ROAR-E 1

Columbia University Robotics Club

Technical Report
MATE ROV 2023 Explorer Class

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Abstract

The Columbia University Robotics Club (CURC) is an interdisciplinary student engineering organisation that manages three projects every year. Among those projects is the Underwater Remotely Operated Vehicle (ROV) project in which students design and engineer an ROV to navigate bodies of water, monitor marine life, and service underwater infrastructure.

ROAR-E 1 is CURC's first fully-engineered ROV. ROAR-E 1 prioritises manoeuvrability, efficiency, and serviceability. Incorporated within a modular and streamlined frame, the ROV is equipped with six T100 thrusters, two Intel depth cameras, and x types of end-effectors.

The development of ROAR-E 1 is the culmination of seven months of intensive research, planning, and development by CURC's 13-person team. This technical document provides an insight into the engineering processes, principles, and challenges faced by CURC members throughout the creation of ROAR-E 1.


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*Waleed Khan and Naomi Toft not pictured.

Task	Need	Specification	Assigned Robot Component
1.1	Position a solar panel array amongst three floating wind turbines.	Grab one out of four vertical 1/2 in PVC pipes in order to position the central pipe within a triangular region.	Primary manipulator
1.1	Moor the panel array to three anchor points located on the bottom of the pool and attached to the PVC framework that holds the floating wind turbines.	Grab the PVC pipe profile of each mooring to lock a carabiner onto a U-bolt. Be able to recover the dropped anchor from any orientation and resume process.	Primary manipulator
1.1	Successfully removing the power port cover. Successfully removing the power port cover is defined as the cover no long in contact with any part of the power connector. The power port cover is considered debris.	Grab a 3 inch end cap and hold it until end of product demonstration without impeding completion of any other tasks.	Primary manipulator
1.1	Install the power connector over the power port.	Grab the PVC pipe profile of the power connector and position it over a smaller PVC profile. Be able to recover the dropped anchor from any orientation and resume process.	Primary manipulator
1.2	Companies must remove biofouling from the floating wind turbines. There will be two types of biofouling on the floating wind turbines: encrusting marine growth and algal marine growth.	Horizontally pull out a pipe cleaner loop from a PVC pipe, and separate a 1/2 in PVC cross that is attached by 1.0 x 0.8 cm Velcro pads to a PVC pipe segment. Be able to achieve these tasks despite potentially signifigant motion of PVC pipes during removal.	Primary manipulator
1.3	At the end of the product demonstration run, instead of returning to the surface, side of the pool companies must pilot their ROV into a "resident ROV" docking station.	Move the ROV in an 85x85x85 cm cubed region and push horizontally, ~3" a 1/2 in PVC end cap within vision of the front camera.	ROV frame
2.1	Companies must measure the dimensions of the coral and create a 3D model of the coral head.	Rotate a camera around an upside-down bowl to fully recostruct the bowl and several attached square pieces of white tape. If necessary features to assist with dimensioning bowl should be within view of the camera.	Bottom camera
2.2	Companies must first collect a water sample from inside a container.	Penetrate plastic cling wrap covering a 3/4 in PVC coupling and extract 50 mL of salty water, without collecting a significant amount of pool water.	Passive syringe-plunger actuating mechanism
2.3	Companies must irradiate a diseased area of the coral with simulated UV light.	Position on top of a 1 in PVC end cap a device that, when powered off, blocks external light from entering the end cap, and, when powered on, illumates the end cap.	Bottom-facing light with 3D-printed shroud
2.3	Companies must also place a tent over the coral head, insert a syringe into a port, and inject a "probiotic" fluid into the tent.	Position a tent, that has a rope attached to the top, over the upside-down bowl from Task 2.1, then inject pool water into the vertical opening of the tent.	Passive syringe-plunger actuating mechanism
2.4	Companies must compare two images to determine the recovery of a seagrass bed from an anchor scar	Stably position bottom camera above 20x20 cm square at bottom of pool until anchor scar changes are identified.	Bottom camera
2.4	Companies must install an Eco-Mooring system to the protect the seagrass and seahorse habitat.	Insert a 16x20 cm (width,depth) T-shaped PVC piece into a 15 cm long 2 in PVC pipe, then rotate the T-shaped piece 720 degrees along the long axis.	Continuous Rotation Manipulator
2.5	Companies must first search two potential sites for invasive predatory fish species to determine which site is safe for release.	Position the ROV on the bottom of the swimming pool and rotate the ROV 180 degrees such that the front-facing camera sees two sets of laminated images, in sequence, that are ~1 m horizontally from the center of the ROV in both directions.	Bottom camera
2.5	Companies must transport the fry to the safe release area.	Place a closed container in a targetlocation.	Passive cage
2.5	Companies must allow the fry time to acclimate to local conditions. Once the fry have acclimated to local conditions, companies must release the fry into the safe area.	After the closed container has been in the target location for 20 seconds, open the container to release the contents and then remove the container.	Passive cage
2.6	Companies must inspect a buoy rope for damage.	Complete a vertical profile at a controlled speed, distance, and orientation from a vertical axis such ten 9x7 cm rectangles are visible from a specific orientation. Orientations will not be consistent.	Front camera
2.6	Companies must also remove a heavy container from the bottom of the pool.	Grab a U-bolt attached to a container weighing no more than 120 N in water and return it to the surface, side of the pool.	Primary manipulator
2.7	Companies must fly a transect line over an area and count the number of frogs.	Complete a horizontal profile at a controlled speed, distance, and orientation from the bottom of the pool. Speed should be limited for identification of the number of frogs-attached-to-PVC-elbows. Distance and orientation should be limited by the bottom camera not viewing more than 65 cm from the centerline of the horizontal profile.	Bottom camera
2.7	Companies must install a long-term camera to monitor the giant frogs into a designated area.	Position a 20x20 cm PVC pipe assembly consisting of horizontal, vertical, and vertically slanted segments in a 40x40 cm region.	Primary manipulator

Table 1: Needs and specifications for product demonstration tasks.

Design Process

The following design process guided the design of components in ROAR-E 1 [1].

1. Problem Definition
2. Background Research
3. Requirement Specification
4. Concept Development
5. Concept Selection
6. Detail Design
7. Manufacturing, Testing, and Revision

For each component, the design process begins with a clear, and precise definition of the problem to be addressed. Then, background research is conducted on existing works. For product demonstration tasks, a needs and specification table was used to develop a clear list of design requirements. Concept development occurs over several group meetings, after which several concepts are generated. Pugh tables are used for concept selection. After concept selection, detail design begins and the design is iterated several times to improve manufacturability, safety, and reliability, while minimizing cost and weight. Commercial-off-the-shelf (COTS) parts are used in the design either when a part that could be manufactured in-house would fail to meet CURC's safety, reliability, and manufacturability standards, or when cost and weight are prohibitive.

Manufacturing and testing begins after the detail design is sufficiently developed, and design revisions are made as necessary.

Design Rationale

I. Frame

The frame protects critical components from impacts, and serves as a mounting point for electronics, thrusters, strain relief, buoyancy, and ballast.

The frame is constructed from commercial 6063 aluminium extrusion, commercial 6061 metal brackets, and 18-8 fasteners. Stock extrusion was purchased, then machined in-house.

The frame was chosen to be made from extrusion stock, as opposed to any plastic sheet stock. Plastic sheet-based designs require large cross-sections for rigidity which increase drag and reduce the maneuverability of the ROV. Moreover, using t-slot channels and hex bolts, components can be rapidly mounted and repositioned. 6063 aluminium was likely chosen by the manufacturer for ease of extrusion.

Commercial 6061 aluminium metal brackets were chosen as we, despite having manufacturing capabilities to machine the profile of brackets out of 6061 aluminium , an economical and strong aluminium alloy, do not have a machine for deburring large quantities of small metal pieces, such as a tumble deburring machine. As safety is a priority for CURC, we opted for commercial brackets. Commercial 18-8 fasteners were chosen for their optimal balance of cost, mechanical properties, and corrosion-resistance. 18-8 was chosen over

316 due to cost and consideration of the expected corrosivity during typical use.in swimming pool water. Based on prior experience with tear-out failure of bolts in extrusion t-slot channels during unexpected collisions, redundancy was incorporated into the design. With 5 fasteners per bracket, and 2 brackets per connection between extrusions, forces in typical use are reliably distributed across bolts, thereby minimising risk of tear-out failure during typical use.

Figure 1: Roar-E 1's frame.

Rigidity, strength, and impact resistance were considered as the frame must handle not only unexpected collisions, but also dynamic, multi-directional forces during typical use. Extrusions with identical lengths are machined simultaneously to improve manufacturing tolerances. As sideways drag forces are expected on the electronics enclosure, exact-grip-length flanged socket head screws are used on the extrusions connected to the enclosure.

II. Buoyancy

Devices for buoyancy affect the stability of the ROV and the behavior of the ROV when unpowered. Two commercially available 1 L water bottles were chosen to provide additional buoyancy, as the ROV was negatively buoyant without them. In anticipation of manufacturing non-idealities and due to a lack of material properties for COTS parts, buoyancy calculations were not performed.

With additional buoyancy and no ballast, the ROV is positively buoyant. To precisely determine the amount of ballast that is needed to achieve neutral buoyancy, which is desirable for enhanced maneuverability, the water bottles are temporarily filled with water until the ROV becomes neutrally buoyant, the mass of the water inside the bottles is determined, and a ballast of corresponding mass is placed inside the center, bottom of the enclosure.

The buoyancy is mounted on an X-frame, constructed out of 7075 aluminum for rigidity. The X-frame was machined in-house and can be rapidly re-positioned along the extrusion t-slot channels.

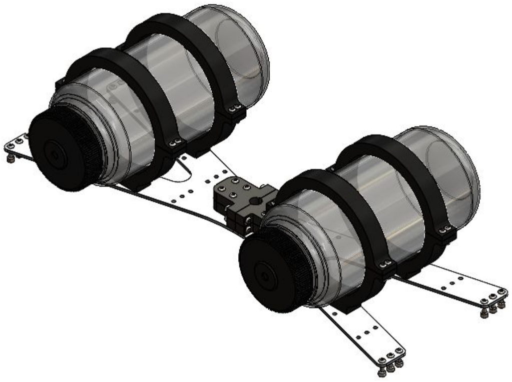


Figure 2: Roar-E 1's buoyancy.

The primary consideration for adding buoyancy is the stability of the ROV. The electronics enclosure is located near the center of mass of the ROV. As the electronics enclosure displaces a significant amount of water relative to the frame, the center of buoyancy is near the geometric center of the electronics enclosure. If the center of buoyancy is above the center of gravity, the conventional, tether-up orientation of the ROV is stable. When the ROV is misaligned from the vertical, "[t]he mismatch between the centers of mass and buoyancy … creates a moment of force, which tends to rotate the body towards a stable equilibrium" [2].

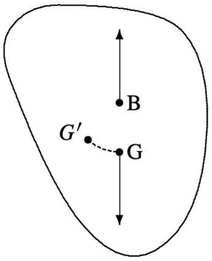


Figure 3: When unstable, a submerged body with center of buoyancy above the center of gravity produces a restoring moment [2].

It was experimentally determined that the ROV was stable without additional buoyancy. However, we determined that additional buoyancy and ballast were required to increase the stability of the ROV, particularly during interaction with product demonstration parts, unexpected collisions, and to counteract unwanted roll or pitch due to misalignments of the ROV's centre of thrust and mass.

III. Manipulators

Because servos are difficult to reliably waterproof, and because IP68 servos are not typically rated for use 4 m underwater, a COTS, depth-rated servo enclosure was chosen to enclose COTS servos for all active manipulators.

Through the use of a needs-metrics matrix, broken down by product demonstration tasks, it was determined that a manipulator capable of grabbing the profile of a vertically oriented ½" Schedule 40 PVC pipe, pinching small objects, and encircling rope loops would be sufficient for Tasks 1.1, 1.2, 2.3, 2.6, and 2.7. Passive, trigger-based mechanisms were utilized for Tasks 2.2 and 2.5, so as to allocate ROV power to other systems and not occupy the primary manipulator with objects that need to be returned to the surface. A continuous rotation mechanism was chosen for Task 2.4 to reliably and efficiently rotate the Eco-mooring.

All manipulators, active and passive, can be rapidly repositioned on ROAR-E 1's frame using t-slots channels on the frame.

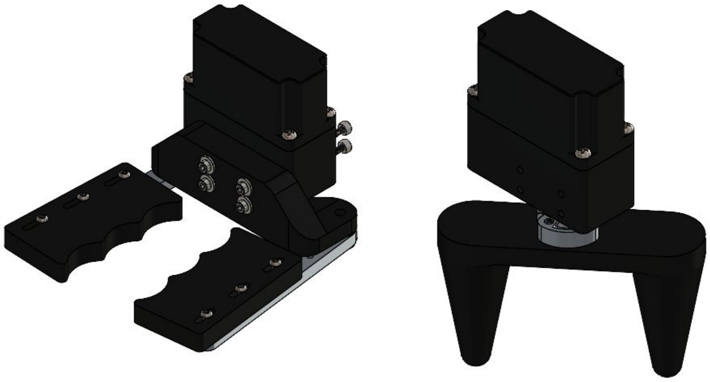


Figure 4: Primary manipulator and continuous rotation mechanism.

IV. Propulsion

ROAR-E 1 uses 6 legacy T100 thrusters in a vectored configuration, with 4 horizontal thrusters and 2 vertical thrusters. T100 thrusters were chosen over T200 thrusters after considering factors such as power consumption, maximum thrust, ease of manufacturing, and safe implementation IP20 thruster guards.

Vertical thrusters were positioned in the front and back of the ROV, enabling drivers to control the pitch of the ROV. Controlling the pitch of the ROV is critical, as some manipulator interactions with product demonstration props may generate significant moments of force about the pitch axis that need to be counteracted for proper control of the ROV.

Thrusters were configured to optimize for maximum thrust and maneuverability. Vertical thrusters generate the maximum rated thrust when moving ROAR-E 1 upwards. Horizontal thrusters are positioned along the symmetry plane of the ROAR-E's frame to minimize the distance between the center of thrust and the center of gravity. The central axes of the horizontal thrusters intersect. Counterclockwise and clockwise propellers are utilized on pairs of horizontal thrusters for optimal water flow and horizontal thruster pairs are oriented to maximize the pressure gradient [3].

IP20 thruster guards were created from COTS, 1018 steel computer fan guards, which were securely mounted to the T100 thruster using custom, form-fit 3D prints. COTS PC fan guards are safe and minimally affect the T100's fluid dynamics. To account for geometrical variance between publicly available T100 CAD models and 3D printing non-idealities, several iterations of the thruster guard mounts were made before converging on a final design..

To efficiently transmit thrust forces to the ROAR-E 1's frame, custom mounts were machined in-house for vertical and horizontal thrusters, optimizing for rigidity and form factor. A novel, 3-part mount was designed for the horizontal thrusters. Rather than rotate the vertical extrusions 45 degrees for a mounting surface, the custom mount positions the thrusters at the 45 degree angle with fewer components and increased reliability. These custom mounts were machined in-house out of 6061 aluminum bar stock to optimize for material properties, machinability, and cost.

To minimize risk of tear-out failure during typical use, motors mounts are not installed with bolts in t-slots, but rather bolts passed through the frame extrusion.

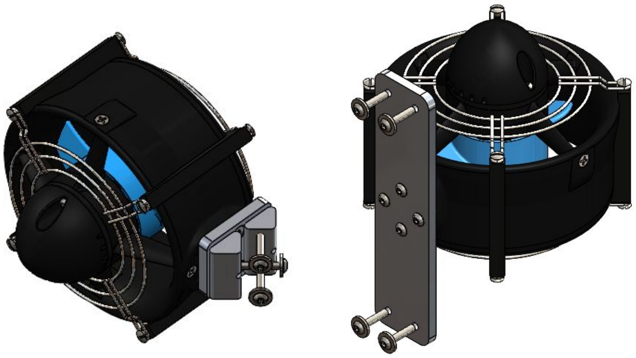


Figure 5: Horizontal and vertical thrusters.

V. Camera

D435i cameras give us the ability to accurately measure depth between 0.1 to 3 meters), orientation (roll and pitch), and capture point clouds that can be converted to meshes. Since the majority of the time, our ROV will be in the range of 0.1 to 3 meters from the bottom of the pool, D435i is the optimal camera choice. The front-facing camera is placed below the ROV to ensure proper anchoring of panel arrays.

Depth sensing capabilities are crucial for autonomous reconstruction of the coral head in task 2.1. A point cloud is extracted from ROAR-E 1's bottom-facing camera when positioned above the coral head, processed in MeshLab, and the imported into SolidWorks for dimensional analysis.

To ensure the ROV maintains a target height during 1.3 and 2.7.we use PID on the depth reading from the bottom D435i camera which measures the distance from the ROV to the bottom of the pool. Every time the driver activates the vertical thrusters, the target depth is updated. We then use PID to ensure the distance between the ROV and the bottom of the pool is maintained at the target depth. P (proportional) is the difference between the target depth and active depth reading which we call error; I (integral) is the sum of error over time which prevents steady state error; D (derivative) is the change in error between time t and time t-1 to prevent overshooting.

VI. Electronics Enclosure and Tether

Extensive research of both custom and COTS watertight enclosures lead to the selection of an COTS watertight enclosure with an IP68 rating. The body of this enclosure is manufactured using injection molding, a technique that cannot be done in-house. The cost and feasibility of of machining a reliable metal enclosure in-house was considered when deciding to purchase a COTS enclosure. The enclosure on used on ROAR-E 1 was selected for its durable construction, robust mounting points both on the inside and outside, and for the robust face-sealing o-ring used for waterproofing. As the enclosure is only depth rated for 2 m, tests were conducted at 4 m to verify the viability of the enclosure during typical use.

The tether consists of a fiber optic USB cable, HDMI cable, and two 12 AWG marine grade cables in a corrosion-resistant jacket that also serves to minimize corkscrewing of the power wires. The cables are passed through a COTS, flexible, and expandable polyamide sleeve that selected expand slightly to form a snug fit around the cables. Custom buoyancy made from COTS, hollow, and incompressible ABS spheres is attached at discrete intervals along the length of the tether, achieving a slight positive buoyancy along the majority of the tether, except for directly above the ROV, ensuring the tether is neutrally buoyant while minimizing risk of entanglement.

The tether passes through multiple COTS cable glands on the top and sides of the electronics enclosure. These cable glands were tested by the manufacturer to individually withstand not only over 50 psi over several hours, but also 16 kg strain without cable slippage. Moreover, the powered cables pass through an custom strain relief clamp that is integrated with the buoyancy frame for redundancy. This strain relief clamp is mounted to the top of ROAR-E 1's frame, and the strain is distributed across 12 bolts to minimize risk of tear out failure.

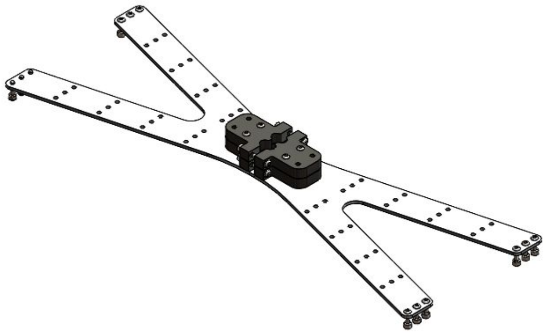


Figure 6: Integrated strain relief clamp.

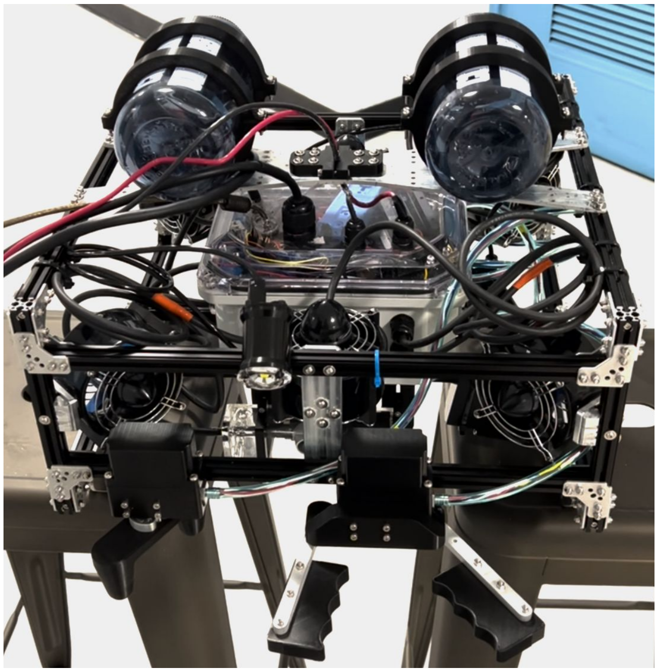
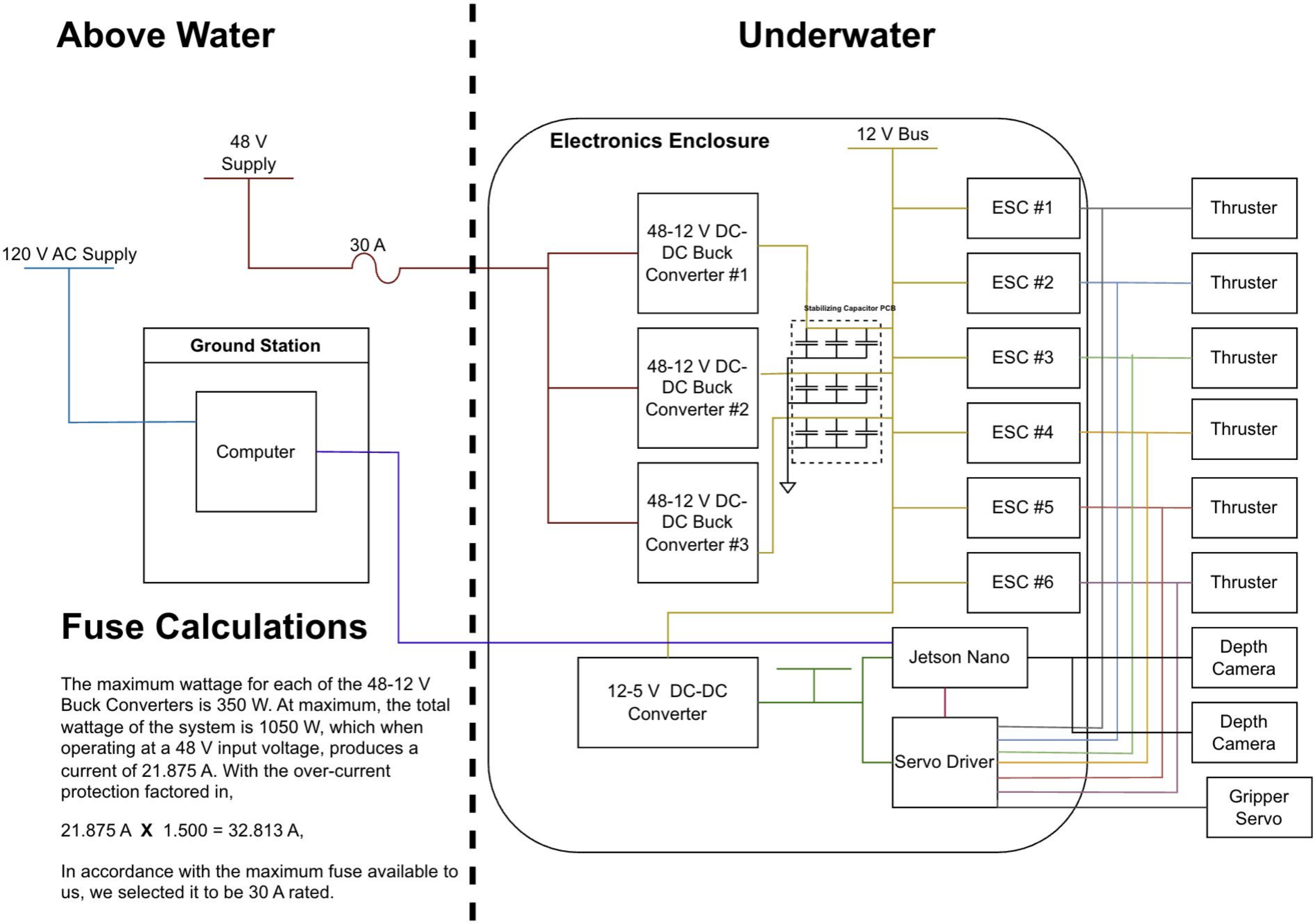


Figure 7: ROAR-E 1, assembled.

VII. Electronics Systems

Three 120 V AC to 16 V DC transformers are connected to produce 48 V DC at up to 30 A, which is then passed through the tether to three PAH350S48-12 DC-DC converters from TDK Lambda, each capable of supplying 12 V DC at a maximum of 25 A, corresponding to 350 W. These converters have a half-brick profile, Over Current Protection (OCP), Over Voltage Protection (OVP), and Over Temperature Protection (OTP). They do not have a minimum required load, and are rated for harsh environments. Capacitors are added to the output of the buck converters in order to reduce OVP-triggering spike voltages that are generated when thruster power is rapidly changed. As the maximum wattage from the converters is 1050 W, the 30 A fuse on the 48 V tether will not blow during typical operation of ROAR-E 1. At any time, there will be up to 4 thrusters running at full power (11.5 A each), 2 lumen lights be dimmed to 50% (7.5 A each), 2 cameras (1 A each), and a Jetson (2 A). As all of these devices operate at 12 V, the electronics may draw up to 780 W at maximum operation, or 87 % of the total power that can be supplied by the converters.

An onboard Jetson Nano is used to control ROAR-E 1's thrusters, manipulators, and lights and receives data from cameras. A 12 V to 5 V converter is used to provide Pulse-Width Modulation (PWM) signals to lights and thrusters.



Fuse Calculations

The maximum wattage for each of the 48-12 V Buck Converters is 350 W. At maximum, the total wattage of the system is 1050 W, which when operating at a 48 V input voltage, produces a current of 21.875 A. With the over-current protection factored in,

21.875 A **X** 1.500 = 32.813 A,

In accordance with the maximum fuse available to us, we selected it to be 30 A rated.

Figure 8: Electronics SID.

VIII. Control Station

The control station consists of a display, controllers, and strain relief as ROAR-E 1 uses an onboard Jetson Nano..

The strain relief on the control station is adapted from a common, commercially available mechanism: a tether cable thimble [4]. When a cable is securely fastened around a thimble, strain is transferred to the thimble. Custom tether cable thimbles were designed based on the minimum bend radii of the cables used. The thimbles are secured on a custom anchoring feature on the control station,, consisting of a shoulder bolt mounted between 3D-printed clamps.

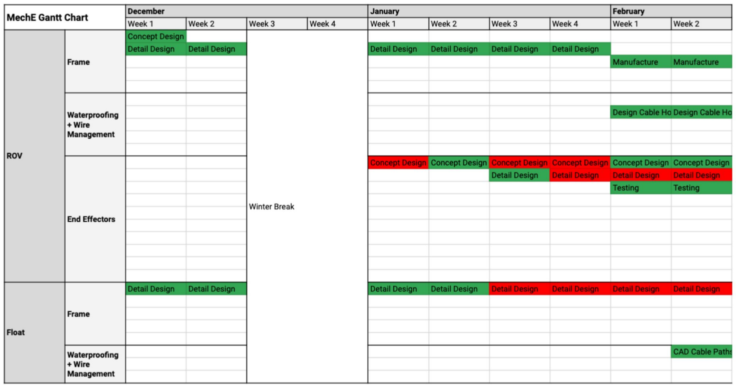
Figure 9: Control Station strain relief.

IX. Control Dashboard

The control dashboards left side displays all readings that are not mission specific and the right side displays mission specific controls. The right side displays the depth, orientation (similar to an altitude indicator), the thruster values from controller input, and light values from controller input. The depth display uses the depth sensor of the D435i camera and the orientation display uses the normal vector relative to gravity from the IMU of the D435i. The left side displays the "mode" the ROV is in where each "mode" corresponds to certain tasks. Such design prevents any unintended controller input as each "mode" limits the functionality of the controller. If a task requires any sort of image capture, the captured image will be displayed at the bottom right of the dashboard.

Logistics

Meetings are organized by mechanical, software, and electrical subteams,scheduled to accommodate as many team members as possible, and occur both periodically on an ad-hoc basis. Meeting agenda are guided by Gantt charts created by the CTO. The CTO reviews and tracks meeting progress, and updates Gantt charts.

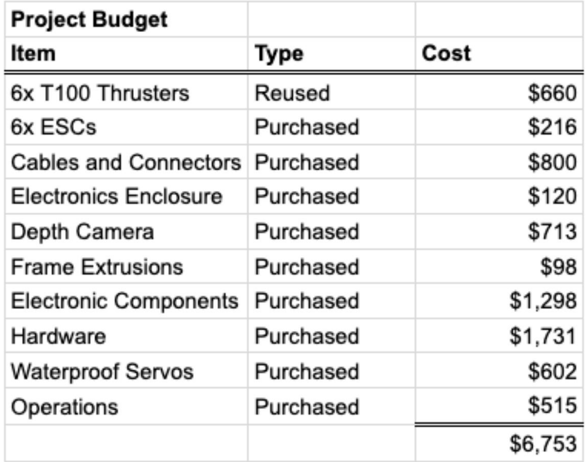


MechE Gantt Chart		December				January				February	
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2
ROV	Frame	Concept Design									
		Detail Design	Detail Design			Detail Design	Detail Design	Detail Design	Detail Design		
										Manufacture	Manufacture
	Waterproofing + Wire Management									Design Cable Ho	Design Cable Ho
	End Effectors			Winter Break		Concept Design	Concept Design	Concept Design	Concept Design	Concept Design	Concept Design
								Detail Design	Detail Design	Detail Design	Detail Design
										Testing	Testing
Float	Frame	Detail Design	Detail Design			Detail Design	Detail Design	Detail Design	Detail Design	Detail Design	Detail Design
	Waterproofing + Wire Management										CAD Cable Path

Table 2: A Gantt chart used by the mechanical team.

Budget and Spending

At the beginning of the semester, a budget is proposed to the treasurer overseeing CURC's budget for MATE ROV, other competitions, and club events. The proposed budget for MATE ROV is constrained by the budget allocated by the school to CURC as an entire club. MATE ROV expenses are tracked, by subteam, through a detailed form required to receive school reimbursement.



Project Budget		
Item	**Type**	**Cost**
6x T100 Thrusters	Reused	$660
6x ESCs	Purchased	$216
Cables and Connectors	Purchased	$800
Electronics Enclosure	Purchased	$120
Depth Camera	Purchased	$713
Frame Extrusions	Purchased	$98
Electronic Components	Purchased	$1,298
Hardware	Purchased	$1,731
Waterproof Servos	Purchased	$602
Operations	Purchased	$515
		$6,753

Table 3: Project budget.

Safety

CURC is committed to following safety procedures and guidelines in the workshop, while operating machinery and the ROV, and in the design of the ROV's mechanics and electronics.

In-house machining is conducted in the Mechanical Teaching Laboratory, which is always supervised by lab staff and when machinery is in use. In CURC, machining is done by team members who have taken a machining course or have received training from lab staff. CURC members must take an official safety training course before using any machines in the laboratory. CURC members do not train other members on machines for safety and liability reasons. Machining is never done alone, safety glasses are always worn in the machining area, loose hair and clothing are secured, close toed shoes are worn, and machining is done with lab-recommended feeds and speeds. Additive manufacturing requests are submitted to lab staff who are responsible for safely using and maintaining 3D printers.Safety glasses are worn when soldering or handling capacitive electronics, and capacitors are discharged before handling.

On-Site Procedures

I. Pre-Power

1. Clean immediate area
2. Verify power is off
3. Inspect enclosure for damage
4. Inspect witness marks on cable glands and penetrators to check for loosening
5. Inspect and verify integrity of tether
6. Inspect and verify integrity of surface-side electrical connections
7. Clear immediate area of tripping and slipping hazards, obstacles, etc.

II. Power-Up

1. Safety Officer announces "Power-Up!"
2. Safety Officer turns on power source
    a. Note that anybody can turn off the power source

3. Listen for auditory confirmation that thruster ESCs are powered
4. Look for visual indication that onboard electronics are operational
5. Test functionality of manipulators, thrusters, cameras, and lights

III. Launch

1. Safety Officer announces “Launch!”
2. Safety Officer deploys the ROV
    a. Note that anybody can say “Abort!”, after which the power is immediately turned off and the deployment is cancelled

I. In-Water

1. 15. Look for unusual amounts of air bubbles or any atypical visual behavior
2. Look for visual indication that onboard electronics are operational
3. If entanglement with product demonstration prop suspected, slowly descend ROV

I. Retrieval

1. Look for unusual amounts of air bubbles or any atypical visual behavior
2. Look for visual indication that onboard electronics are operational
3. Safety Officer announces “Retrieval!”
4. Anybody turns off the power source
5. Safety Officer removes ROV

Technical Challenges

Among others, the team was faced with two major technical challenges. The first issue became apparent during the initial testing of the thrusters. We discovered that while the thrusters could run at full speed, once we switched them off or when directionality was rapidly changed, the Overvoltage Protection (OVP) function on our converters would trigger, leading to a power loss that required “[recovery] turning [the] input line off and then turning it on again” [5]. This was a surprise and took many tests and consultations to come to a conclusion because previous, lower-quality converters used by the team had effectively managed the changes in thruster power. We solved the problem by adding appropriately rated capacitors, noting that increases in capacitance enabled the converters to handle larger changes in power. We are looking into better-suited converters with OVP autorecovery features.

The waterproofing challenge was due to the HDMI and USB cables that communicate between the onboard Jetson Nano and the surface control station. Although the cable glands we intended to use could accommodate the cables, the connector ends were too large to pass through. Our initial plan was to splice the cables in order to get the cable gland through; this proved to be a delicate, time-consuming process that did not go right the first few tries. We decided to use epoxy and laser-cut acrylic to make custom cable pass-throughs.

Non-Technical Challenges

Retention of team members has been a challenge due to their status as students, juggling classes and various extracurricular commitments. The demanding midterm and finals seasons severely limited the time available for project work, and by the beginning of May, members were moving off campus to return home or start their internships. This resulted in a handful of team members cramming to finish the ROV during the last few weeks before the deadline. Moreover, many team members are not located in New York, limiting in-person meetings between semesters. The most critical challenge jeopardizing CURC's qualification for the world championships was securing a suitable site to record the qualifying video. Despite submitting a request in advance to utilize Columbia University's Dodge Fitness Center pool, the team encountered unanticipated delays in receiving approval to test ROAR-E 1. Other facilities in New York were either unsuitable or unwilling to accommodate our needs, due to factors such as safety and permit requirements. A team member bought an above-ground pool, but was told there was no place on campus we were authorized to set it up. Eventually, the pool was set up at the team member's home.

Future Improvements

Mechanically, on ROAR-E 2 we would like to focus more on the design and manufacturing of custom manipulators, now that a robust frame has been designed for ROAR-E 1. Electrically, we would like to identify and implement more robust DC-DC converters that have autorecovery after OVP is triggered. We would also like to design custom PCBs to increase the reliability and reduce the profile of the electronics used throughout ROAR-E 2. Programmatically, we may consider using ROS if it is determined that having a more compartmentalized software architecture is beneficial. As a team, we will also reflect on ways to increase member retention, attract new talent, and increase knowledge transfer.

References

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