Slugbotics

Technical Documentation

Santa Cruz / California / United States of America

Company Core Members:

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Mechanical Structure Integration:
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Topside Communications Systems:
28’ Alexander Hamilton

Float:
26' Nathan Pham

Electrical Systems Integration:
27’ Layla Peachee

Vision and Detection:
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27’ Andy Wu

Robotic Manipulator Systems:
26’ Zander MendozA

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Abstract:

Located along the California Coast, UC Santa Cruz offers a unique inspiration for students to explore the intersection of marine science and engineering. As a newly formed team with limited experience in engineering, the focus was on developing foundational skills in remotely operated vehicle (ROV) design and construction. The result was a functional, competition-ready ROV featuring a control system, a mechanically sound manipulator, a high-clarity camera unit, a safe and efficient electrical power distribution system, and a stable modular frame. To manage development efficiently, the team was divided into six subteams—Topside Communication System, Electrical Systems Integration, Navigation and Propulsion Systems, Mechanical Structure Integration, Vision and Detection, and Robotic Manipulator Systems—each responsible for a specific subsystem. This structure enables members to engage deeply with particular components while contributing to a cohesive whole. Regular communication through biweekly general meetings and weekly subteam work sessions was crucial to our progress, fostering collaboration and building critical skills in project management, scheduling, budgeting, and the engineering design process. This report presents the conceptual approach and technical design decisions behind this year's Slugbotics ROV, alongside an overview of the team's organizational structure and workflow. The final product reflects the dedication and growth of a young team committed to learning through hands-on engineering.

Photograph of ROV Test Day

Photo of ROV

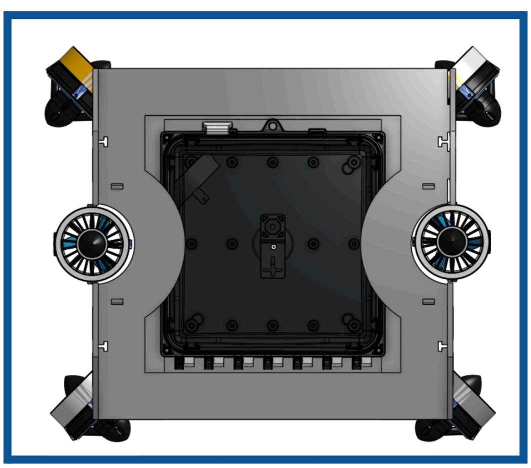
Project Management:

In structuring our team, we deliberately chose not to follow a traditional horizontal integration model where members are divided strictly into mechanical, electrical, and software subgroups. Instead, we organized around individual ROV subsystems such as the manipulator arm, frame, cameras, topside control, electrical integration, and propulsion movement. This approach enables members to develop a deeper understanding of the complete functionality and design of their subsystem. It fosters more meaningful interdisciplinary collaboration, as teams are naturally required to work closely across mechanical, electrical, and software boundaries to ensure seamless integration. Additionally, this structure gives each member a stronger sense of ownership and accountability of their contribution to a specific tangible part of the ROV. This model has proven to be beneficial for our diverse team which includes several robotics and computer engineering majors who seek hands-on experience blending mechanical, hardware, and software challenges.

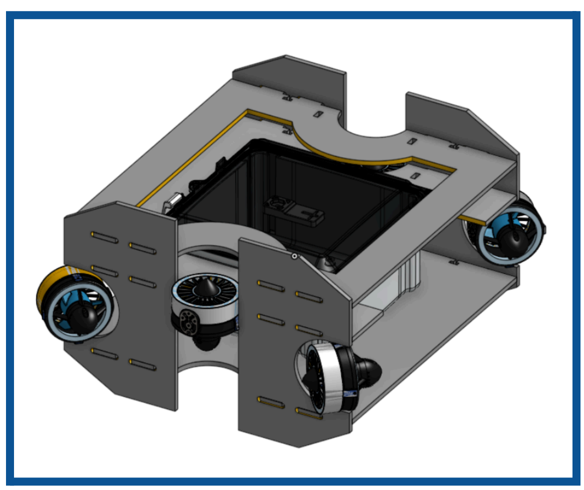
Engineering Design Rationale:

Mechanical System:

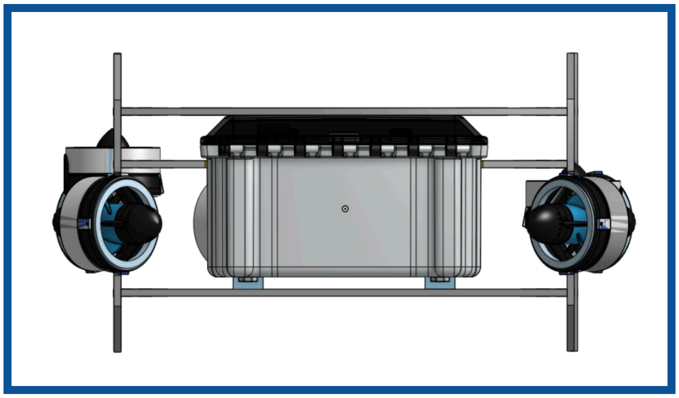
We selected 0.25-inch-thick high-density polyethylene (HDPE) sheets for the construction of the ROV frame. HDPE is chemically inert and highly resistant to corrosion, making it ideal for long-term submersion. It is also lightweight and easy to machine using the ShopSabre CNC machine available at the Slugworks machine shop under Baskin Engineering at UCSC. The material offers a favorable balance between structural rigidity and flexibility, allowing it to absorb shocks and mechanical stresses without cracking, which is an important property when needing to handle heavy components and during deployment. Unlike some plastics that absorb water and degrade over time, HDPE has near-zero water absorption and maintains its structural integrity underwater. Additionally, a newly formed team operating under tight budget constraints, we selected HDPE for its cost effectiveness compared to metal composite materials like carbon fiber.



CAD Assembly of Frame (Top View)



Isometric View

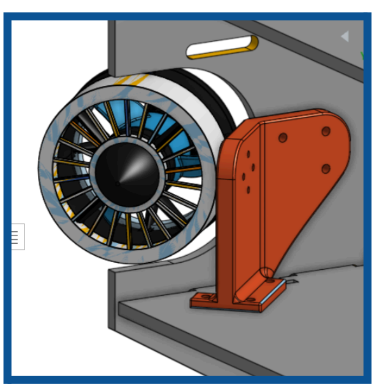


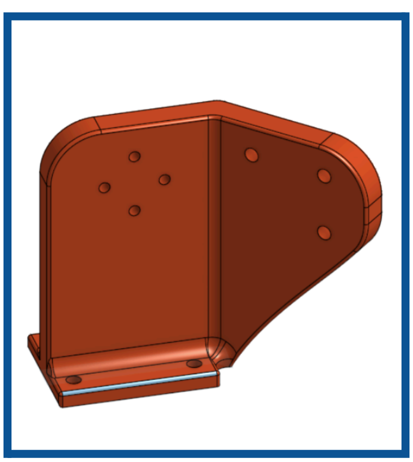
Back View

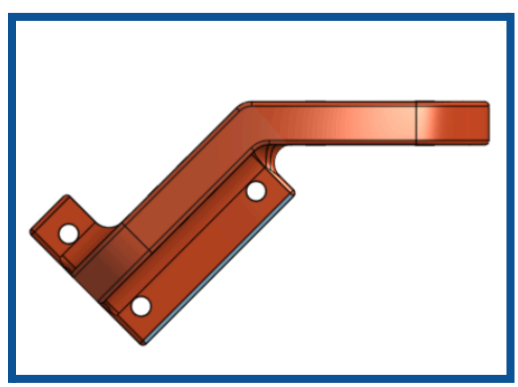
The design of the ROV frame is centered around the electrical enclosure, which serves as the primary size constraint of the system. With dimensions of approximately 11” by 11” by , the enclosure occupies a significant portion of the internal volume, consequently dictating the minimum dimensions of the overall frame. The goal was to accommodate the enclosure while maintaining functionality and accessibility. In order to preserve space and reduce the size of each horizontal HDPE shelf, the thrusters were partially integrated into the frame rather than being fully mounted externally. Although placing thrusters farther from the center of mass of the ROV would increase torque, embedding them partially inside the frame decreases the ROV’s drag as well as the bulkiness of the ROV, providing a balance between maintaining a compact design and achieving maneuverability.

The internal structure is divided into three main horizontal shelves. The base shelf serves as a mounting platform for the robotic manipulator, electrical enclosure, and buck converter. The middle shelf provides support for the bottom edge of the electrical enclosure, including a cutout for the enclosure lid to open upwards for easy access. The top shelf enhances structural rigidity by further connecting the side vertical walls together and reducing warping while handling the ROV. The vertical panels are split into 4 pieces to provide the necessary clearance for the vertical facing thrusters centered along the side of the ROV.

Mounts for the thrusters were designed on Onshape and 3D printed out of PLA at the Createrspace at Slugworks under Basking Engineering. One mount was designed to be secured to the frame and extend inward at a 45 degree angle.

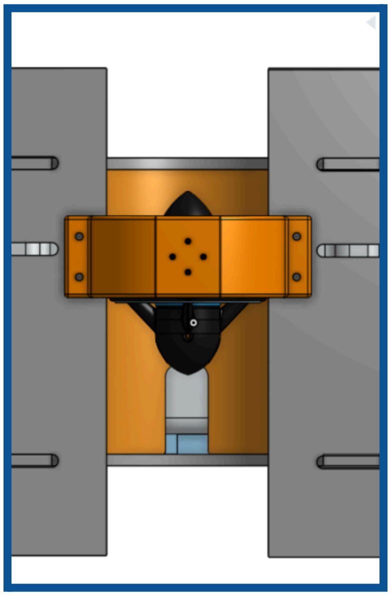




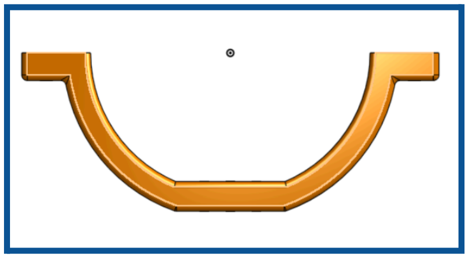


Thruster on Angled Mount **Isometric View** **Top View**

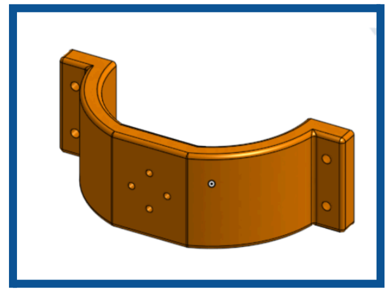
A second mount was designed to secure the vertical frame panels for the upward facing thrusters. A semi-cylindrical clearance panel was designed to provide extra vertical support for the frame, close off the space between the two HDPE vertical panels, and allow space for wiring to pass through. The semi-cylindrical shape acts as an inset within the frame to ensure there is clearance below and above the thruster for water to be propelled.



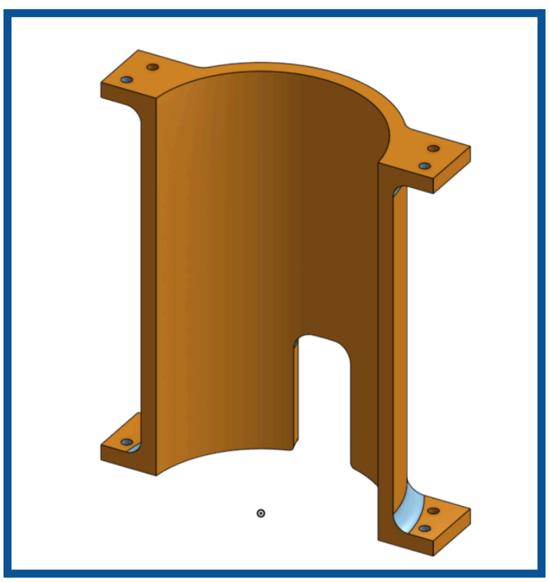
Vertical Facing Thruster



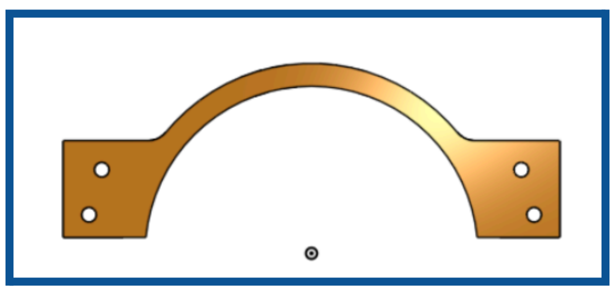
Top View



Isometric View



Clearance Panel for Thruster

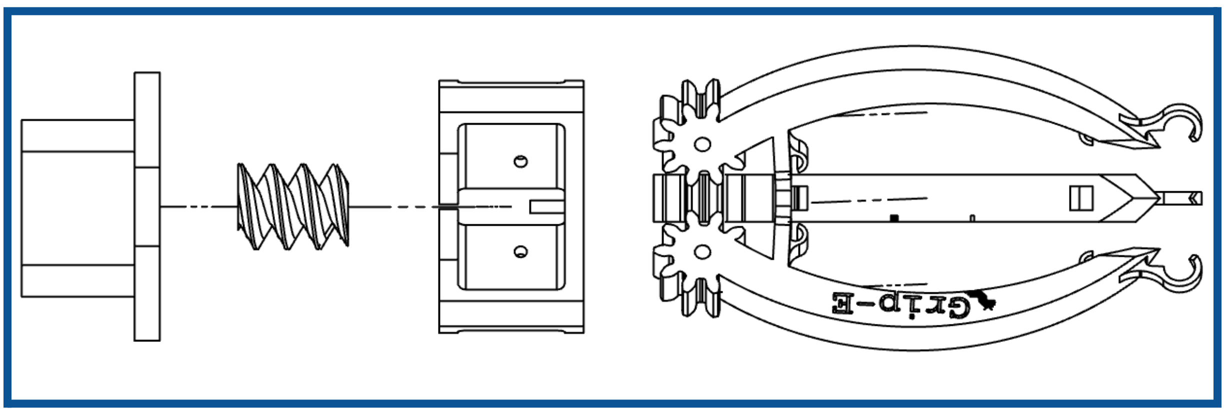


Top View

Robotic Manipulator:

The robotic manipulator (mechanical arm), fastened to the base shelf of the frame, is built from 4 main components: 3 fingers, a worm gear, a base, and a motor housing. The three claw-like fingers are attached through pins to slots in the base, allowing them independent rotation. Inside the base, a pin stemming from the center holds the worm gear in place, centered between the fingers' gears. This worm gear, when rotated, spins the gears at the base of each finger, opening and closing the claw. A stepper motor, held in the motor housing, is attached directly to the worm gear, allowing direct correlation between the stepper motor and worm gear rotation. Alongside these components, two servos are attached to extension pieces of the arm, allowing for greater movement and ability by enabling twisting motion and angle manipulation.

To waterproof the servos and stepper motor, we used epoxy to create a base sealing layer and then utilized o-rings to allow for waterproofing on rotational parts. Furthermore, to waterproof the wires at their entry point to the main control box, we utilized a waterproof putty that allowed for a tight seal.



Assembly of ROV's Manipulator

Electrical System:

The first steps our electrical integration team took where to find a suitable enclosure for the wiring and make a rough electrical diagram to determine what components needed power. Our criteria for the enclosure were that it had to be waterproof, rated IP-68 to handle being completely submerged, as well as big enough to fit everything it needed to. Once the enclosure was sourced, we began to organize and put together our components. The enclosure houses 6 ESCs, an Arduino, and a Raspberry Pi. To power these components, we have a 12V power busbar and common ground for the ESCs and a step-down converter to give the microcontrollers 5V power. In order to optimize space, we 3D printed two shelves, a lower shelf to hold all 12V components, and an upper shelf to hold the 5V microcontrollers.

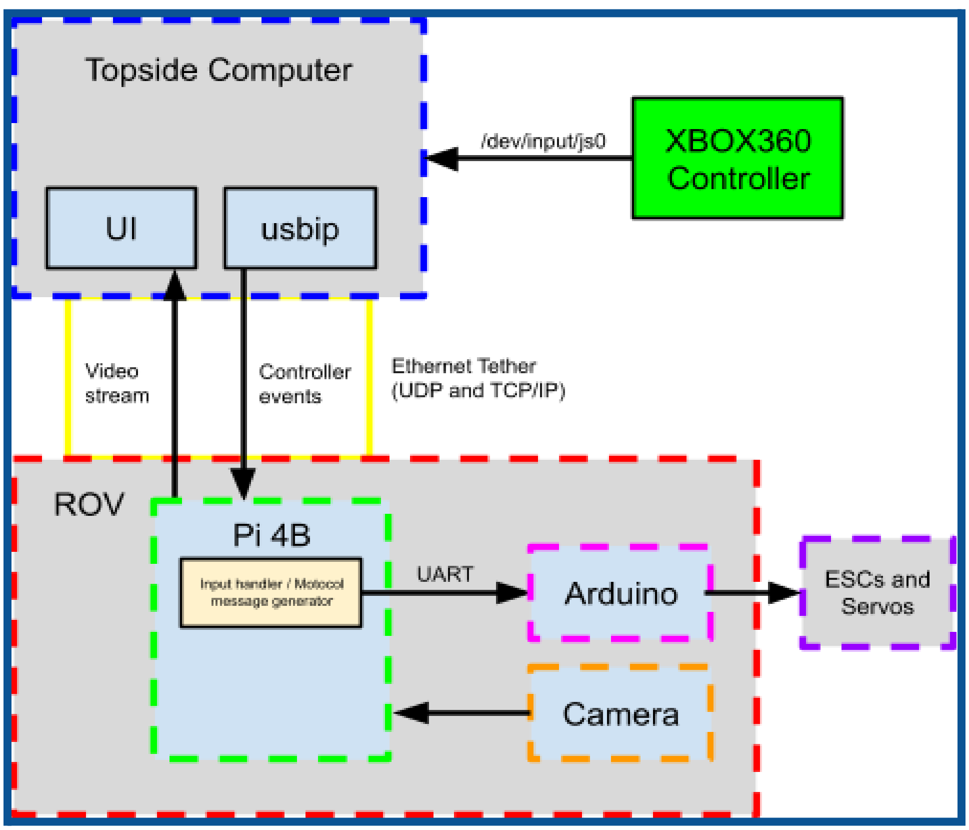
We mounted our 48V to 12V step-down converter just outside the enclosure to avoid unnecessarily heating up the rest of the electronics. This converter connects the tether from the topside, which gives us 48V, to the 12V busbar in the enclosure. Every wire that enters or exits the enclosure, including the motors, arm, vision, and step-down converter, was put through a gland nut, or penetrator, which was then covered in waterproof Pool Putty. This ensures that absolutely no water can enter the enclosure and damage our system.

The tether is composed of an Ethernet cable and 48V power and ground wires, wrapped in a plastic braided expandable sleeve. These connect the ROV to topside, where we get our 48V and our input commands from the laptop and controller. A carabiner is used to connect the tether to the frame and provide strain relief to the wiring.

Control System:

At the highest level, the ultimate goal of our control framework is to map inputs from a game controller attached to our topside computer into throttles and positions for our motors and servos. respectively, on the ROV.

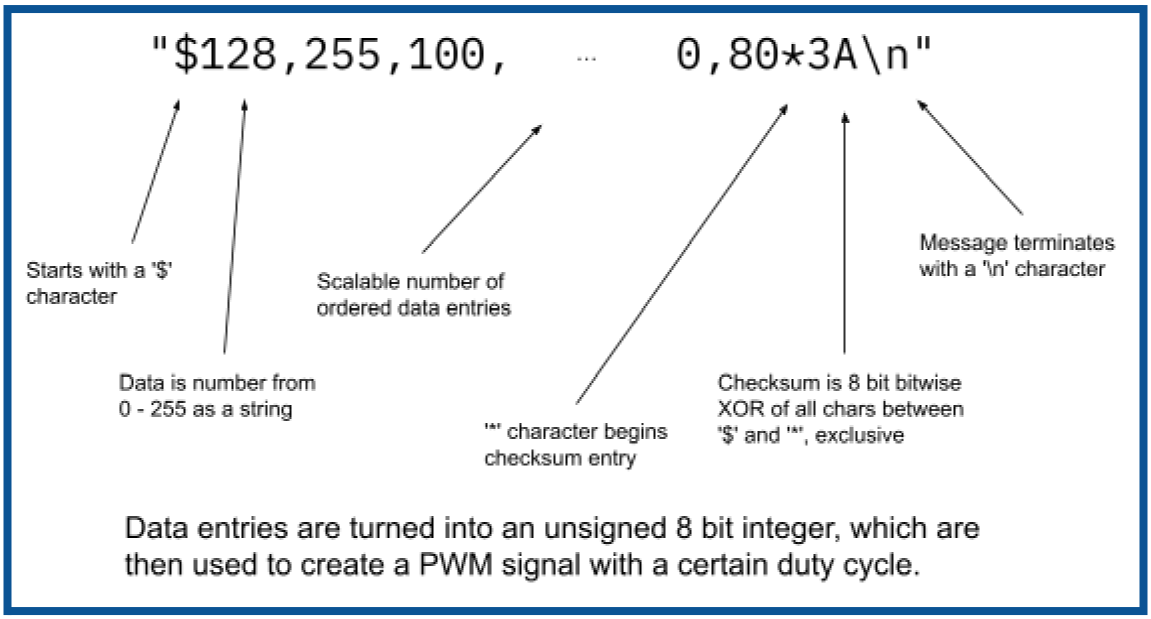
Our final implementation of this involves a Raspberry Pi 4B directly attached via ethernet to the topside computer, with an Arduino Mega 2560 Rev 3 as a peripheral to the Pi. The Pi is responsible for performing higher-level processing (since it has the capability of running an easy-to-work-with Linux environment), while the Arduino runs the PWM signals to the motor escs and servos (since it is better at real-time operations and it has better PWM capability). We initially used only the Pi to run PWM signals, but we found out the hard way that it isn't very good at creating precise enough signals at a quick enough speed – it only has 2 PWM channels and it is running a non real time OS.



High-level diagram of our Topside-ROV MCU connection

To communicate between the Pi and the Arduino, we utilize the USB ports on the Pi and the Arduino, which very conveniently gives us access to using UART as a quick and easy method to transfer messages. We realize that I2C is better performing and more scalable for our purposes, but it would introduce a lot more hardware and more potential for bugs. Also, we only have a single peripheral to the Pi in our final product, so the advantages that I2C has over UART are less applicable.

However, a notable issue with using UART is that it does not provide a message format with which to send messages. Thus, we devised a protocol similar to NMEA0183 that we call the Motocol.



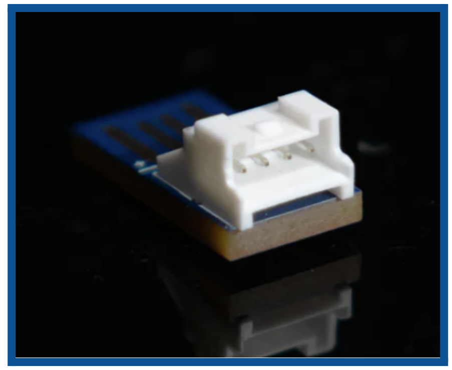
<u>Diagram of our Motocol protocol message format</u>

The Arduino runs bare metal code that receives messages from the Pi (which should be in the Motocol format), and translates them into usable unsigned 8-bit integers. These integers are then used to run a PWM signal with a variable duty cycle.

As for running the PWM signals, the standard Arduino library provides very limited options. By default, the Arduino Mega 2560 runs 490 Hz for all of its PWM-capable pins, except for pin 13, which runs it at 980 Hz. Our motor ESC's maximum update rate is 400 Hz, while the standard servo PWM rate is at 50 Hz. As such, we cannot use the Arduino to run any viable PWM signal without any changes. In order to achieve precise frequency and duty cycles, we had to modify the settings of the control registers on the ATMega2560 (The TCCRn and the OCRn registers).

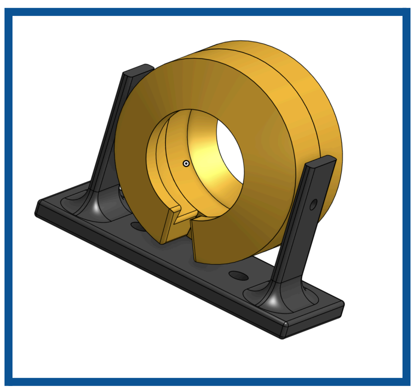
Vision:

exploreHD camera

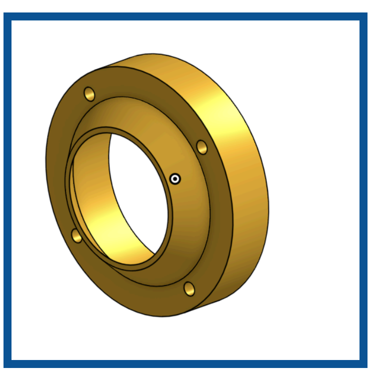


4-Pin JST to USB

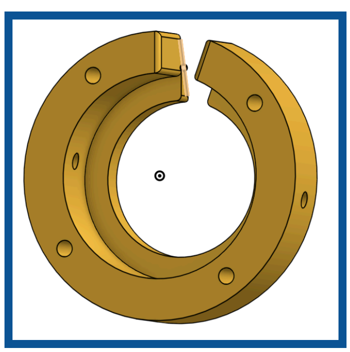
Slugbotics is honored to be sponsored by DeepWater Exploration, a San Diego-based company that creates waterproof cameras and accessories for ROVs and other marine robots. DWE donated their exploreHD camera for use on the ROV. The camera is fully waterproofed and is connected through a DWE JST to USB connector to the Raspberry Pi, where footage is streamed using a Python script. We designed two programs to analyze footage: one to detect shipwreck elements, and one to measure objects live. These programs are run on the Pi using SSH and are initialized from the topside computer. In order to attach the camera to the frame, we ran through many iterations of casing before settling on a design that had a case to hold the camera to a mount, while also being tight enough to hold the camera in place. This was our design.



Camera Case & Mount



Front View



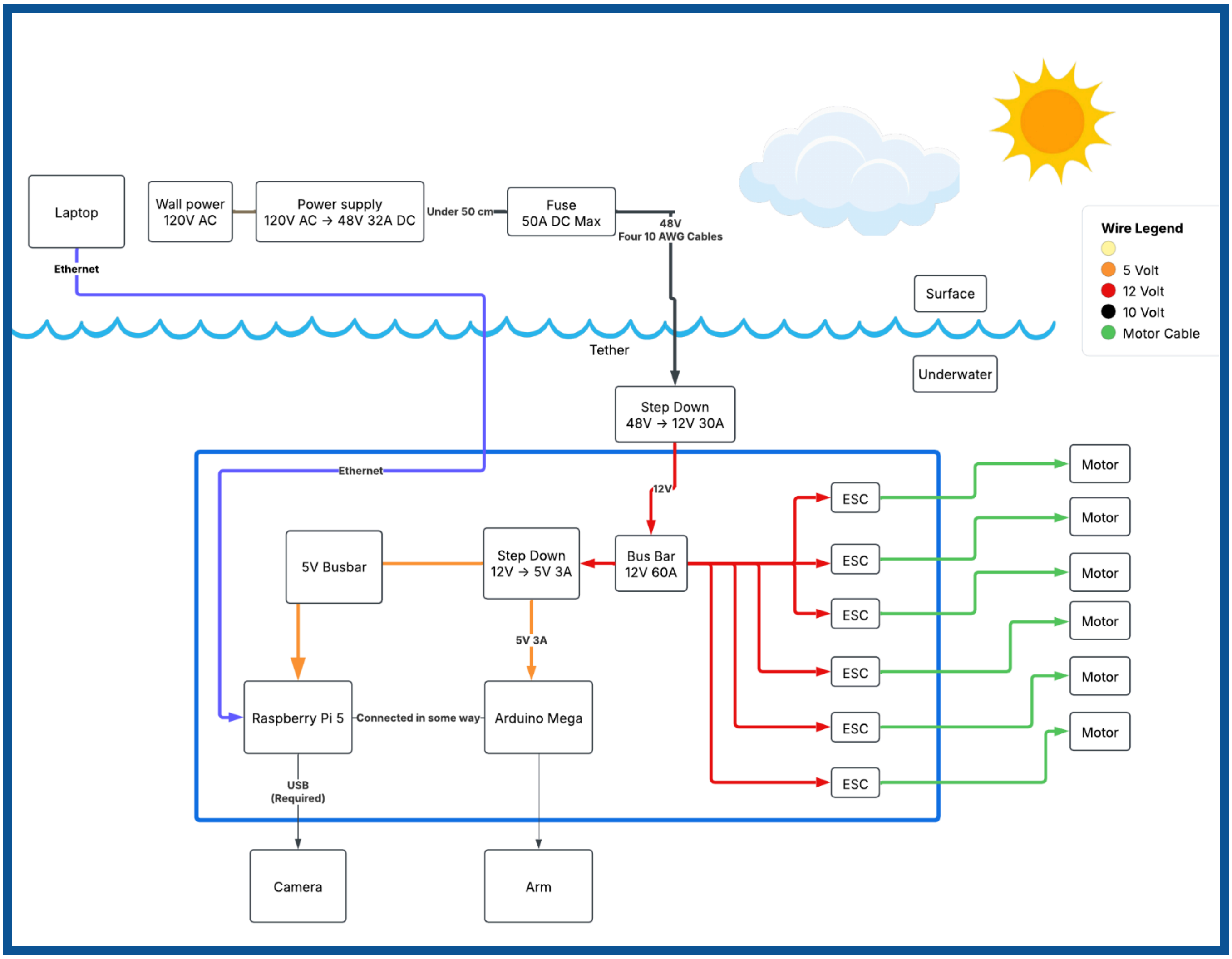
Back View

Camera Case Mount

We designed the case to use M3 .5x7mm screws, and attached the mount to the HDPE sheet.

The programs we wrote to use computer vision were written in Python using the OpenCV Library and Yolov8 detection model, and the vision model is optimized to detect the shipwreck differences as written in the competition manual.

System Integration Diagram:



Safety Procedures:

Construction:

During the assembly of the ROV and its corresponding components, multiple safety measures were put in place. Safety glasses and gloves were worn during all appropriate procedures.

When any physical modifications were done to the ROV, the components were clamped to a non-moving surface to make sure that they would not slip out of grasp and hurt the working student or those in the immediate surroundings of the workshop. Conductive electrical components were not left exposed and properly crimped, heat-shrunk, and attached to the ROV. Internally, fuses, common ground bus bars, and proper electrical waterproofing strategies were executed to prevent any electrical hazards.

Operations:

On both the ROV and Float components, all motors are properly covered to fit within the <1cm requirement. Any sharp corners were filed. The required fuse and connectors were used. A kill switch was integrated. The development of the ROV was overlooked by “Slugworks”, an on-campus organization that does safety training, keeps the club space running, and upkeeps safety standards in the club work space.

Data & Organization

To hold our CAD data, we used Onshape to design CADs and store them for usage. The combination of features of designing and storing data made it very appealing and allowed our team to have access to everyone’s CADs, which benefits us when designing parts to integrate with each other. We also made a bill of materials (BoM) which held information about every part purchased, and a costing sheet to track donations, reused materials, or newly purchased materials, which also calculated our total cost.

Accounting:

Budget Planning:

UCSC MATE Project Costing Sheet 24'-25'				
Group: UCSC Slugbotics	From: 9/24/24	To: 5/25/25		
Income Source				Ammount
Slugbotics Fund				$ 1,000.00
Total Income				$ 1,000.00
Description	Cost per	Quantity	Type	Subtotal
HARDWARE				
Threaded Insert for Plastic Tapered Single Vane Brass Thread Inserts 1/4-20 Pack of 50	$8.69	1	Purch...	$ 8.69
M3-0.5 x 7mm Button Head Socket Cap Screws Quantity 120	$8.99	1	Purch...	$ 8.99
Plexiglass Sheets Acrylic Sheets 12 Pack of 8.5x11" 0.04	$14.99	1	Purch...	$ 14.99
30g Plastic Glue - Ultra-Strong Adhesive for Plastic Models	$7.49	1	Purch...	$ 7.49
O-Rings	$6.23	1	Purch...	$ 6.23
Subtotal				*$ 46.39*
ELECTRONICS				
Crimp Pin Connector Kit	$10.99	1	Purch...	$ 10.99
Solid Core Colored Breadboard Wires	$15.19	1	Purch...	$ 15.19
Quick Connect Nylon Bullet Connectors	$9.49	2	Purch...	$ 18.98
Harsh Environment High-Current Distribution Bars	$27.49	2	Purch...	$ 54.98
Waterproof heatshrink	$14.99	1	Purch...	$ 14.99
10awg Silicone Electrical Wire	$16.98	1	Purch...	$ 16.98
Adafruit Industries LLC 2448	$6.95	1	Purch...	$ 6.95
60A Littlefuse Holder	$6.46	1	Purch...	$ 6.46
SBS50 Anderson Connector	$4.45	4	Purch...	$ 17.80
36V / 48V to 12V 40A Buck Converter	$39.99	2	Purch...	$ 79.98
200 ft 10 gauge copper wire	$48.98	1	Purch...	$ 48.98
6 gauge copper wire	$29.99	1	Purch...	$ 29.99
60A Fuse	$1.99	5	Purch...	$ 9.95
T200 Thruster	$258.00	6	Re-Used	N/A
Raspberry Pi 4 Model B	$35.00	1	Re-Used	N/A
Arduino Mega 2560 Rev3	$50.00	1	Re-Used	N/A
Copper Terminal Connectors and Heat Shrink Kit	$19.66	1	Purch...	$ 19.66
exploreHD 3.0 (400m) Underwater ROV/AUV USB General Vision Camera	$300.00		Donation	N/A
4-Pin JST to USB Type-A Adapter (5 Pack)	$18.00	1	Purch...	$ 18.00
Subtotal				*$ 369.88*
Total Expsense				**$ 416.27**

ROV Development budget

MATE Comp Budget 2025		DATE:	6/17 to 6/21	2025 Competition info: https://materovcompetition.org/world-championship	Goal:	Finish acquiring funding by may 10th
Location:		Alpena, Michigai	4 Days			
# of People-	4					
					Hotel	
Costs:						
Registration	Flight Costs	Lodging	Robot Transpoi	Food		
$550	~$567 x person	$89 / Night	~600	$30 / Day		
	roundtrip	Double bed	USPS	per person		
All people included						
	2268	712		480		
Total =	4610					

Ramada by Wyndham, Alpena - **$89 USD/night**

1000 US Highway 23 N | Alpena, Michigan 48707

+1 (989) 254-6162

Comfort Suites by Choice Hotels is offering standard rooms (2 double beds) at a special group rate of $89 USD/night (plus taxes and fees) for MATE ROV Competition participants. **The last day to book is May 16, 2025.** MUST CALL TO RESERVE ROOM UNDER THIS BLOCK.

Featured Amenities:

- Breakfast
- Parking
- Pool
- Free WiFi

Hotel Information:

- Check-in is at 3:00 PM
- Check-out is at 11:00 AM
- Code when calling: **MATE ROV Competition**

Travel Budget

Sponsors & Acknowledgements

Slugbotics thanks these organizations for their contributions and/or sponsorships.