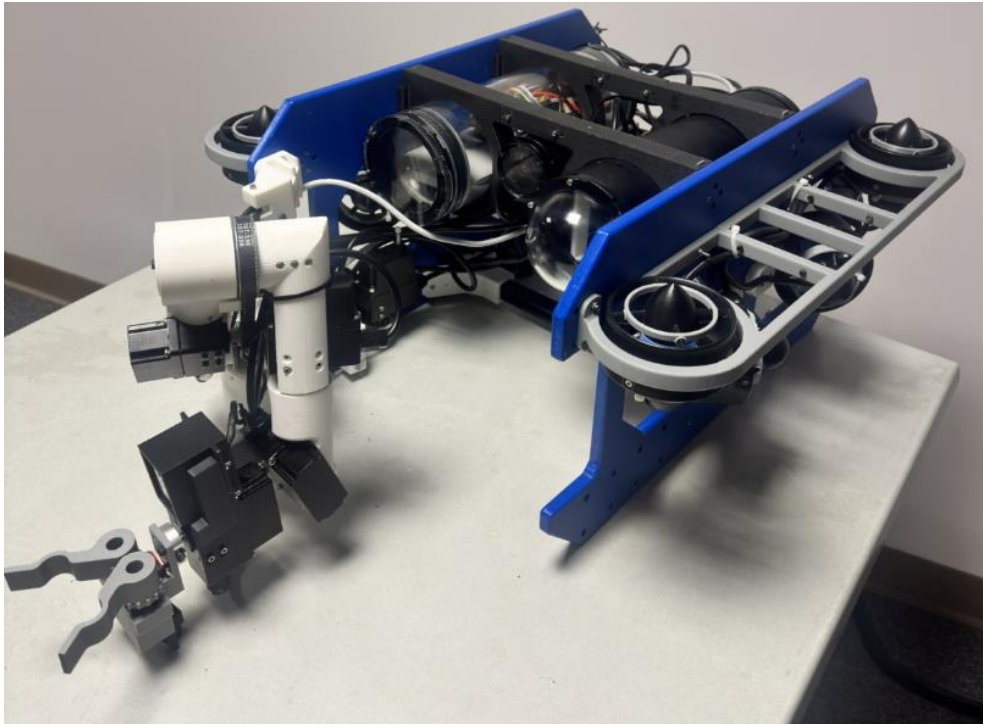


2026 Technical Documentation

Dreadyacht

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Table of Contents

- 1.0 Abstract
- 2.0 Teamwork
- 3.0 Design Rationale
- 4.0 Vehicle Structure and Buoyancy
- 5.0 Control and Electrical Systems
- 6.0 Custom Power Management PCB
- 7.0 Software Controls
- 8.0 Propulsion
- 9.0 Payload and Tools
- 10.0 Six-Axis Robot Arm
- 11.0 Build vs. Buy, New vs. Used
- 12.0 System Integration Diagram
- 13.0 Safety
- 14.0 Accounting
- 15.0 Acknowledgements and References

1.0 Abstract

Underwater Robotics UConn (URUC) is an undergraduate-led robotics team that designs, manufactures, tests, and operates remotely operated vehicles for the MATE ROV Competition. For the 2026 season, URUC developed Dreadyacht, an Explorer-class ROV designed for high maneuverability, precise manipulation, and robust electrical integration. Dreadyacht uses eight Blue Robotics T200 thrusters, a custom 2.2 kW power management PCB, dual electronics enclosures, a cleanly managed tether, dual camera views, mission-specific static tools, and a six-axis robotic arm. The vehicle was designed around the 2026 mission requirements for coral collection and imaging, subsea observatory service, iceberg/green-crab data tasks, buoy and lobster-pot recovery, wind-to-platform power connection, and float profiling. URUC used concurrent engineering, CAD integration, bench testing, and pool testing to develop a compact vehicle that emphasizes controlled high-power delivery, operator visibility, modular tool changes, and repeatable safety procedures.

2.0 Teamwork

2.1 Project Management

URUC operates as a student company organized around an executive board, technical leads, and project teams. The leadership structure keeps ownership clear while allowing newer members to contribute to mechanical,

electrical, software, business, operations, and documentation work. Technical leads guide subsystem decisions, while the executive board manages schedule, resources, safety, integration, and external representation.

Position	Primary responsibility
President	Sets technical direction, coordinates leads, manages long-term goals, and represents the team.
Vice President	Coordinates integration between subteams and supports schedule execution.
Treasurer / Business Lead	Tracks funding, purchasing, sponsorships, travel planning, and cost accounting.
Secretary / Documentation	Records technical progress and organizes report material.
Safety Officer	Maintains safe shop behavior, PPE use, and deployment procedure discipline.
Technical Leads	Guide design and build work within frame, electrical, software, manipulator, and float projects.
Employees	Work in project teams, prototype parts, test subsystems, and support competition operations.

Table 2.1 URUC personnel structure and responsibilities.

2.2 Schedule and Communication

URUC planned development around the MATE competition schedule, moving through concepts, onboarding, prototype development, integration, pool testing, and competition preparation. The schedule was treated as flexible because integration problems are expected in building a high-performance ROV.

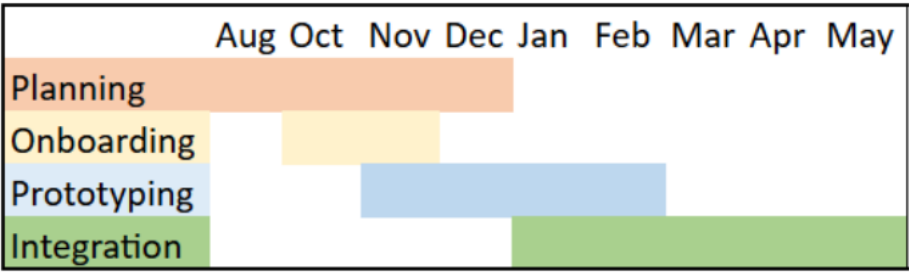


Table 2.2 URUC development schedule

Team resources were centralized through various platforms that all support cloud development and collaboration. Microsoft SharePoint for files and documentation, Freedcamp for task tracking, GroupMe for fast communication, Onshape for CAD, and GitHub for software. URUC also used a 15-minute cleanup and documentation protocol at the end of meetings: members returned tools, cleaned work areas, and submitted a short form describing their work. This supported the company philosophy of Kaizen, or continuous improvement through small, repeatable process changes.

3.0 Design Rationale

3.1 Planning and Design Process

Dreadyacht was developed through a concurrent engineering process. Instead of designing each subsystem separately and forcing integration at the end, the mechanical, electrical, software, and manipulation teams worked in parallel around a shared CAD model and common mission requirements. This reduced late-stage interference between the frame, thrusters, electronics enclosures, tether, cameras, and robotic arm.

3.2 Systems Approach

URUC used the MATE RFP as the starting point for all major vehicle decisions. The final vehicle layout was shaped by systems-level decisions: the arm required forward workspace, the cameras required unobstructed views, the thrusters required clean flow paths, and the electronics needed to remain serviceable inside the tubes. This approach drove the design of the custom power board. Instead of choosing a generic buck converter and wiring around it, the team designed the PCB around the vehicle model: four 14 V propulsion channels each pair one horizontal and one vertical thruster load, while a fifth 7.4 V channel powers arm servos and logic systems. This matched the electrical architecture to realistic maneuvering rather than only theoretical maximum current.

4.0 Vehicle Structure and Buoyancy

4.1 Frame

Dreadyacht's frame is optimized for the MATE 2026 competition. The dual HDPE plates are light, inexpensive, and strong, and houses internal wiring and waterproof enclosures. The ROV features an 8-thruster layout providing robust control and thrust in all 6-axis of motion. Custom thruster guards and mounts for watertight electrical enclosures were designed using the Onshape CAD software and printed them in PLA with 35% infill to have a suitable strength to weight ratio. The extra holes in the HDPE on either side of the frame are an intentional design choice to allow for modular attachments and iteration. To keep the frame rigidly fastened, we designed custom 3D Printed mounts to hold aluminum extrusions across the frame. With each piece held at a fixed 354mm distance apart, these aluminum extrusions also double as mounting points for other components on the ROV.

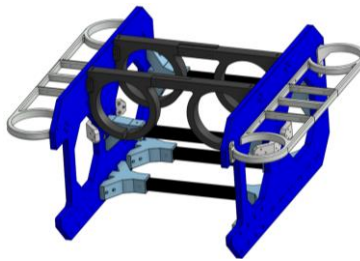


Figure 4.1 Frame outline without other components

4.2 Buoyancy and Ballast

The vehicle was balanced to operate close to neutral buoyancy with a slight preference toward predictable recovery. The electronics tubes and frame volume provide baseline buoyancy, while ballast can be adjusted after tool changes or arm configuration changes. This was important because the long manipulator and tether can shift the center of mass and center of buoyancy during operation. Ballast adjustments were therefore treated as part of the final integration process rather than as a one-time calculation.

The tether was also designed around neutral buoyancy. Two 18.3 m power conductors and the data line were routed through a reinforced protective hose selected to offset the wire mass with displaced water volume. This reduces the tether drag on the ROV and prevents the tether from pulling the vehicle during precision tasks.

5.0 Control and Electrical Systems

5.1 Electronic Design and Cabling

Dreadyacht separates electronics into a power conversion enclosure and a control enclosure. The surface system provides 48 V power and Ethernet through the tether. Inside the vehicle, the custom power PCB distributes regulated power to ESCs, thrusters, arm servos, and logic systems. The control tube contains the LattePanda 3 Delta, Pixhawk flight controller, depth sensor interface, camera links, and servo control path. This separation improves packaging and reduces the chance that high-current propulsion wiring interferes with sensitive control electronics.

The full electrical system integration diagram is included in Section 11.0 to keep the electronic design section focused on design rationale and subsystem choices.

5.2 Tether

The tether carries 48 V power and Ethernet communication between the surface station and the ROV. The power conductors use 10 AWG copper wire to reduce voltage drop while keeping the tether flexible enough for pool operation. The 18.3 m tether creates a 36.6 m round-trip conductor path for DC power. Under a 30 A load, the selected wire limits voltage drop and tether heating while remaining manageable for the tether tender.

Mechanical strain relief is used on both the surface and vehicle sides so tensile loads are transferred into clamps and frame members rather than into penetrators or solder joints. The tether is routed through a custom clamping assembly that compresses the reinforced outer sheath without crushing internal wires.

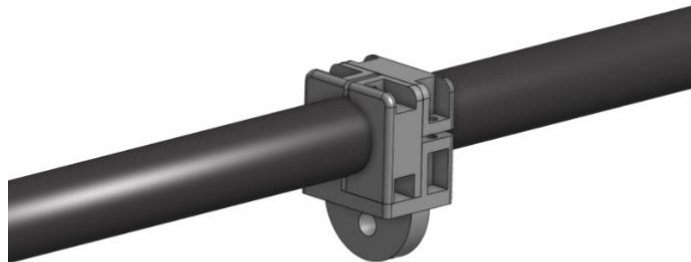


Figure 5.2 Custom tether strain-relief clamp designed to transfer tether loads into the frame rather than the penetrators.

5.3 Tether Management Protocol

1. Assign one team member as the tether tender for the full run.
2. Lay out the tether in a clear figure-eight pattern before deployment.
3. Verify surface strain relief, vehicle strain relief, power, and Ethernet connections.
4. Maintain enough slack for motion without allowing loops near props or task structures.
5. Prevent personnel from stepping on the tether or dragging it across sharp edges.
6. After recovery, disconnect power first, then data, and coil the tether carefully.

5.4 Cameras and Penetrators

Dreadyacht uses a dual-camera system to give the pilot both navigation awareness and close-up manipulator visibility. The main frame camera is housed in a serviceable PVC enclosure with acrylic viewports and O-ring flanges. It provides the primary forward view for vehicle driving. A second camera is mounted near the arm to give a close view of the end effector during fine manipulation. Because the arm camera must remain compact, it uses a potted design with a small acrylic viewport rather than a large air-filled enclosure.

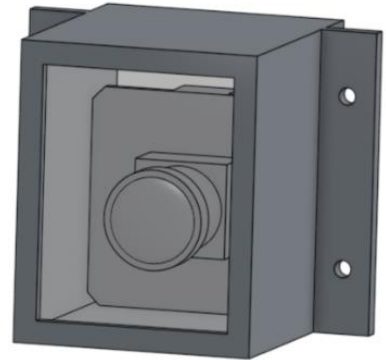


Figure 5.4 Camera housings. The main frame camera uses a serviceable O-ring enclosure, while the arm camera uses a compact potted housing for manipulator visibility.

Cable penetrations were minimized and organized by enclosure. The design goal was to keep high-current wiring in the power enclosure and sensitive control wiring in the logic enclosure. All penetrator paths were routed to avoid tight bends, pinched wires, and unsupported loads during tube closing.

6.0 Custom Power Management PCB

Dreadyacht's custom power management PCB was developed to solve one of the vehicle's main electrical problems: distributing high-current power to an eight-thruster ROV in a compact, serviceable way that matches how the vehicle moves. The board converts the 48 V tether input into four 14 V propulsion channels and one 7.4 V

auxiliary channel. A commercial converter was considered, but many off-the-shelf options were bulky, fixed at 12 V instead of the desired 14 V thruster voltage, difficult to fit inside the electronics tube, or required separate waterproofing outside the pressure enclosure. Designing the board in-house allowed URUC to control output voltage, connector placement, serviceability, and packaging.

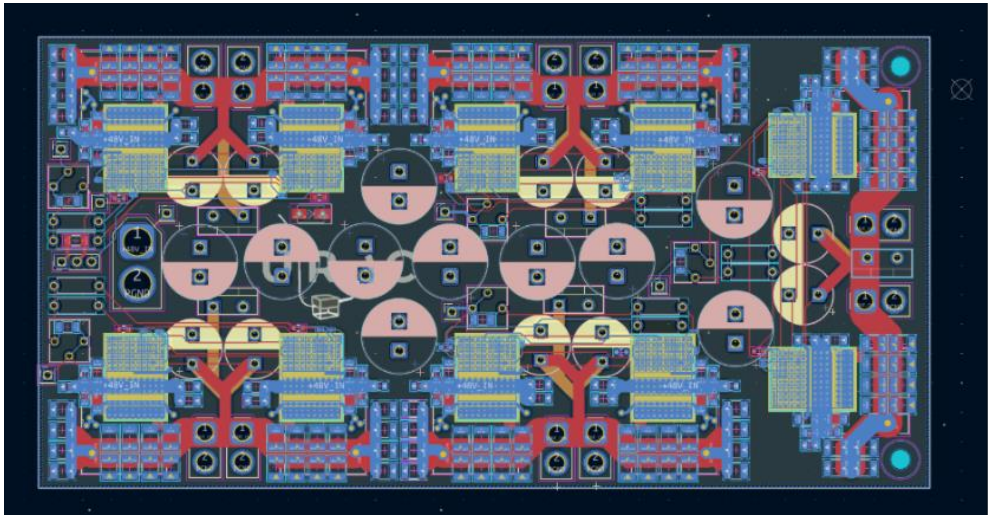


Figure 6.0 PCB footprint and routing model designed in KiCad before assembly.

6.1 Channel Architecture

The PCB uses five independent output channels. Each channel is built from two Vicor PI3526 buck regulator modules connected in parallel. This allows each channel to pool current capacity while spreading heat across a larger area of the board. Four channels are used for propulsion. Each propulsion channel powers one 45-degree horizontal thruster and one vertical thruster. This spreads realistic combined-axis loads across the board rather than creating a single overloaded horizontal rail and a single overloaded vertical rail. The fifth channel is trimmed to 7.4 V for the robotic arm servos and logic tube power path.

Channel	Output	Loads	Design reason
1	14 V	Horizontal thruster + vertical thruster	Mixed-axis propulsion load sharing
2	14 V	Horizontal thruster + vertical thruster	Mixed-axis propulsion load sharing
3	14 V	Horizontal thruster + vertical thruster	Mixed-axis propulsion load sharing
4	14 V	Horizontal thruster + vertical thruster	Mixed-axis propulsion load sharing
5	7.4 V	Arm servos + logic power	Isolated auxiliary power

Table 6.1 PCB channel allocation strategy.

6.2 Layout and Serviceability

The physical layout was built around repeated channel blocks. Each channel contains two Vicor modules, local ceramic and electrolytic capacitance, voltage trim circuitry, and output connectors. This repeated layout made the board easier to inspect because one channel could be compared directly against the others during assembly and testing. High-current paths were kept short and direct where possible. Bulk capacitors were placed near the regulator channels to reduce voltage ripple during load changes, while smaller ceramic capacitors were used for high-frequency filtering. XT60 and XT30 connectors were chosen because they are compact, keyed, mechanically secure, and easy to inspect. Compared with screw terminals or loose splices, these connectors made the system easier to assemble and troubleshoot at competition. The board also had to balance current capacity with manufacturability. A very heavy-copper design would improve current handling, but it also increases routing constraints and makes dense areas around the Vicor modules harder to manufacture. The final layout balanced current capacity, compact size, and manufacturability while keeping the board small enough to fit inside the electronics tube.

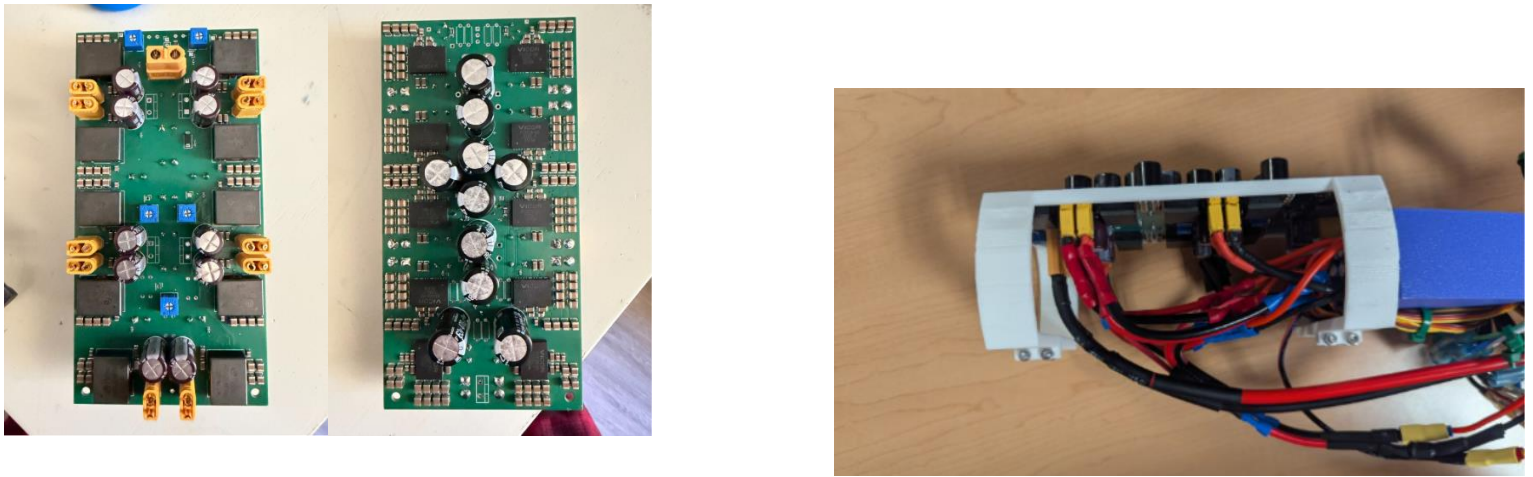
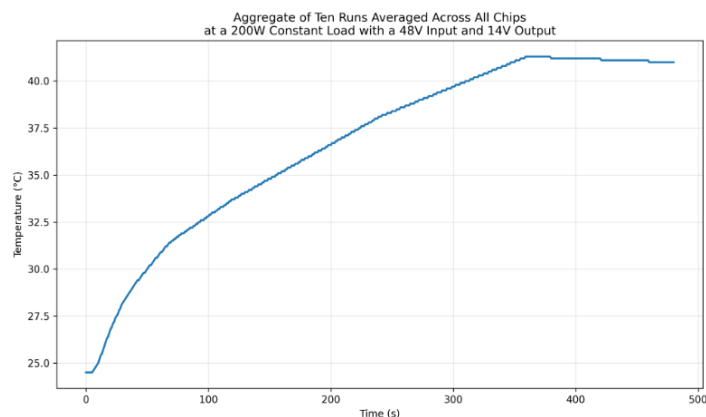


Figure 6.2 Assembled PCB top side, bottom side, and power tube assembly

The physical layout was built around repeated channel blocks. Each channel contains two Vicor modules, local ceramic and electrolytic capacitance, voltage trim circuitry, and output connectors. XT60 and XT30 connectors were chosen because they are compact, keyed, mechanically secure, and easy to inspect. Compared with screw terminals or loose splices, these connectors made the system easier to assemble and troubleshoot at competition.

6.3 Thermal Testing

Thermal testing was performed at 48 V input and 14 V output under a 200 W constant load. The averaged chip temperature rose from room temperature to just



over 40 degrees C before leveling off, showing controlled thermal behavior during sustained bench testing while still confirming that higher-power thruster tests require monitoring.

Figure 6.3 Thermal test at 200 W constant load. Averaged chip temperature stabilized near 41 degrees C.

7.0 Software Controls

The software control system uses a wired connection between the surface laptop and an onboard LattePanda 3 Delta running Ubuntu 22.04/22.05. The surface laptop provides the operator interface, while the onboard computer communicates with the Pixhawk flight controller, cameras, sensors, and arm control system. QGroundControl is used for vehicle driving and camera display because it provides a reliable interface to the Pixhawk/ArduSub control stack and reduces the amount of custom code required for basic vehicle motion.

Python bridges are used to integrate additional devices and task-specific functions. The software team chose Python because it is familiar to the team, fast to develop, and well-supported for robotics, image processing, and hardware communication. For the 3-D imaging task, the surface station runs COLMAP, an open-source photogrammetry package that can reconstruct 3-D geometry from overlapping images. COLMAP was selected because it is command-line friendly on Ubuntu and can run efficiently on limited surface-station time.

For the European green crab identification task, the team trained a YOLO object detection model using official MATE resource images. YOLO was selected because it performs object detection in a single pass, making it appropriate for a small, focused dataset and real-time operator support. The model outputs bounding boxes around detected crabs to help the pilot identify targets quickly and consistently.

The arm is manually controlled through a master arm pendant rather than autonomous inverse kinematics. Each pendant joint maps to the corresponding underwater arm joint, and software limits prevent commands outside the physical range of the servos. This approach reduces software complexity while keeping control intuitive for the operator.

8.0 Propulsion

Dreadyacht uses eight Blue Robotics T200 thrusters. The T200s were selected because they provide strong thrust for their cost and are widely used in student and commercial ROV systems. Four thrusters are mounted at 45 degrees for horizontal translation and yaw, and four thrusters are mounted vertically for depth control and resurfacing.

Each thruster operates at approximately 14 V with a maximum current draw of 20.7 A, creating a theoretical maximum propulsion draw of approximately 2.32 kW if all eight thrusters were commanded to full output simultaneously. The vehicle is not designed to run all thrusters at full command continuously. Instead, the control strategy limits sustained output, while the power system provides headroom for short-duration maneuvering.

Full forward throttle produces approximately 44.2 N of thrust per T200, while reverse produces approximately 34.5 N. With four horizontal thrusters mounted at 45 degrees, the vehicle produces approximately 111.3 N of horizontal force in any direction. The four vertical thrusters provide approximately 176.8 N upward and 138 N downward. This makes the vehicle fast enough to move between task areas and strong enough to resurface with game pieces or return for tool changes.

The horizontal thruster placement evolved during design. Corner-mounted thrusters gave strong turning authority but increased the ROV footprint and exposed the thrusters to task props. Moving the thrusters inward and aligning them with frame cutouts protected the thrusters, reduced turbulence with vertical thrust vectors, and improved control near delicate mission objects. Ring-style thruster guards were used because they protect the propellers without blocking flow as much as mesh guards.

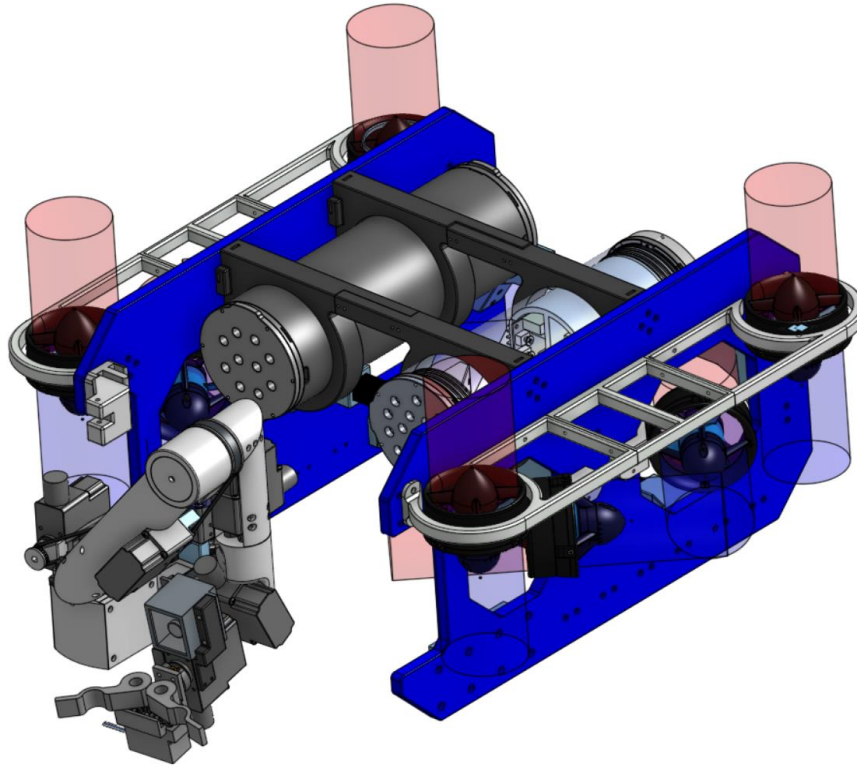


Figure 8.0 Visualization of hydrodynamic flow from thrusters

9.0 Payload and Tools

9.1 Modular Manipulator Interface

Dreadyacht uses a modular interface for static task tools. Dynamic motion is handled by the six-axis arm, while task-specific static tools support carrying, holding, or releasing mission objects. This avoids redesigning the entire manipulator for every task and allows the team to swap tools between runs.



Figure 9.1 Static task tools: basket-style payload carrier and spool-holder concept for buoy-anchor recovery.

Tool	Purpose	Mission use
Basket	Holds collected coral species and basket stars together	Task 1.1 collection and transport
Spool holder	Carries a line that can deploy after attaching to the buoy anchor	Buoy anchor recovery
Sonar mount	Provides an interface for the MATE-provided imaging sonar	Bonus imaging task
Arm claw	Grips pipes, hooks, coral, and task objects using a geared claw	General manipulation

Table 5. Task tools and their mission roles.

9.2 Claw Mechanism

The primary claw uses 3-D printed components, a geared symmetrical closing mechanism, and a continuous-rotation wrist yaw joint. One claw half is driven directly by the servo output while the second side follows through the gear train. A dual-bearing secondary shaft reduces radial loading and improves smoothness. The inner claw profile includes flat contact areas for thin objects and a circular cutout sized for small PVC features used in task props. Waterproof adhesive sandpaper was added to the contact surfaces to improve grip on smooth plastic and metal objects.

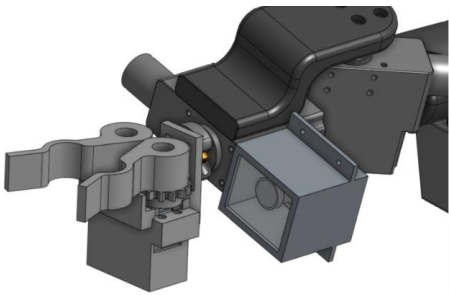


Figure 9.2 Claw and wrist mechanism designed for symmetric gripping and continuous wrist rotation.

10.0 Six-Axis Robot Arm

The 2026 MATE ROV competition contains many manipulation-focused mission tasks, many of which require the vehicle to interact with objects from specific angles. Due to the complexity of these manipulation tasks, the team determined that a multi-axis robotic manipulator would provide a significant increase in scoring capability despite the added complexity introduced to the ROV.

While simpler manipulator systems offer reduced weight and complexity, they lack the dexterity required to reliably complete the mission objectives as fast as possible. Additionally, the team found the integration complexity of more axes to be linear, as support for one subsea actuator enables support for more with relative ease. As a result, the team selected a 6-degree-of-freedom robotic arm capable of arbitrary end-effector positioning and orientation.

The arm was designed with the following goals in mind:

- Dexterity to complete all manipulation tasks
- Minimize drag and effect on stability
- Compact packaging within the vehicle frame
- High reliability in an underwater environment
- Low-cost manufacturability
- Intuitive manual control for the operator

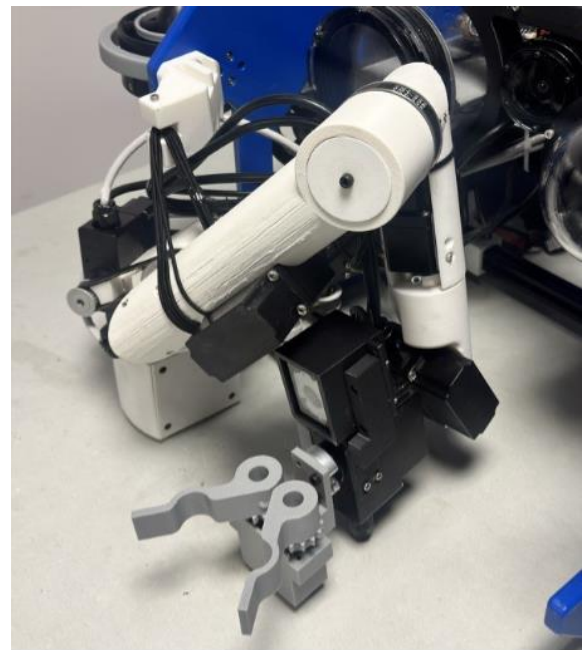
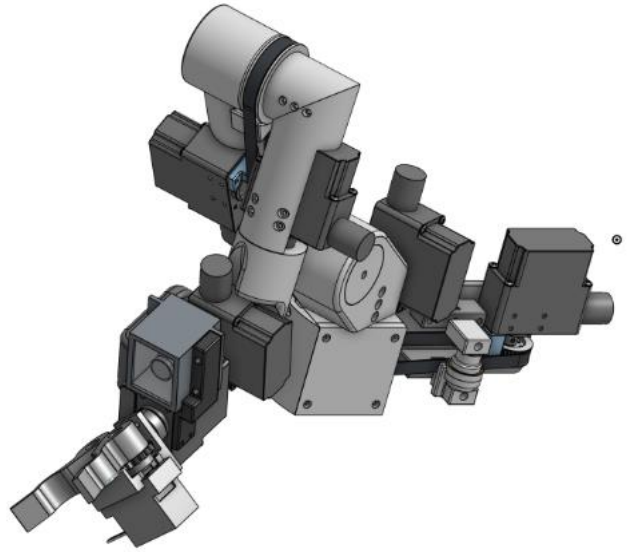


Figure 10.0 CAD rendering of the arm (top) and in folded position (bottom)

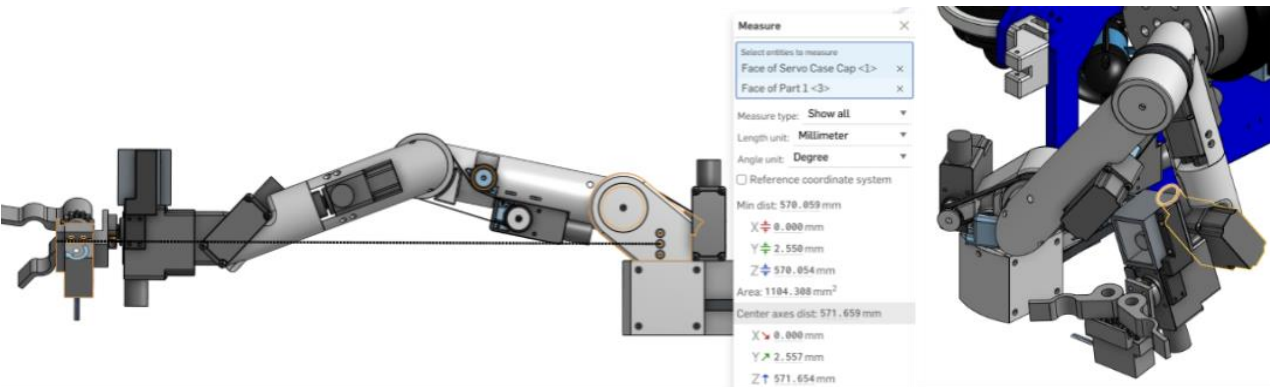
The arm is manually controlled using a pendant controller rather than operating autonomously. This means the design does not require industrial-level positional accuracy and could prioritize simplicity and robustness. This allowed the use of waterproofed hobby-class servos and lightweight 3D printed structures while still maintaining sufficient performance for competition tasks.

The overall concept of the manipulator and master arm controller was partially inspired by the Reach Robotics Bravo manipulator. Their compact joint layout and intuitive control demonstrated an effective approach

for underwater manipulation. Dreadyacht’s final design was extensively modified around the team’s own constraints.

10.1 Arm Architecture

The 2026 MATE mission tasks do not require excessive reach or end-effector speed, so the arm was designed to be as compact as possible. The final design has a reach of approximately 57 cm while being able to fold into a compact footprint for integration onto the ROV. Keeping the arm compact reduces bending loads, required actuator torque, underwater drag, and destabilizing forces on the ROV. The arm still must allocate room for its systems such as gearing, bearing stacks, cable routing, and clearance between links.



CAD rendering of the arm in its full extended position (left) and full retracted position (right)

The arm was mounted on the lower right side of the ROV to maximize forward workspace while minimizing interference with the central camera, thrusters, and destabilizing moments. This configuration also improves operator intuition during manual control because the pendant controller can be operated right-handed. Most of the arm structure was manufactured from PLA using FDM 3D printing. The MATE competition does not require high payloads or continuous-duty operation, so lightweight printed links provide sufficient strength while simplifying manufacturing and iteration.

Joint	Function	Load	Description
J1	Base rotation	Moderate	Rotates entire arm about vertical axis
J2	Shoulder	Very High	Primary lifting joint
J3	Elbow	High	Extends workspace
J4	Wrist roll	Low	Enables grasping from the side of objects
J5	Wrist pitch	Moderate	Enables grasping from the top of objects
J6	Continuous wrist yaw	Low	Enables spin of the claw and held object

Table 10.1 joint layout

10.2 Actuator Design

The actuator system is at the core of any robotic manipulator; it was important to select actuators with a balance of reliability, simplicity, and power. A high degree of freedom robotic arm ideally uses low-backlash BLDC actuators with precise encoders. However, these are expensive, difficult to waterproof, and increase electrical and mechanical complexity.

Option	Torque	Backlash	Complexity	Waterproofing Cost
Integrated BLDC actuators	High	Low	High	Very High
Stepper + encoder actuators	Low (Requires gearing)	Moderate	High	High
DC motor + encoder	Low (Requires gearing)	Moderate	Moderate	Moderate
Hobby servos	Moderate	High	Low	Low

Table 10.2 actuator selection matrix

The final design therefore uses hobby-class servo motors housed in waterproof servo enclosures from Blue Trail Engineering. These affordable actuators provide sufficient torque, integrated gearboxes, encoders, and drivers, perfect for the lightweight mission objects. While backlash does show up as end effector error, this is acceptable for this application due to manual control and can be improved upon using gear ratios.

10.3 Transmission Design

The primary joints, J1, J2, and J3 experience higher torque loads than hobby-class servos can directly support, which means that their outputs cannot be directly coupled to the joints. Direct drive would also require larger joint packaging, particularly at the base joint where axial servo placement would increase the arm footprint. As a result, external gear reductions were added to the primary joints, multiplying available torque, and dividing servo backlash by the chosen ratios. Due to the limited control angle of the selected high torque servo motors, the ratio must be low enough to enable sufficient range of motion. The team looked at multiple low-ratio gearing options, considering torque capacity, complexity, footprint, backlash, efficiency, and waterproofing cost.

Option	Torque	Complexity	Footprint	Backlash	Efficiency	Waterproofing Cost
Spur Gears	Moderate	Low	Low	High	Moderate	Low
Planetary Gearbox	High	High	Medium	Moderate	Moderate	High (needs sealing)
Worm Gear	High	Low	Low	Low	Low	Moderate
Chain Drive	Very High	Low	High	High	Low	Moderate
GT3 Belt Drive	Moderate	Moderate	High	Very Low	High	Low
Cycloidal	High	High	Medium	Very Low	High	Moderate

Table 10.3 transmission selection matrix

GT3 belt reductions were ultimately selected because they provided the best balance of low backlash, efficiency, waterproof simplicity, and sufficient torque capacity for the required reductions. Since the manipulator only required relatively low ratios for its workspace, 3:1 for J2 and J3 and approximately 1.4:1 for J1, the additional complexity and sealing requirements of planetary or cycloidal gearing were unnecessary. Compared to spur gears and chain systems, belt reductions introduce almost no backlash, improving controllability. The final pulley systems were fully modeled in CAD, including pulley tooth counts, center distances, wrap angles, and theoretical belt lengths.

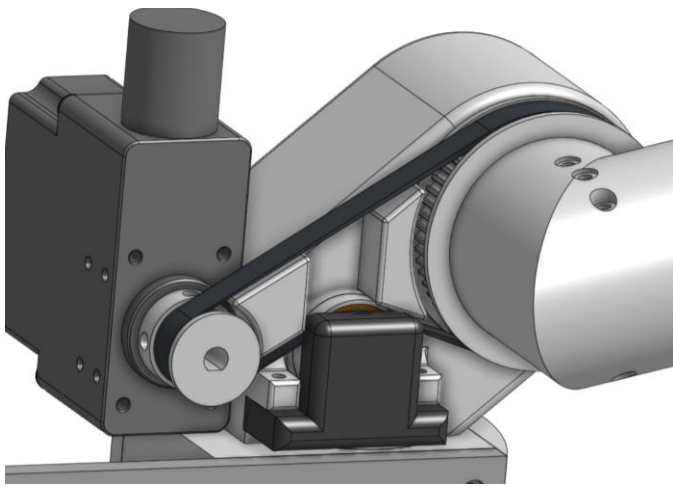


Figure 10.3 - 300mm GT3 Timing belt for J2

10.4 Torque Considerations

The worst-case moment occurs when the arm is fully extended. In this configuration, the center of mass of the arm past J2 is approximately 194 mm from the shoulder joint, with a mass of approximately 3.6 kg. A simple moment calculation shows the required torque on J2, which results in approximately 70 kg·cm of required static holding torque at J2.

M = mgr = 3.6(9.81)(0.194) = 6.85N · m

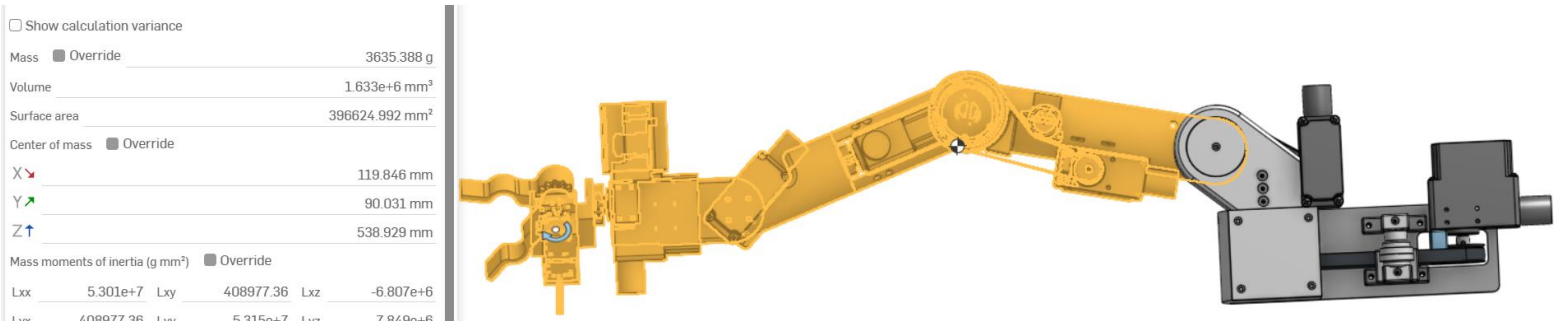


Figure 10.4 Fully extended arm mass and center of mass measurement

The servo motors for J2 and J3 are rated for 25 kg·cm continuous torque and 70 kgcm stall torque. With the selected 3:1 GT3 belt reductions, the continuous output torque becomes approximately 75 kg·cm. This load is near the continuous torque capability of the actuators. To improve torque margin, marine-rated bungee-cord counterbalance was added to the arm to offset gravitational load.

The manipulator also operates underwater, where buoyancy significantly reduces the effective weight of the arm and required joint torque. Testing demonstrated that the J2 and J3 servos did not exceed approximately 2 A current draw during above-water motion operating at 7.4V, despite a rated stall current of 6 A. This indicates that the actuators were operating substantially below stall torque during realistic operation.

J2 was used as the primary torque validation case because it supports the entire mass of the manipulator. J3 experiences lower loading because it only supports the wrist and end-effector assembly, resulting in lower torque at the elbow joint.

Joint	Actuator	Ratio	Peak Torque	Continuous Torque	Output Range
J1	25 kg 270° servo	1:1.406	35.15 kgcm	11.95 kg·cm	192°
J2	70 kg 357° servo	3:1	210 kg/cm	75 kg·cm	119°
J3	70 kg 357° servo	3:1	210 kg/cm	75 kg·cm	119°
J4	25 kg 270° servo	1:1	25 kg/cm	8.5 kg·cm	270°
J5	40 kg 180° servo	1:1	40 kg/cm	13.5 kg·cm	180°
J6	25 kg continuous rotation servo	1:1	25 kg/cm	8.5 kg·cm	Continuous

Table 10.4 Joint Actuator Specs

A continuous rotation actuator was specifically selected for J6 because the 2026 MATE mission includes a task requiring the vehicle to rotate a handle to simulate the acoustic release of a whale-safe fishing gear retrieval buoy.

10.5 Bearing and Structural Design

One of the mechanical challenges in the manipulator was achieving sufficient joint stiffness while operating underwater with lightweight, low-cost components. The internal servo bearings alone could not support the bending moments generated by the arm at J1, J2, and J3. As a result, the arm needed external bearing stacks with large spacing between bearing pairs to resist moment loads and reduce joint flex. When it comes to bearings underwater, the lubrication needs of traditional steel ball bearings dictate the affordable options.

Option	Load Capacity	Stiffness	Friction	Effectiveness Underwater	Cost
Steel Bearings	High	High	Moderate	Low (Needs sealing)	Low
Flanged PTFE Bearings	High	Low	High	High	Medium
Fully Sealed Steel Bearings	High	High	Low	High	Very High
Nylon-Glass Ball Bearings	Moderate	Moderate	Low	High	Low

Table 10.5 Bearing selection matrix

The final design uses dual 6204 nylon-glass ball bearings on J1, J2, and J3 with at least 35 mm of spacing between bearings to maximize stiffness and load capacity. The bearings were rated by the manufacturer for a 7.0 kN dynamic load and a 3.2 kN static load, however upon testing at UConn's Structures Laboratory using a hydraulic press, the bearings demonstrated approximately 2.1 kN static load capacity before shattering.

With a calculation using the J2 Moment load, we can find the radial load on the bearing stack with 35mm spacing between the two nylon-glass bearings.
$$F = \frac{M}{d} = \frac{6.85}{0.035} = 196N$$

This gives the bearing stack a roughly 9x safety factor in the worst-case static shoulder loading condition, which ensures the arm maintains stiffness during shock loads and deceleration.

The bearings are only rated for ABEC 1 precision, which would directly translate into play at the end effector. To prevent this, preload was introduced in all three bearing stacks. This preload was created using a spacer (pictured in blue below) between the bearing inner races that increased the spacing by approximately 1 mm beyond the default assembly spacing. This produced joints with almost zero detectable play while still maintaining smooth motion.

The diagram to the right shows the section view of the preloaded bearing stack used on the primary joints. The blue spacers increase the distance between the inner bearing races, generating preload through the bearing assembly while the outer races remain fixed in the housing. The red highlighted regions indicate the areas where preload is applied within the bearing stack.

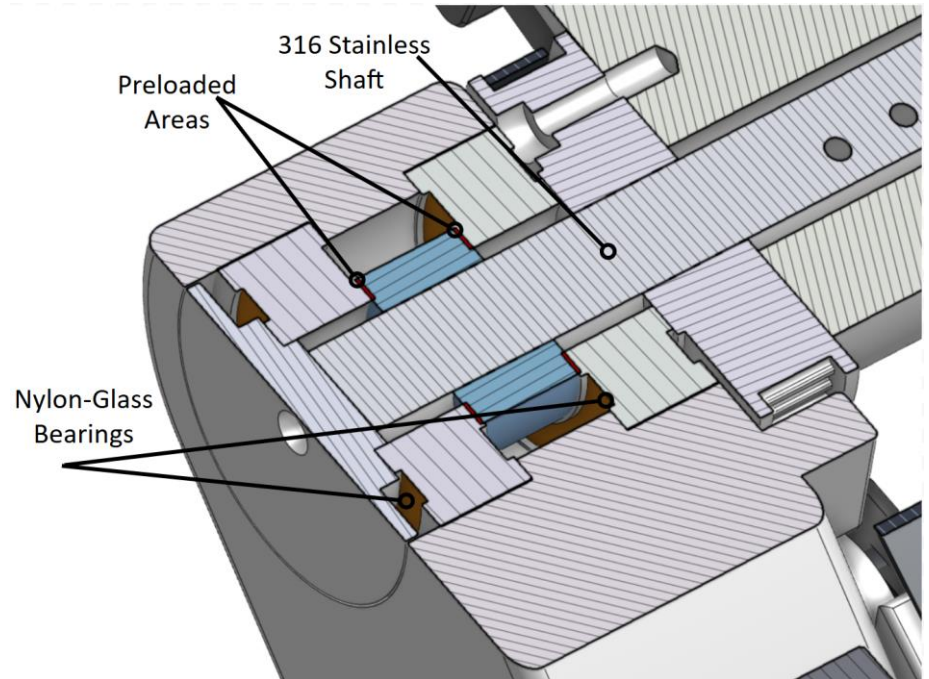


Figure 10.5 Section-view of the J2 bearing stack

The smaller wrist joints (J4–J6) use the smaller integrated steel bearings already present inside the Blue Trail Engineering waterproof servo housings. These joints experience substantially lower moment loads and therefore did not require additional external bearing support.

10.6 Manufacturing and Iterative Design Improvements

The manipulator was designed to be manufacturable primarily using in-house fabrication methods. Throughout development, several major design flaws and manufacturing limitations were discovered through testing and iteration. Many features of the final design were direct responses to failures observed during physical prototyping.

Many arm components were manufactured from PLA using FDM 3D printing. Structural components were printed using 30% infill, while lower-load peripheral components were printed at 20% infill. During manufacturing, it was important to keep track of each part's infill to import density specs into the CAD model for buoyancy calculations.

The main structural mounting plate and 60t timing belt pulleys were CNC machined from 6061 aluminum, while the primary shafts for J1, J2, and J3 were manufactured on a lathe and mill from 1/2-inch 316 stainless steel. All manipulator hardware uses 304 stainless steel fasteners for corrosion resistance underwater.

Early iterations of the arm relied heavily on brass heat-set inserts embedded into PLA components. While this worked for low-load mounting features, it repeatedly failed in high-load structural locations such as servo mounts and transmission assemblies. These locations experience the full reaction torque generated by the arm and frequently strip the inserts from the printed plastic. The final design instead uses through-bolts or captive nut inserts for all structural and load-bearing joints. This significantly improved reliability and eliminated thread failures under load.

Designing a precise belt system introduced its own set of structural issues addressed during prototyping. Early iterations attempted to use exact pulley spacing, so the belts would fit at their nominal lengths without tensioners. In practice, however, print tolerances, belt stretch, and pulley alignment prevented consistent belt tension. This caused belt slip under load, which breaks the alignment between the servo's absolute encoder and the arm links, rendering the manipulator unusable.

To solve this issue, adjustable idler tensioners were added to the J1, J2, and J3 belts. During testing of the first tensioner iteration, significant joint slop was observed when the arm moved downward and rapidly stopped. The tensioners on both J2 and J3 were placed on the gravity-loaded span of the belt because it simplified packaging and mounting geometry. Under gravity load from the arm, even small compliance in the adjustable plastic idler mounts resulted in movement at the end-effector. Although the flex in the tensioner assembly was small, the large pulley diameter and reduction ratio amplified the motion into noticeable end-effector slop, especially when the arm decelerated during downward motion.

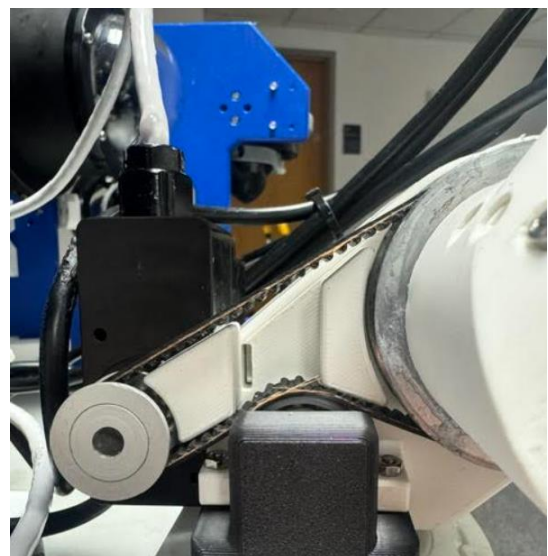
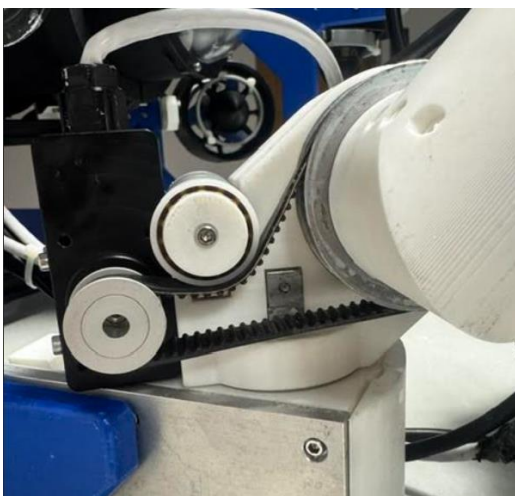


Figure 10.6 J2 Pulley system idler iteration 1 and 2

The final iteration relocated the tensioners to the non-gravity-loaded side of the belt path. In this configuration, gravity loads transfer directly through the fixed pulley system instead of through the adjustable tensioner assembly. This redesign greatly improved joint stiffness and nearly eliminated visible arm slop during normal operation.

10.8 Master Arm Controller

The manipulator is controlled using a scaled master arm controller that mirrors the kinematic layout of the underwater arm. The operator directly controls the position of the underwater arm by physically moving the master arm. This intuitive control method is simple, reliable, and allows the operator to subconsciously counteract servo backlash and encoder error.

Mounted on the grip of the controller is a two-axis joystick. The joystick X-axis controls the target claw leveling angle, while the joystick Y-axis controls the claw itself. The joystick button activates preprogrammed functions such as automatically returning the manipulator to its resting position and placing objects in our modular basket [6.1].

The controller is lightweight and comfortable to operate. Each joint uses dual 6803 steel ball bearings to provide smooth motion and ensure magnet-encoder alignment. J1 and J2 include hard stops which mirror the angular limits of the underwater servos, preventing the operator from commanding unreachable joint positions. Software limits ensure that the target angle never leaves the bounds of the arm's motion and prevent the arm from colliding with the frame of the ROV.



Figure 10.8 Master Arm Controller

The pendant arm uses an Arduino Giga as the local microcontroller for the arm control system. The arm has three AS5600 and two MT6701 magnetic encoders that communicate over I2C. They are split across the Arduino Giga's three separate I2C channels which eliminates the need for a I2C multiplexer commonly required to solve I2c address conflicts. The Arduino reads the encoder positions from each joint and sends that position data to the LattePanda inside the ROV, where a Python control script interprets the encoder values and translates them into servo PWM commands for the arm. The LattePanda runs higher-level control logic and outputs the final PWM

signals that drive the arm servos. This follows the same general software approach used elsewhere on the ROV, where Python maps controller/input data into PWM pulse widths for motors and servos.

11.0 Build vs. Buy, New vs. Used

URUC built custom systems when commercial options limited performance, packaging, or mission integration. The team purchased components when the commercial part was reliable, cost-effective, and not a performance bottleneck. This allowed development time to focus on the custom power PCB, robotic arm, frame integration, tether strain relief, camera housings, and task tools.

System	Decision	Justification
Blue Robotics T200 thrusters	Buy new/reuse as available	Reliable, known performance, and strong thrust-to-cost ratio.
Custom power PCB	Build in-house	Needed custom 14 V propulsion channels, 7.4 V auxiliary output, and tube-specific packaging.
Six-axis robotic arm	Build in-house	Mission tasks required custom reach, mounting, and low-cost underwater integration.
Pixhawk + QGroundControl	Buy/use existing ecosystem	Reduced custom driving code and provided proven thruster control.
Camera housings	Build in-house	Needed packaging specific to frame and arm mounting constraints.
COLMAP / YOLO	Use open-source software	Reduced development time while meeting imaging and recognition needs.
Tether strain relief	Build in-house	Needed custom mechanical interface to frame and MATE surface setup.

Table 8.0 Build vs. buy decisions and system justification.

12.0 System Integration Diagram

The system integration diagram shows how surface power, surface data, the power conversion enclosure, control enclosure, ESCs, thrusters, cameras, sensors, and arm servos connect into a single vehicle system.

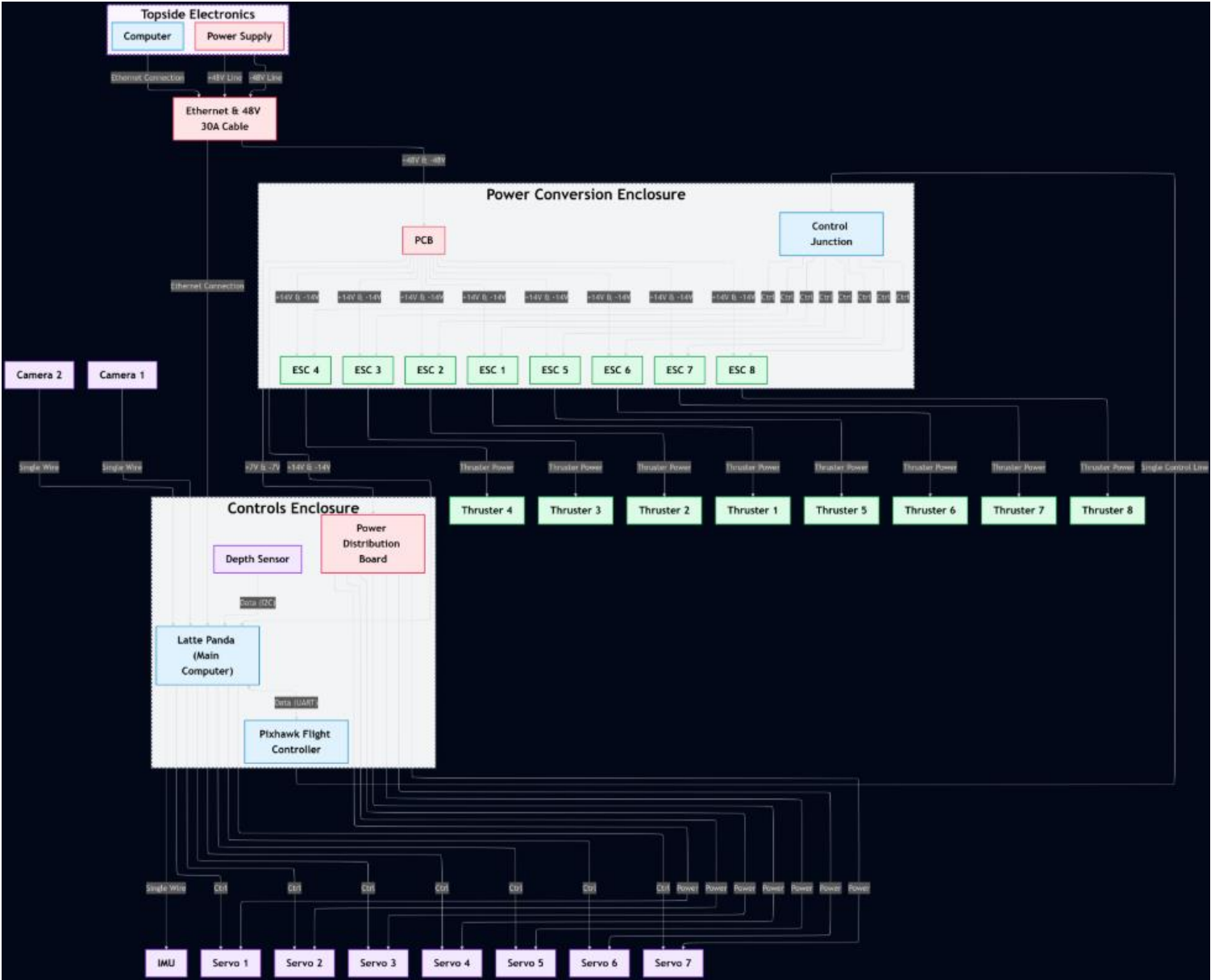


Figure 12.0 Dreadyacht electrical SID. The diagram separates surface electronics, power conversion, control electronics, propulsion, cameras, sensors, and arm servos.

13.0 Safety

URUC’s safety philosophy is to prevent hazards before deployment rather than rely on reaction during a run. Safety covers personnel, equipment, and the competition environment. The main hazards are high-current electrical power, spinning thrusters, water intrusion, pinch points on the arm, tether entanglement, and poolside tripping hazards.

13.1 Personnel Safety

All members are expected to wear closed-toe shoes, safety glasses when manufacturing or testing, and appropriate clothing around rotating tools and the pool deck. Only trained members operate power tools, soldering equipment, or the ROV power system. During pool operation, roles are assigned before deployment: pilot, operations director, tether manager, ROV handler, and safety observer.

13.2 Equipment and Vehicle Safety

Thrusters use ring-style guards to reduce contact risk while maintaining flow. Gear shrouds were placed over all potential pinch points to prevent accidental injury. The tether uses strain relief so loads are transferred to structural clamps instead of penetrators. The electronics tubes are inspected before closing, vented during assembly to avoid pressure buildup, and vacuum tested before water exposure. The custom PCB is mounted with accessible connectors and uses polarity checks, fused input protection, transient suppression, and staged bring-up procedures.

13.3 Operational Safety

Before deployment, the team verifies that the power supply is dry and away from the pool edge, the tether is clear of walkways, the ROV is free of loose parts, the electronics tubes are dry, and all personnel are in position. During operation, the tether manager controls slack and prevents loops from entering task structures. The pilot announces before hands-on recovery, and the handler retrieves the ROV by the frame rather than by the tether or arm.

14.0 Accounting

14.1 Budget Planning

URUC combined university funding, fundraising, grants, donations, and in-kind sponsorships to support the 2026 build season. The team increased available resources through the Ignite fundraiser and used the additional budget to support ROV electronics, competition travel, tools, and long-term team equipment.

Funding source	Amount (USD)
Retained earnings from 2024-2025	\$995.92
Ignite fundraiser	\$9,040.00
Undergraduate Student Government	\$15,000.00
Elyton donation	\$1,000.00
Krenicki Arts and Engineering Institute grant	\$650.00
Total available cash funds	\$26,685.92

Table 14.1 Available cash funds for the 2025-2026 season.

In-kind sponsor	Estimated value (USD)
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Onshape	\$3,500.00
SimScale	\$5,000.00
Navy STEM Anchor	\$500.00
Freedcamp	\$4,800.00
Total in-kind value	\$13,800.00

Table 14.2 In-kind sponsorships and software support.

Category	Budgeted cost (USD)
Lab safety	\$300
Equipment	\$2,000
Research and development	\$500
Surface station	\$1,500
ROV structure	\$1,000
ROV electronics	\$5,000
Float	\$2,000
Recruitment	\$500
Team operations	\$500
Competition fees	\$600
Competition travel	\$9,000
Total planned budget	\$22,900

Table 14.3 Planned budget allocation for the season.

14.2 Travel Estimate

Category	Description	Cost (USD)	Quantity	Subtotal
Airfare	Reimbursement per employee	\$200	12	\$2,400
Lodging	House rental / Airbnb	\$4,200	1	\$4,200
Car rental	SUV rental	\$800	1	\$800
Total				\$7,400

Table 14.4 Estimated world championship travel costs.

14.3 ROV Cost Accounting

Category	Type	Representative items	Value (USD)
Structure	Purchased / manufactured	HDPE frame, 3-D prints, aluminum extrusions, acrylic and aluminum tube assemblies	\$760
Propulsion and controls	Purchased	T200 thrusters x8, ESCs x8, Pixhawk 6, tether components	\$2,600

Custom electronics	Manufactured / purchased	Buck conversion PCB, PCB fabrication and assembly, Arduino Giga, arm controller encoders	\$1,510
Manipulator electronics	Purchased	High-torque servos, waterproof servo enclosures, belt drives, bearings	\$1,450
Computer	Donated	LattePanda 3 Delta at fair market value	\$270
Total estimated ROV value			\$6,590

Table 14.5 Estimated ROV component value by category. Purchased, manufactured, and donated items are separated by type.

15.0 Acknowledgements and References

URUC thanks the University of Connecticut, the Undergraduate Student Government, the Krenicki Arts and Engineering Institute, Elyton, Onshape, SimScale, Navy STEM Anchor, Freedcamp, mentors Giovanni Donato and Oliver Mackinnon, and all students, alumni, sponsors, and faculty who supported the 2026 season. The team also thanks MATE for organizing the competition and providing the RFP, safety standards, and educational framework that guided this project.

15.1 References

- [1] MATE ROV Competition. 2026 Explorer/Pioneer/Ranger Technical Documentation Scoring Requirements.
- [2] Blue Robotics. T200 Thruster product documentation and performance data.
- [3] Vicor. PI352x-00 ZVS Buck Regulator datasheet and layout guidance.
- [4] ArduSub / QGroundControl documentation for Pixhawk-based ROV control.
- [5] COLMAP: Structure-from-Motion and Multi-View Stereo reconstruction software documentation.
- [6] Ultralytics YOLO documentation for object detection model training and inference.
- [7] Onshape CAD documentation and education resources.
- [8] SimScale cloud simulation documentation.
- [9] Christ, R. D. and Wernli, R. L. The ROV Manual: A User Guide for Remotely Operated Vehicles.

Appendix A: Safety Checklist

Stage	Required checks
Before closing electronics tubes	Confirm all wires are connected, routed, and not pinched. Verify penetrators are sealed and lubricated. Inspect tubes for cracks, moisture, debris, and damaged O-rings. Open vent plugs before closing.
While closing tubes	Seat flanges evenly on the machined O-ring interfaces. Keep tether wires oriented without twisting or pulling. Confirm no conductors are trapped between sealing surfaces.

After closing tubes	Install locking cords, close vent plugs, and run a negative-pressure test before water exposure. Do not deploy if pressure drops, moisture appears, or any connector is loose.
Pre-deployment	Check frame, arm, thrusters, guards, tether, and tools for damage. Clear the pool deck. Assign pilot, tether manager, ROV handler, and operations director. Keep power equipment dry and away from the water.
Deployment	ROV handler installs the correct tool and holds the vehicle by designated frame areas. Pilot confirms readiness before hands-off release. Never lift or carry by the tether or arm.
During operation	Tether manager maintains safe slack and prevents loops near props or task structures. Pilot stops immediately for water intrusion, abnormal current, exposed wiring, or loss of control.
Recovery and shutdown	Pilot returns to launch area and announces ready for hands-on recovery. Handler retrieves by the frame. Disable power before tool changes or electronics inspection. Rinse appropriate components after saltwater exposure.

Table A1. Construction and operation safety checklist.