features of the ROV include: a spacious electronics bay, fully custom-designed electronics featuring a multiphase buck converter to provide maximum available power, and a stainless steel frame with four manipulators and four cameras. These features make it capable of performing complex tasks needed to maintain renewable energy generators and aquaculture in the oceans. It is also able to perform some tasks autonomously using its four cameras.

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. This document explains several of the design decisions that went into this robot.

Safety

Safety Philosophy

The safety of our team members and the fellow design teams we share a space with in our university's makerspace, Sears think[box], is our highest priority. 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

The ROV meets all safety requirements as set forth by the MATE competition. 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 company 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 team lead and CEO/Mentor, Benjamin Voth, 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 hardware lead, Cole Mousa, is responsible for the development of all electrical aspects of the robot. Our mechanical lead, Gershon Gilman, is responsible for the design of all physical parts of the robot. Our software lead, Ryan Karpuszka, 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.

Table 1: Project Phases

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

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 doing outreach in nearby schools. 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.

Table 2: ROV Budget

Budget Item	Total Budgeted	Spent	Balance
Boot Camp	$302.25	$358.00	-$55.75
Outreach	$400.00	$24.05	$375.95
MATE ROV	$10,300.00	$7,161.87	$3,138.13
ROV Travel	$9,500.00	$9,331.68	$168.32
Total	$20,502.25	$16,875.60	$3,626.65

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 ROV sums to \$6411.45, with the control station and supporting electronics costing an additional \$474.52.

Mechanical

Frame

Structural Design

The frame is manufactured from 22 ga (0.762 mm) 304 Stainless Steel sheet metal. In choosing material and manufacturing methods, 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 relatively neutral buoyant design that was only slightly negatively buoyant such that movement came with ease. We had previous experience using 6061 Aluminum sheet, however because of the number of manipulators and number of heavy tasks this year, we aimed to minimize the size of the ROV - resulting in the need of a more dense material than 6061 to maintain our target buoyancy (2.7 vs 8 g/cm^3).

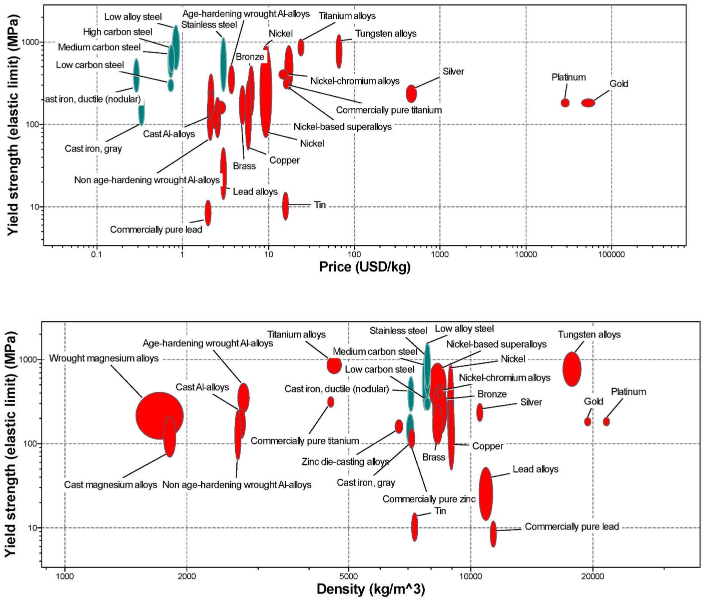


Fig. 1: Metal materials considered for the frame are compared in cost and strength (top) and in strength and density (bottom) using CES EduPack.

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

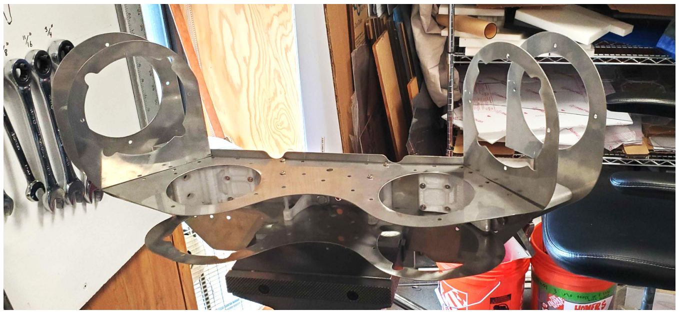


Fig. 2: Side assembly, one half, of the frame

By utilizing a sheet metal design for the frame we provided ourselves the flexibility of modular construction as each component of the frame was 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. Using MatterHackers RYNO engineered PETG filament, we achieved superior tensile strength in our gussets. To make replacement and redesign of gussets simple and uniform we used standard #6-32 stainless steel fasteners whenever possible and made sure that the design is symmetric in both the *X* and *Y* axes, as to eliminate any potential moments and thereby simplify buoyancy design.

Thruster Selection & Configuration

For this year's ROV, we elected to utilize a mix of T100 and T200 thrusters from Blue Robotics. Specifically, there are four vertically oriented T200 thrusters located near each corner of the frame which allow the robot to translate vertically, pitch, and roll. There are also four T100 thrusters which are oriented horizontally on 45° angles at each of the frame corners, with adjacent thrusters perpendicular to each other. These thrusters allow the ROV to translate horizontally in both axes and to yaw. Combined, the ROV can move with 6 degrees of freedom.

The decision to use a mix of thruster models stems from a desire to minimize costs where possible, and a need to limit the power draw - the T100 thrusters are both cheaper and less powerful than their T200 counterparts. By mixing them, we meet a happy medium. 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 goal for the design of the E-Bay this year was to make it bigger than our previous year models and to make it square, 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.

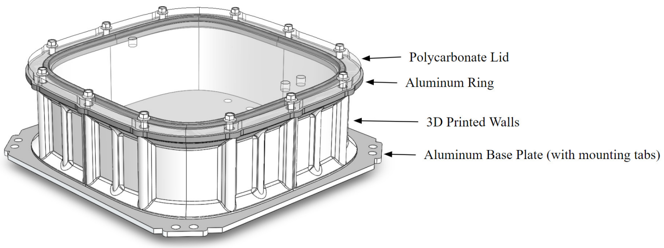


Fig. 3: E-Bay Model Featuring Squircle Shape

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.

The walls were 3D printed out of polycarbonate on a Stratasys Fortus 400mc industrial Fused Deposition Modeling (FDM) printer. In the previous two years, our custom E-Bay design had been machined out of a single block of aluminum. This technique was quickly dismissed this year 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 decide how thin the walls could be, we performed finite element analysis (FEA) using SolidWorks' Simulation package. FEA allows us to place a defined pressure over all external faces, simulating 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 Figure 4.

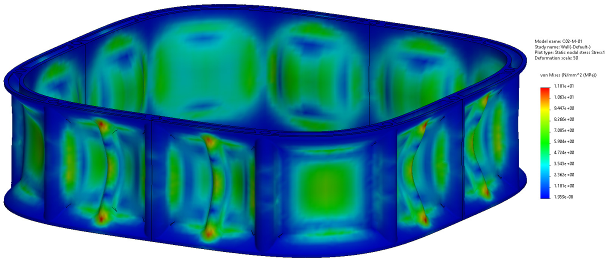


Fig. 4: FEA Stress Analysis

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 so that we could 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.

Fig. 5: E-Bay Prototype (left); E-Bay Prototype next to final E-Bay (right)

We prototyped the E-bay at a mini scale (seen in yellow in Figure 5) to test our manufacturing approach and assembly method. From our prototypes, we had issues with epoxy getting into the bolt holes, so we modified the walls to include channels for the epoxy to sit in and raised edges surrounding the bolt holes seen in Figure 6.

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 Figure 6.

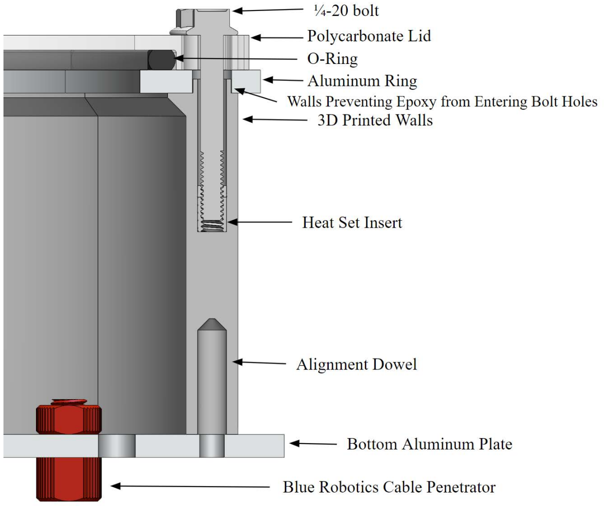


Fig. 6: E-Bay Wall Cross Section

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 came concerns about buoyancy. For ease of control, our target was to make the robot as close to neutrally buoyant as possible. Initially, our plans were to make the E-Bay much larger, but we found that the buoyant force created by the E-Bay alone would require the ROV mass to approach the 35 kg limit to maintain neutral buoyancy. We instead scaled down the E-Bay to the current size as described in the previous section, which accounts for around 150 N of buoyant force. 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 neutral. However, we found when testing the robot that it was still slightly negatively buoyant - ultimately, fasteners were not included in our mass calculations and ended up weighing a considerable amount. We weighed the robot in water and added approximately 750 cm^3 (0.75 kgf) of closed cell foam to attain neutral buoyancy.

Payload and Tools

Manipulators

The manipulators we have designed to perform this year's tasks were mainly split into two separate categories: dropping off or depositing props (*PVC Deployer*) and picking up and maneuvering props (*Linkage Claw*). We also incorporated an electromagnet for the pin pulling tasks. The following table shows our initial outline of tasks and the manipulators.

Table 3: Task Outline

	Task	Manipulator
Marine Renewable Energy	Cutting damage cable	Magnet
	Remove section of damaged cable	Linkage Claw
	Install new section of cable	PVC Deployer
	Secure new section of the cable	
	Remove/recover failed buoyancy engine	Linkage Claw
	Attach new buoyancy engine	PVC Deployer
	Deploy hydrophone	PVC Deployer
	Recover hydrophone	Linkage Claw
	Recover ghost net	Magnet
Offshore Aquaculture and Blue Carbon	Patch damaged net	PVC Deployer
	Remove encrusting marine growth	
	Remove algal marine growth	
	Collect mort	Linkage Claw
	Prune seagrass	Linkage Claw
	Plant seagrass	PVC Deployer
Floats	Recover CO-BGC float	Linkage Claw
	Build and deploy custom float	PVC Deployer

PVC Deployer

The PVC Deployer design is the latest evolution of the SmartClaw design that saw use on our first ROV, *Wobbegong*. The design of this year's PVC Deployer is a refinement of last year's manipulator design, which did not see competition. While previous designs would grab and retrieve props while underwater, the new design is focused solely on *deploying* props, which would be handed to the ROV surface side by a crew member. The PVC Deployer has two separate pieces that need to be placed on either side of the object in order to grab onto it, making it relatively easy to drop items off with accuracy.

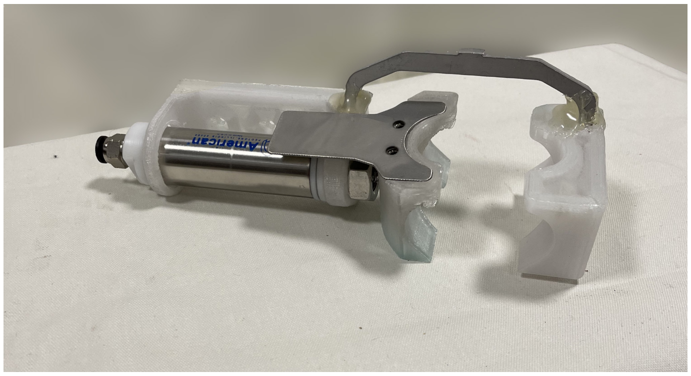


Fig. 7: PVC Deployer

There are two identical PVC Deployers on *CWRUstacean*, one on the front and one on the back, both 'left-handed' from the view of the camera.

Linkage Claw

Contrary to the PVC Deployer, the main use of the Linkage Claw is to *pick up* props that are within the pool itself and bring them back to the surface or another area within the pool. Unlike the PVC Deployer, the Linkage Claw also has the ability to grab onto 2” PVC and other non-PVC objects.

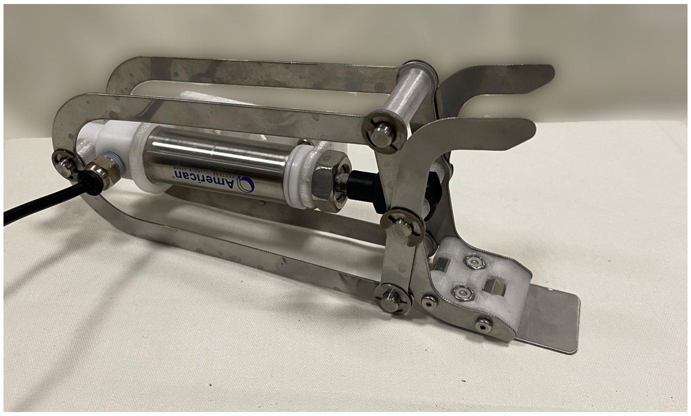


Fig. 8: Linkage Claw

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. To aid with grabbing onto non-PVC objects, such as the mort, there is a plate attached to the bottom arm of the Linkage Claw to provide more surface contact. Additionally, this ‘scoop’ aids with picking up objects resting on the pool floor such as the mort and the sea grass bed. As with the PVC Deployer, there are two identical Linkage Claws on *CWRUstacean*, one on the front and one on the back, always ‘right-handed’ from the view of the camera and on opposing sides of the PVC Deployers.

Magnet

Through our initial analysis of the required tasks, we came to the conclusion that the ROV would require a separate manipulator to aid in tasks that involved tent stakes. Initially, we had brainstormed and prototyped a ‘spinning-whisk’ type mechanism which would catch on the hook of the tent stake and pull it out.

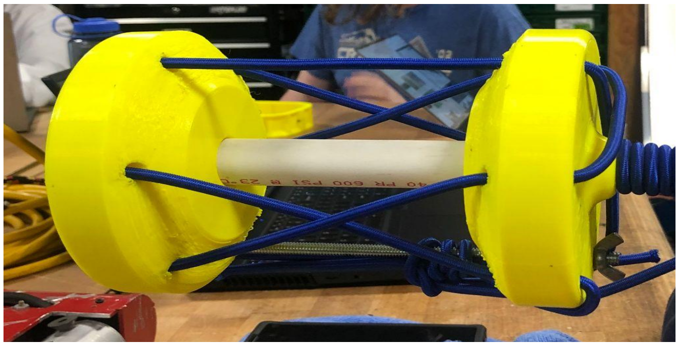


Fig. 9: Prototype Tent Stake Whisk Puller

Ultimately, this design was difficult to position on the ROV frame, and posed a challenge to actuate. We then realized that the tent stakes are a ferrous, magnetic metal. We immediately decided on implementing an electromagnet instead, and were able to spec a sufficiently sized electromagnet which was easily positioned centrally on the rear of the frame and controlled by our 12 V relay board.

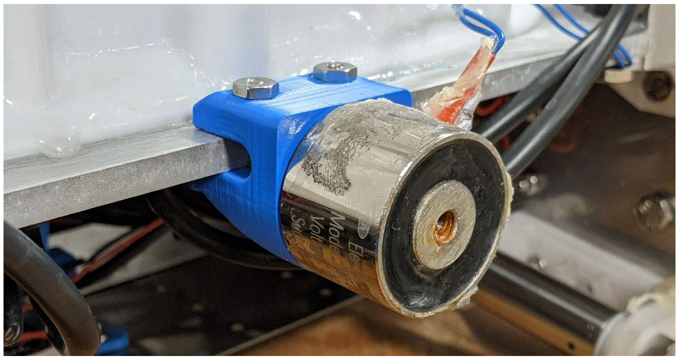


Fig. 10: Tent Stake Electromagnet

Cameras

The robot has two wide-angle cameras placed on the front and the back. These cameras are placed so that the front and back manipulators are in the field of view and as such are the main cameras for human-controlled flying of the ROV. There is also a stereo camera placed centrally on the front which is utilized for computer vision tasks. Finally, there is a bottom-facing camera for mapping the wreck. All of the single cameras (excluding the dual cam) feature a custom designed ring light integral to the enclosures, which also serve to aid in potting and hence waterproofing the cameras.

Vertical Profiling Float

The main body of our vertical profiling float is made out of 60 cm long, 10 cm OD high-pressure hard polycarbonate tubing with four ¼" (6.35 mm) 6061 aluminum support rods running through it. Our design includes end caps and support plates throughout the tube which were 3D printed with MakerGear PLA filament. Our buoyancy engine consists of a 300 mL polypropylene syringe attached to two plunger rods made out of 6061 aluminum with a T8 brass nut that is driven by an 8mm lead screw attached to our motor. A preliminary design of our float is shown below in Figure 11 and our current design of the buoyancy engine is shown in Figure 12.

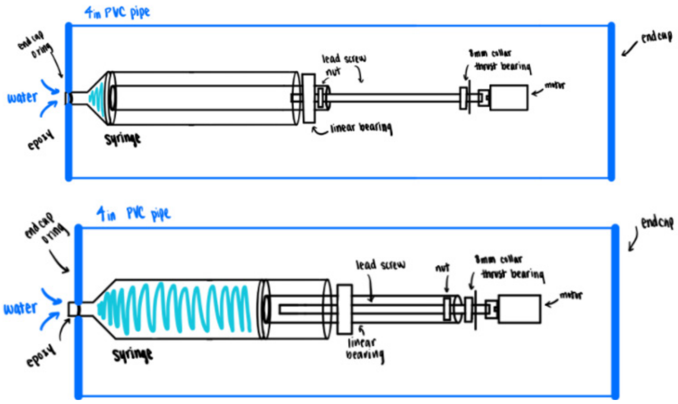


Fig. 11: Preliminary Profiling Float Design

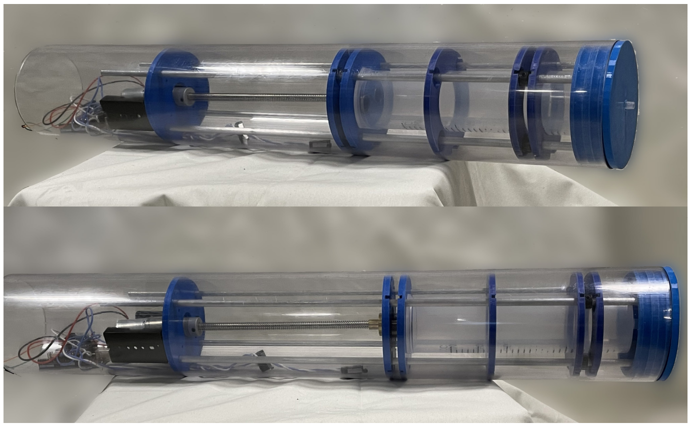


Fig. 12: Current Float Design (plunger rods not shown)

Our process flow diagram is also shown below in Figure 13. 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 5.097±0.150 L, 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.

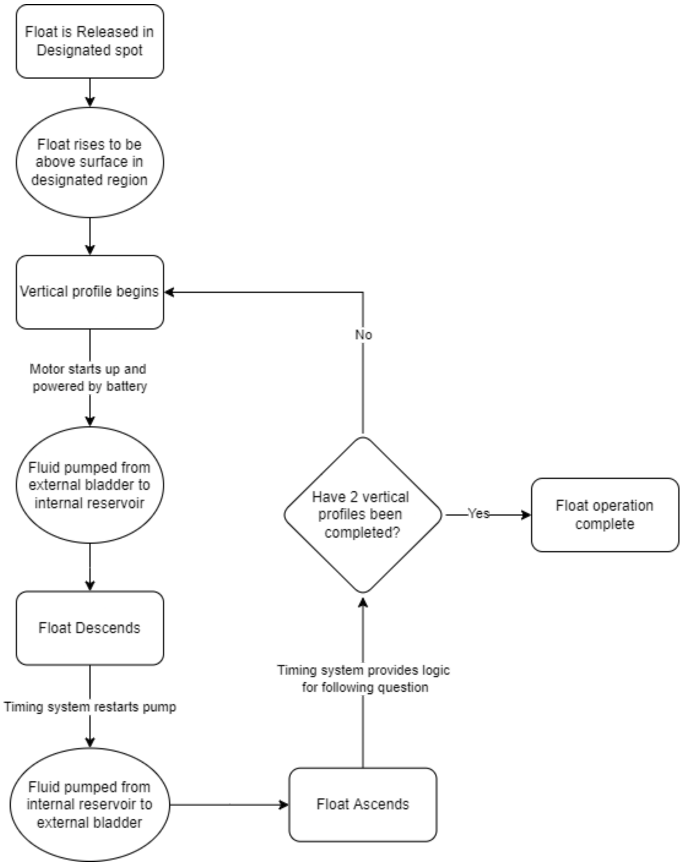


Fig. 13: Profiling Float Process Flow Diagram

Electrical

Subsystem Overview

Our 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 first are made at our control station, where they are then sent down the tether to our 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 our watertight electronics bay, which is centered on the frame of the robot. Sensors and cameras have their own custom housings which are sealed with epoxy.

Control Station

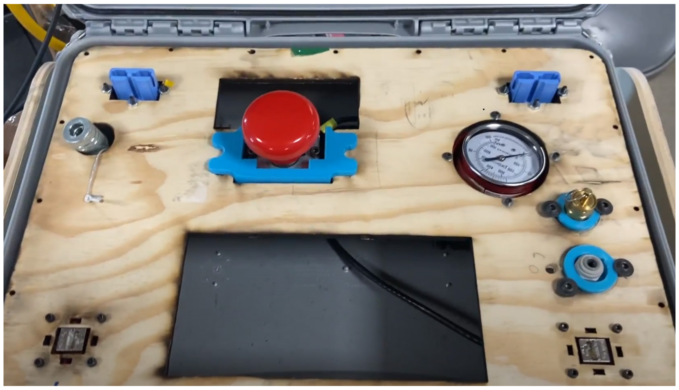


Fig. 14: Top-Down View of Control Station

From an electrical perspective, the control station is very simplistic. The control station takes in 48 V from the surface power supply, which is 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 of the control station. 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. This electronics 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 electronics bay. The main connections entering the electronics bay are the 48 V tether power and Cat6A ethernet tether cable. The connections exiting the electronics bay are those that go to each of the thrusters, the USB cables to connect to the cameras, the cables connecting to the solenoids, the cable connecting to the electromagnet, and the cables going to power the various lights on our robot. Inside the electronics 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 will be described in detail below. An image of the mockup of our electronics bay with the main components placed in it can be seen in Figure 15. This mockup was used to roughly figure out the placement of these electronics.

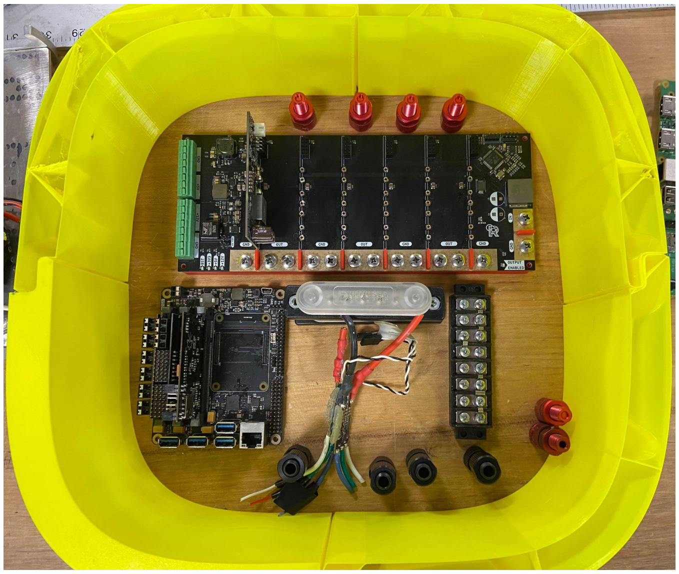


Fig. 15: Electronics Bay Mockup with Electronics

Power Conversion and Distribution

The 48 V power from the tether is received by MMPSU (the Modular Multiphase Power Supply Unit), a 6 phase 2.4 kW DC-DC buck converter designed by Repowered-Robotics. 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 main motherboard using standard connectors. All wiring used for power delivery was sized according to the maximum current that would pass through each power rail. For the main 12 V rail, 10 AWG wire was used, as up to 30 A of current is expected. For the connection from the auxiliary rails, only a maximum of 5 A is expected, so 20 AWG wire was 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 an enormous amount of effort to design and build a power delivery solution capable of providing the necessary ~1.5 kW of power needed to run the robot. For this reason and for the elegance of the solution, MMPSU was purchased and integrated into our design. An image of MMPSU can be seen below in Figure 16.

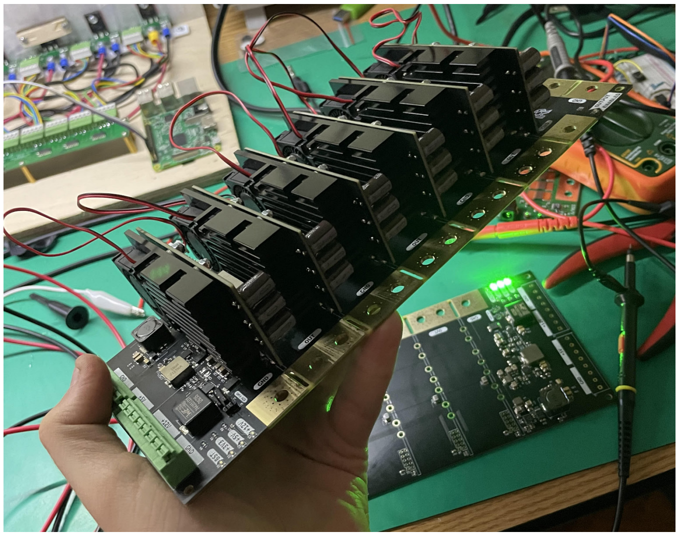


Fig. 16: Image of Completed MMPSU

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 and inclusion of many desirable features, namely the support of a PCIe x1 lane. We used this PCIe lane to provide four high-speed USB 3.0 connections, which were used for our cameras and to connect to our flight computer. The motherboard does a small amount of power conversion, namely 12 V to 3.3 V, in order to power all the necessary components. Other than PCIe, our motherboard has Ethernet, which is used to talk with the surface computer, 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. Our largest constraint was to fit the motherboard into our electronics bay, which necessitated a custom design. The motherboard itself can be seen below in Figure 17.

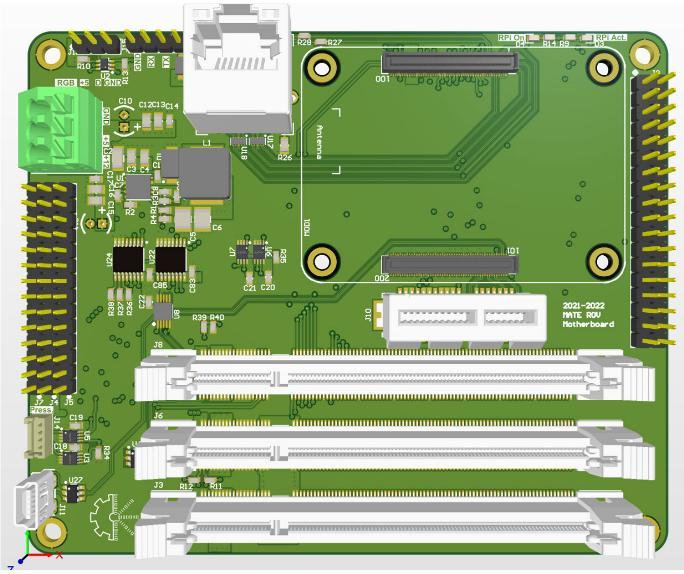


Fig. 17: Motherboard Design

Relay Daughterboard

The daughterboard we created for our design this year is the relay board. This board contains six solid-state relays which are used to turn on and off external devices - such as lights, the electromagnet, and solenoids. This daughterboard connects directly to the motherboard through the use of a SODIMM slot. The relay board itself can be seen below in Figure 18.

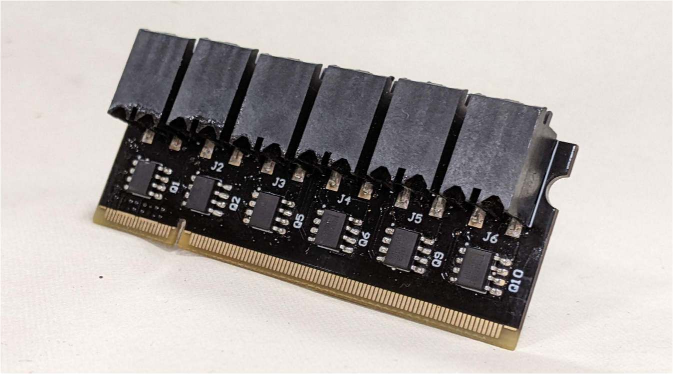


Fig. 18: Relay Daughterboard Design

Pixhawk Flight Controller

Our main flight computer that gives instructions to the ESCs, which control the thrusters, is an off-the-shelf Pixhawk 1. This is a standard flight computer that contains all the needed features to efficiently run our robot. While attempts were made to create a custom Pixhawk, time limitations and chip shortage issues made this venture unfeasible. Our motherboard does contain an expansion slot for a custom Pixhawk board for when this is created in the future.

Float Electronics

For the float, the electronics were relatively simplistic. An Arduino Uno was utilized to control a small brushed DC motor that controlled our buoyancy engine. Two limit switches were placed on either side of the syringe in order to provide data as to when the syringe was at either of its extremes. A magnetic reed switch was used to know when the float was deployed. A simple loop was created where the float would move the motor until a limit switch was hit, wait an amount of time, then move the motor in the opposite direction until the limit switch was hit and wait again. This loop would continue multiple times in order to complete the vertical profiles. A simple H-bridge board was used to switch the direction of the brushed motor and to provide speed control. The entire electronics stack is powered by 4 AA batteries in series.

Tether Design

Competition Requirements

Our tether was designed to conform to the requirements set forth by the competition. To begin with, our 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. Our tether is approximately 10 m long, providing adequate length to complete all tasks in the pool. The tether itself 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, as is required.

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 one of the team members to move the tether from the surface in such a way as to keep it out of the way of the robot.

Software

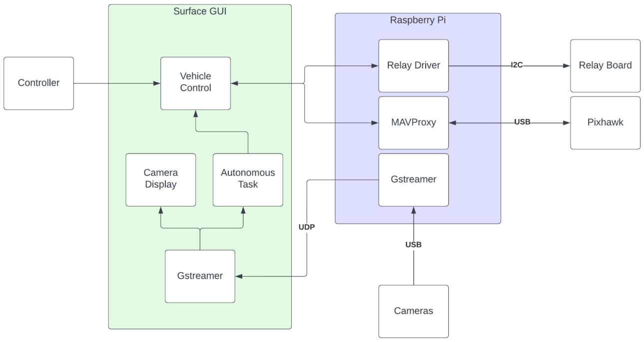


Fig. 19: Software Block Diagram

The two main components of the software are the Surface GUI and the Raspberry Pi. The Surface GUI handles displaying the camera streams to the driver and sending controls to the robot. The Raspberry Pi is responsible for transmitting the camera streams to the surface computer and relaying controls to the Pixhawk and Relay Board.

Controls

To control the robot, the Surface GUI can switch between several different modes of control. The default mode is manual control from a controller connected by USB. The values of joysticks and buttons are read and translated into controls for all 6 degrees of freedom. The mapping from controller inputs to robot commands depends on which camera the pilot is looking at such that the same input will move the robot forward from the pilot's perspective regardless of the orientation of the camera. This reduces the cognitive load on the pilot. The GUI can also switch to several autonomous modes of control. Autonomous control uses the camera streams and computer vision algorithms to decide which controls to send to the robot.

Thrusters are controlled by the Pixhawk running ArduSub firmware. This was chosen because it is free, open source, and natively supports our thruster configuration to provide 6 degrees of freedom. ArduSub was also chosen because it provides software to run in simulations.

Manipulators

On the robot, there are 6 available controls: two front manipulators, two back manipulators, the electromagnet, and lights. Each manipulator is mapped to a button on the controller. To actuate a manipulator, the GUI sends a two byte message to the Relay Driver on the Raspberry Pi. The Relay Driver reads the message and then sends the appropriate data to the registers on the relay board over I2C which will turn on or off the appropriate device.

Cameras

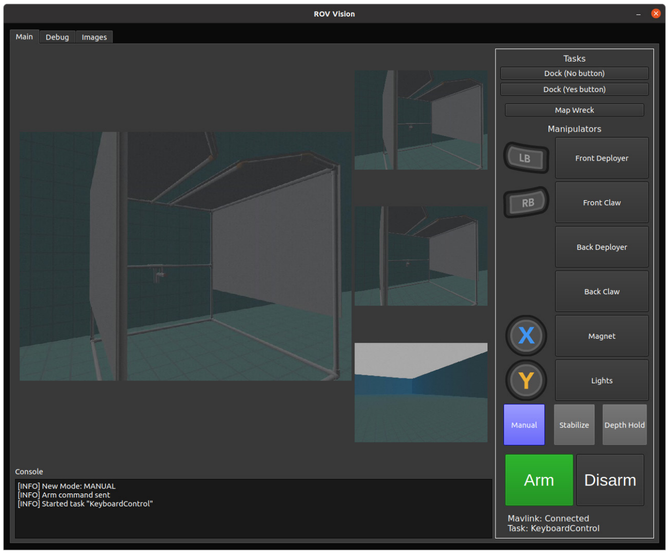
Cameras are connected to the Raspberry Pi over USB. The Raspberry Pi uses a GStreamer pipeline to send each camera feed over UDP to the surface computer. The pipelines use JPEG encoding to minimize the latency of the stream. The Surface GUI runs a GStreamer pipeline for each camera stream. On each frame, the display is updated. Frames are also sent to autonomous tasks when they run.

GUI

Our GUI supports Competition and Debug operating modes. Both modes allow users to arm and disarm a physical or simulated ROV, and to control this ROV with keypresses or external controllers. They also allow users to view streams received by OpenCV from either the Gazebo simulation or live cameras. The Competition mode provides a Tasks list from which operators may initiate automated routines or open utilities. The Debug mode supports streaming from video files as well as pausing, resetting, and image filtering streams.

Gazebo Simulation

The GUI supports running with a Gazebo simulation. This allows testing of autonomous tasks without using the physical robot. Operators start the topside software by running a setup script which initializes a Gazebo simulation using the JSON configuration files specified in command line arguments alongside the main application. This simulation then broadcasts a JPEG UDP stream on a local port, to be received by GStreamer pipelines fed to the main application via further config files. The application can interface with the simulation to command the ROV and reset the simulated world. Simulation worlds are individualized for each task, but all support randomized currents to more realistically represent competition conditions. Random currents are achieved by applying a buoyancy force on the ROV in a random direction.



```
[INFO] New Mode: MANUAL
[INFO] Arm command sent
[INFO] Started task "KeyboardControl"
```

Mavlink: Connected
Task: KeyboardControl

Fig. 20: Screenshot of the Surface GUI running with a Gazebo Simulation

Autonomous Docking

A FORWARD command is sent to the ROV. OpenCV captures a live camera feed, and isolates the red pixels in that feed by thresholding the red channel of each frame. OpenCV generates a rectangle around the largest contour generated by the threshold. If this rectangle's area is larger than a constant percentage of the frame's area, this docking task is terminated with a stop_thrusters command. Otherwise, a THROTTLE, PITCH, or YAW command is sent to the ROV to move the rectangle toward the center of the frame.

Fish Measurement

The stereo camera is used to measure the length of the fish. Several pictures are taken of each fish. The operator marks the fish tip and tail on each image. The software then uses the difference in X coordinates across the stereo images to calculate the 3D location of the fish. The software then calculates the average distance between the two points to obtain the fish length. The software can run a calibration on the camera using images of checkerboard patterns to account for distortion, making the measurements more accurate.

Wreck Mapping

A separate window for this task may be opened from the main GUI with a button press. This window allows operators to draw a brown stick diagram of the wreck atop a four by two grid of red lines.

Transect Stitching

When the robot goes over the transect, it takes pictures of each rectangle in the grid (8 images total). We have software that locates the blue poles and red string in each image using color masks and line detection. Then it creates a final stitched image by lining up the poles and string in the correct order.

System Integration Diagrams

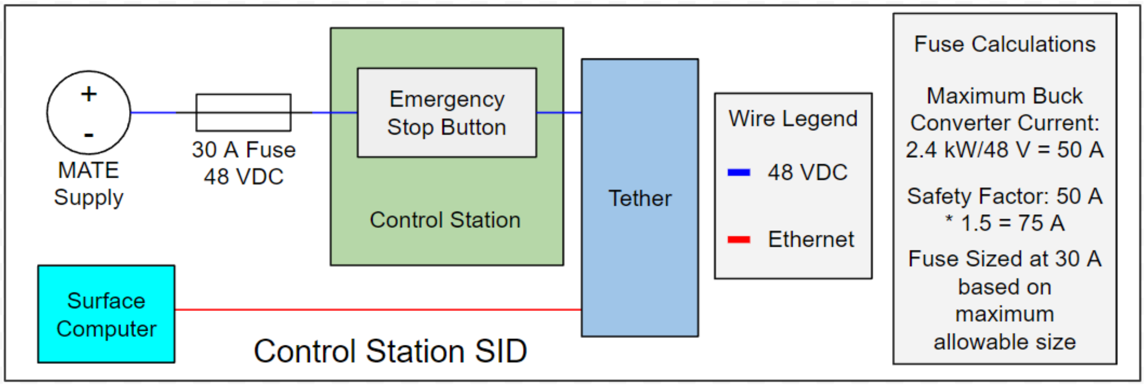


Fig. 21: Control Station Electrical SID

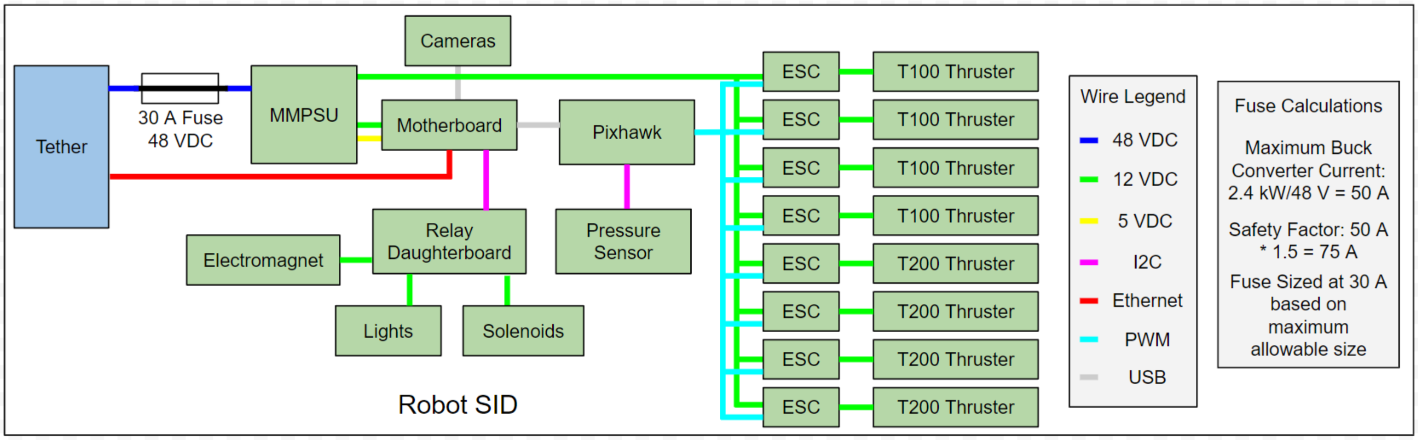


Fig. 22: ROV Electrical SID

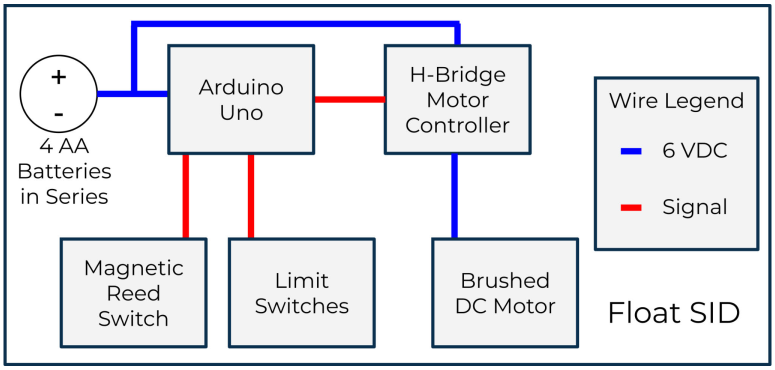


Fig. 23: Float SID

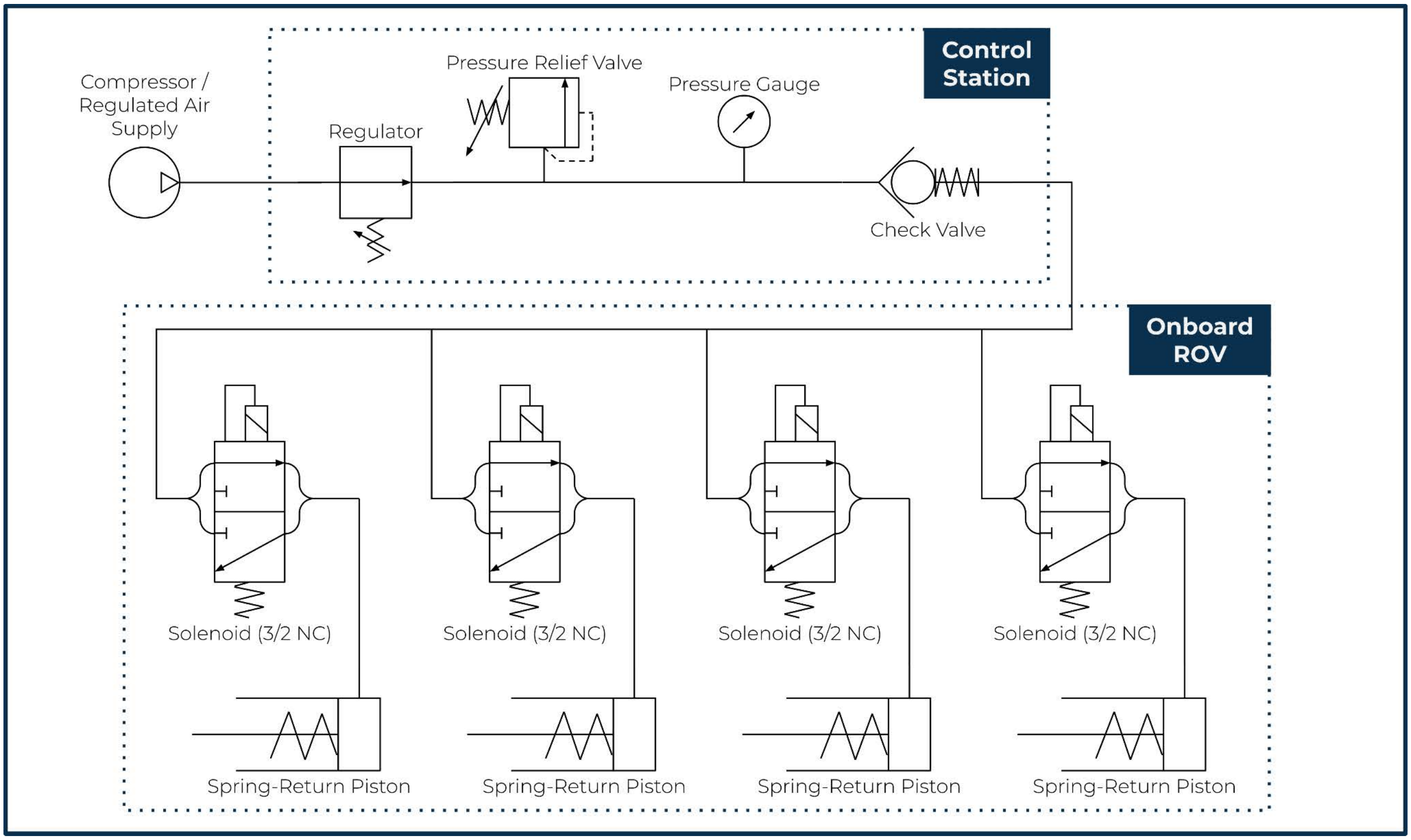


Fig. 24: ROV Pneumatic System SID

Appendix

Safety Checklists

Pre-Dive

Verify power is off

Inspect ebay 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 Ebay 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 ebay

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 ebay

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 ebay

If water exists in ebay, remove lid from ebay and dry all components

Check for corrosion on all electronics

Ensure all entry points are watertight

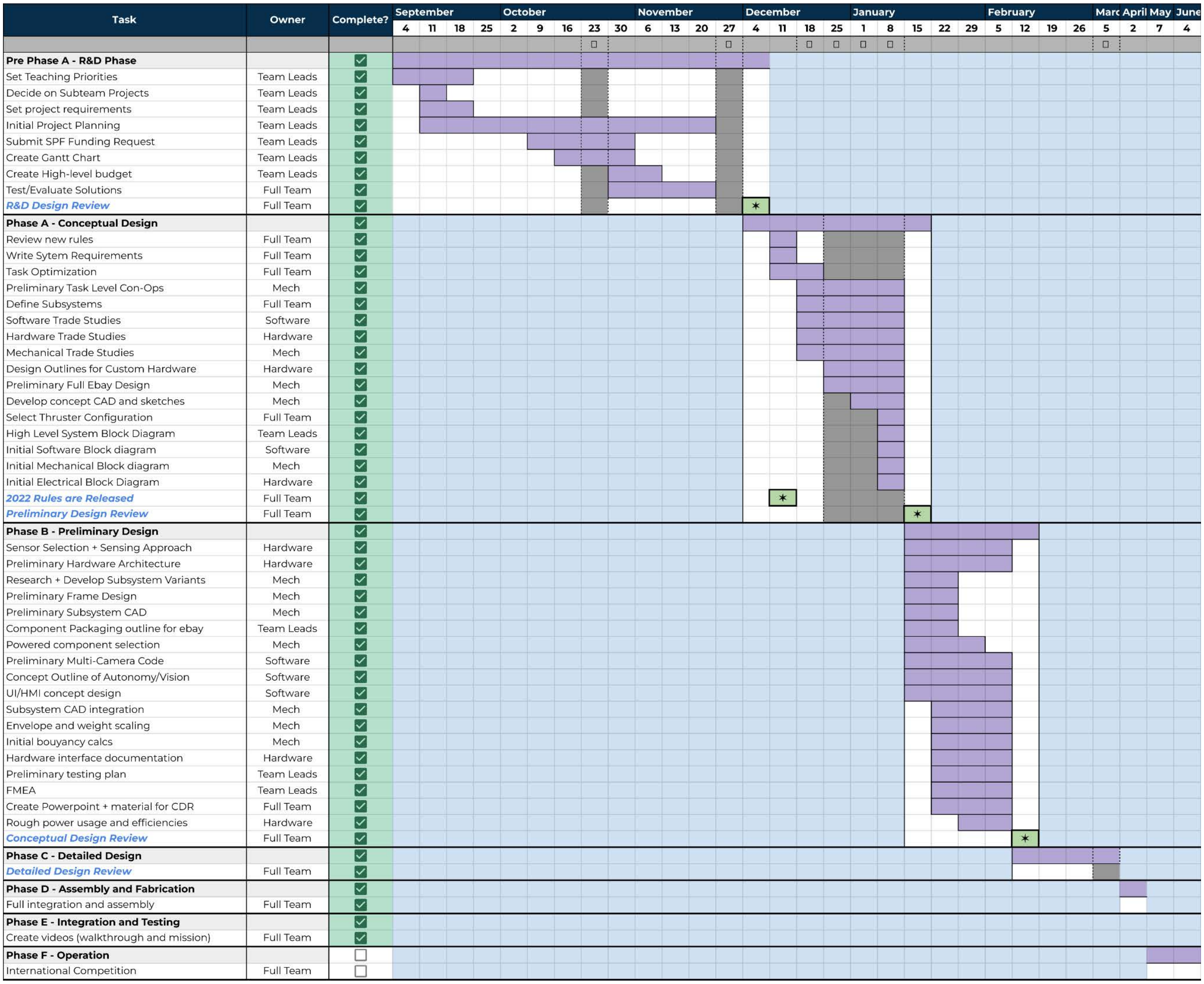
After drying, test full system to ensure complete functionality

Mission Layout and Planning

Table 4: Mission Planning

	On Dive (ROV takes with)		At Depth (ROV performs in pool)		For Recovery (ROV returns with)	
	Subsystem	**Task**	**Subsystem**	**Task**	**Subsystem**	**Task**
1	PVC Deployer / Float	Deploy float	Whisk Puller	Pulls pins on cable	Linkage Claw	Remove old cable
	Linkage Claw	Deploy hydrophone	Camera	Inspect cable	Linkage Claw	Recover buoyancy module
			Passive & Whisk Puller	Release buoyancy module	Linkage Claw	Recover GO-GBC float
			Whisk Puller	Release ghost net	Passive	Remove ghost net
			Whisk Puller	Remove marine growth	Linkage Claw	Prune seagrass
			Computer Vision	Inspect fish pen	Linkage Claw	Prune seagrass
2	PVC Deployer	New buoyancy module	Linkage Claw	Collect mort	Linkage Claw	Recover hydrophone
	PVC Deployer	Install new cable	Linkage Claw	Drop mort in bucket		
			Passive	Secure new cable		
			Computer Vision	Measure fish size		
3	PVC Deployer	Patch net	Computer Vision	Shipwreck		
	PVC Deployer	Plant seagrass		Secure buoyancy module		
			Computer Vision	Docking		

Gantt Chart

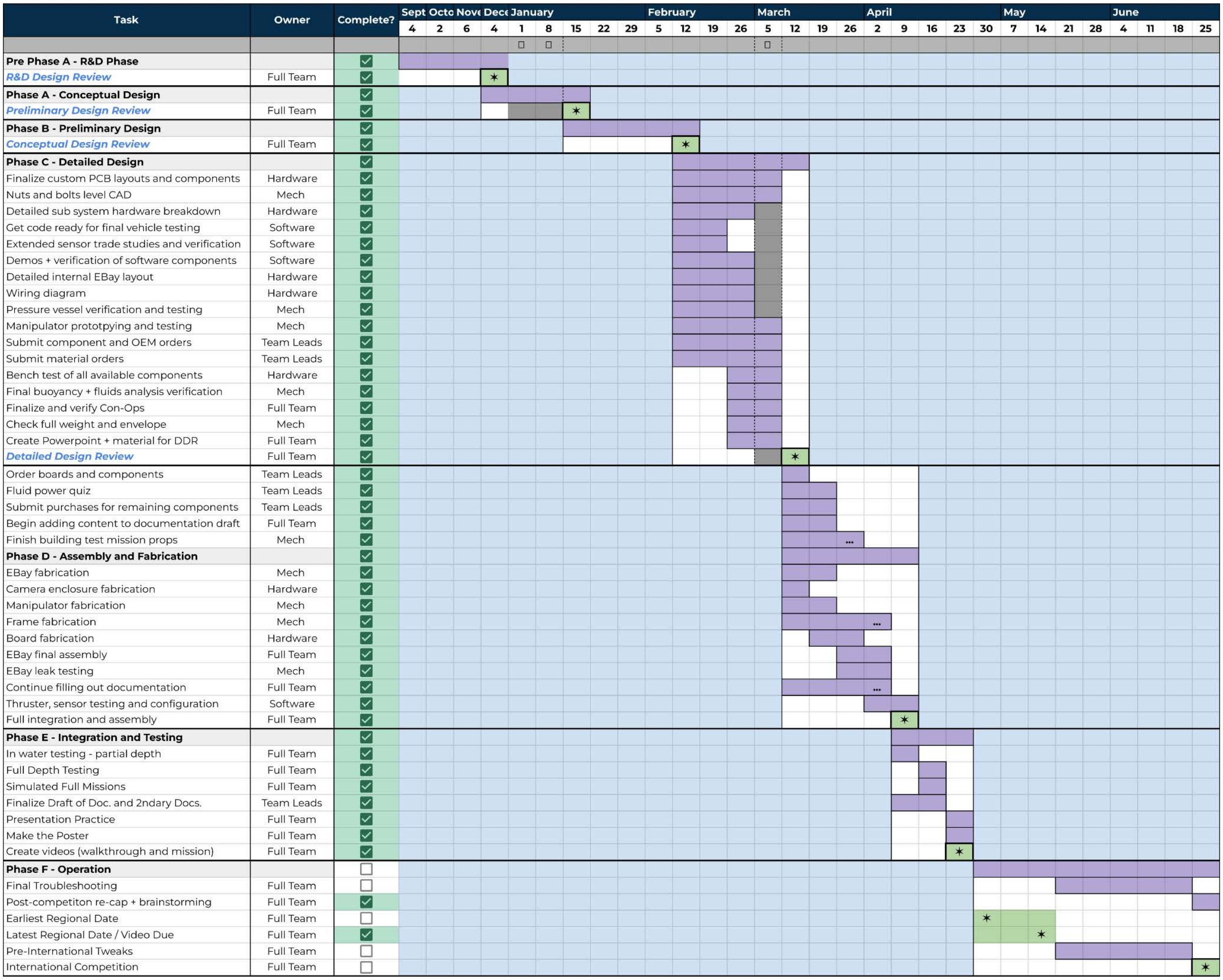


Task	Owner	Complete?
Pre Phase A - R&D Phase		☑
Set Teaching Priorities	Team Leads	☑
Decide on Subteam Projects	Team Leads	☑
Set project requirements	Team Leads	☑
Initial Project Planning	Team Leads	☑
Submit SPF Funding Request	Team Leads	☑
Create Gantt Chart	Team Leads	☑
Create High-level budget	Team Leads	☑
Test/Evaluate Solutions	Full Team	☑
R&D Design Review	Full Team	☑
Phase A - Conceptual Design		☑
Review new rules	Full Team	☑
Write Sytem Requirements	Full Team	☑
Task Optimization	Full Team	☑
Preliminary Task Level Con-Ops	Mech	☑
Define Subsystems	Full Team	☑
Software Trade Studies	Software	☑
Hardware Trade Studies	Hardware	☑
Mechanical Trade Studies	Mech	☑
Design Outlines for Custom Hardware	Hardware	☑
Preliminary Full Ebay Design	Mech	☑
Develop concept CAD and sketches	Mech	☑
Select Thruster Configuration	Full Team	☑
High Level System Block Diagram	Team Leads	☑
Initial Software Block diagram	Software	☑
Initial Mechanical Block diagram	Mech	☑
Initial Electrical Block Diagram	Hardware	☑
2022 Rules are Released	Full Team	☑
Preliminary Design Review	Full Team	☑
Phase B - Preliminary Design		☑
Sensor Selection + Sensing Approach	Hardware	☑
Preliminary Hardware Architecture	Hardware	☑
Research + Develop Subsystem Variants	Mech	☑
Preliminary Frame Design	Mech	☑
Preliminary Subsystem CAD	Mech	☑
Component Packaging outline for ebay	Team Leads	☑
Powered component selection	Mech	☑
Preliminary Multi-Camera Code	Software	☑
Concept Outline of Autonomy/Vision	Software	☑
UI/HMI concept design	Software	☑
Subsystem CAD integration	Mech	☑
Envelope and weight scaling	Mech	☑
Initial bouyancy calcs	Mech	☑
Hardware interface documentation	Hardware	☑
Preliminary testing plan	Team Leads	☑
FMEA	Team Leads	☑
Create Powerpoint + material for CDR	Full Team	☑
Rough power usage and efficiencies	Hardware	☑
Conceptual Design Review	Full Team	☑
Phase C - Detailed Design		☑
Detailed Design Review	Full Team	☑
Phase D - Assembly and Fabrication		☑
Full integration and assembly	Full Team	☑
Phase E - Integration and Testing		☑
Create videos (walkthrough and mission)	Full Team	☑
Phase F - Operation		☐
International Competition	Full Team	☐

Fig. 25: Project Gantt Chart, Phases Pre-A through B (cont. next page)

Included in the partial Gantt chart in Figure 25 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.



Task	Owner	Complete?
Pre Phase A - R&D Phase		☑
R&D Design Review	Full Team	☑
Phase A - Conceptual Design		☑
Preliminary Design Review	Full Team	☑
Phase B - Preliminary Design		☑
Conceptual Design Review	Full Team	☑
Phase C - Detailed Design		☑
Finalize custom PCB layouts and components	Hardware	☑
Nuts and bolts level CAD	Mech	☑
Detailed sub system hardware breakdown	Hardware	☑
Get code ready for final vehicle testing	Software	☑
Extended sensor trade studies and verification	Software	☑
Demos + verification of software components	Software	☑
Detailed internal EBay layout	Hardware	☑
Wiring diagram	Hardware	☑
Pressure vessel verification and testing	Mech	☑
Manipulator prototpying and testing	Mech	☑
Submit component and OEM orders	Team Leads	☑
Submit material orders	Team Leads	☑
Bench test of all available components	Hardware	☑
Final buoyancy + fluids analysis verification	Mech	☑
Finalize and verify Con-Ops	Full Team	☑
Check full weight and envelope	Mech	☑
Create Powerpoint + material for DDR	Full Team	☑
Detailed Design Review	Full Team	☑
Order boards and components	Team Leads	☑
Fluid power quiz	Team Leads	☑
Submit purchases for remaining components	Team Leads	☑
Begin adding content to documentation draft	Full Team	☑
Finish building test mission props	Mech	☑
Phase D - Assembly and Fabrication		☑
EBay fabrication	Mech	☑
Camera enclosure fabrication	Hardware	☑
Manipulator fabrication	Mech	☑
Frame fabrication	Mech	☑
Board fabrication	Hardware	☑
EBay final assembly	Full Team	☑
EBay leak testing	Mech	☑
Continue filling out documentation	Full Team	☑
Thruster, sensor testing and configuration	Software	☑
Full integration and assembly	Full Team	☑
Phase E - Integration and Testing		☑
In water testing - partial depth	Full Team	☑
Full Depth Testing	Full Team	☑
Simulated Full Missions	Full Team	☑
Finalize Draft of Doc. and 2ndary Docs.	Team Leads	☑
Presentation Practice	Full Team	☑
Make the Poster	Full Team	☑
Create videos (walkthrough and mission)	Full Team	☑
Phase F - Operation		☐
Final Troubleshooting	Full Team	☐
Post-competiton re-cap + brainstorming	Full Team	☑
Earliest Regional Date	Full Team	☐
Latest Regional Date / Video Due	Full Team	☑
Pre-International Tweaks	Full Team	☐
International Competition	Full Team	☐

Fig. 26: Project Gantt Chart, Phases C through F (cont. from previous page)

Acknowledgements

We would like to thank our club's faculty advisor, Professor Richard Bachmann from the Mechanical and Aerospace Engineering department. We would also like to thank other professors and alumni who provided us with feedback during our design reviews, specifically professor Jason Bradshaw and CWRUbotix alumni Kayla Anderson, Peter Koudelka, and Adam Cordingley. We also want to thank our university, Case Western Reserve University, for fueling our creativity and giving us the opportunity to use the Sears think[box] building to construct our robot.

Thank you to the staff of the Veale Recreation Center, specifically aquatics manager Jess Warfield and the Donnell Pool lifeguards, for allowing us to test our ROV in the pool.

Lastly, we must thank our university alumni and the Gene Haas foundation for being funding sources. Our team, and the two other competitive robot teams under the CWRUbotix

club, would not have been able to compete without their generous donations.

Budget

Table 5: Project Operating Budget

CWRUbotix 2022 Budget (USD)

Budget Category	Item Category	Type	Amount	Total Purchased	Budget Allocated
Electrical	Power Electronics (MMPSU)	Purchased	$1,067.09	$3,270.25	$3,500
	Control Electronics (Boards, Parts)	Purchased	$446.16		
	Electronics (OEM Components)	Purchased	$692.90		
	Thrusters (T100 / T200 Cores)	Purchased	$898.58		
	Tether (Wiring, Flotation)	Purchased	$165.52		
Mechanical: Components	Pneumatic System Components	Purchased	$426.83	$1,455.92	$1,500
	Fasteners and Mechanical Hardware	Purchased	$604.48		
	Waterproofing (O-Rings, Penetrators)	Purchased	$151.06		
	Float Components	Purchased	$246.07		
	Electromagnets	Purchased	$27.48		
Mechanical: Raw Material	Stainless Steel Sheet Stock	Purchased	$213.28	$1,173.53	$1,400
	3D Printer Filament	Purchased	$262.00		
	E-Bay (Stock, 3D Printing)	Purchased	$648.17		
	Float Stock (Tube, Rods)	Purchased	$50.08		
	Bouyancy Foam	Donated	$26.00		
Manufacturing	Waterjet Time	Purchased	$83.00	$83.00	$100.00
	Epoxy	Donated	$139.99		
Software (Controls, Sensors, Supporting Resources)	Control Station (Case, Components)	Purchased	$336.52	$794.01	$1,000.00
	Testing Power Supply (Plywood, Parts)	Purchased	$150.74		
	Cameras, Sensors	Purchased	$262.76		
	Testing Hardware and Supplies	Purchased	$43.99		
	Controllers and Control Laptop	Donated	$738.00		
Total Construction Expenses				**$6,776.71**	**$7,500**
Lodging and Travel (Internationals)	Flights	Purchased	$4,615.32	$9,331.68	$9,000
	Housing	Purchased	$2,072.68		
	Team Meals	Purchased	$2,000.00		
	Rental Cars and Gas	Purchased	$643.68		
Total Lodging and Travel Expenses				**$9,331.68**	**$9,000**
Cash Income	think[box] Student Project Fund	Cash	$2,500.00	$14,268.81	$16,500.00
	Undergraduate Student Government	Cash	$1,268.81		
	Case Alumni Association	Cash	$6,000.00		
	Grants (Gene Haas, CWRU)	Cash	$4,500.00		
Total Cash Income for 2022				**$14,268.81**	**$16,500.00**
				Expenses	$16,108.39
				Total Donation Value	$903.99
				Cash Income	$14,268.81
				Rollover	-$935.59

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