



Aurora

Technical Documentation

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Table of Contents

1 Introduction	3	5.1 Testing Methodology	16
1.1 Abstract	3	5.2 Troubleshooting Strategies	17
2 Design Rationale	4	6 Logistics	17
2.1 Innovations	4	6.1 Company	17
2.2 Design Process	4	6.1.1 History	17
2.3 Manufacturing Process	5	6.1.2 Structure	18
2.3.1 Build vs Buy	5	6.1.3 Management	18
2.3.2 Mechanical	6	6.2 Accounting	19
2.3.3 Electrical	6	6.2.1 Budget	19
2.4 Vehicle Structure	6	6.2.2 Costing	20
2.5 Core Systems	7	7 Conclusion	20
2.5.1 Mechanical	7	7.1 Future Improvements	20
2.5.2 Electrical	9	7.2 References	20
2.5.3 Software	11	8 Appendices	21
3 Non-ROV Device	15	8.1 Safety Checklist	21
3.1 Mechanical Design	15	8.2 Company Structure & Job Description	21
3.2 Electrical Design	15	8.3 Project Budget	22
4 Safety	16	8.4 Project Costing	23
4.1 Safety Features	16	8.5 SIDs	24
4.2 Safety Procedures	16	8.5.1 Pneumatic	24
5 Testing & Troubleshooting	16	8.5.2 Electrical	25

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Figure 1: AUR’s Acknowledgments.

1 Introduction

1.1 Abstract

AUR is a student-led team based in Alexandria, a city known for its deep marine heritage, submerged historical sites, and active maritime industry. Driven by the need for safer underwater operations, AUR develops innovative Remotely Operated Vehicles (ROVs) designed to handle exploration, inspection, and maintenance tasks—reducing reliance on human divers and the risks they face.

This year marks our current team's first time participating in the MATE ROV Competition³, building on the experience our former members gained developing last year's ROV, *Giulietta*². AUR introduces **Aurora**, our newest ROV engineered for precision, maneuverability, affordability and reliability in demanding underwater environments. Aurora is built on a strong yet lightweight HDPE frame and utilizes bilge pump propulsion, enabling smooth movement across six degrees of freedom. The vehicle's modular electronic systems are protected within sealed HDPE enclosures, while two 3D-printed manipulator arms, powered by a pneumatic system, provide effective object-handling capabilities. To enhance piloting accuracy and situational awareness, Aurora is equipped with three wide-FOV USB cameras delivering high-definition, real-time video feeds to the surface station. These are supported by onboard PID control for stable maneuvering, live telemetry for continuous system monitoring, and computer vision processing to assist with mission-specific tasks. Together, these systems ensure that the pilot has both the visual information and the automated support needed to operate efficiently and confidently.

Developed through continuous prototyping, testing, and refinement, Aurora highlights the team's engineering expertise, creativity, and dedication to underwater robotics. The project builds upon AUR's experience in providing robotic solutions, demonstrating our commitment to innovation and technical excellence. This documentation outlines Aurora's design, fabrication, and operational performance, presenting the journey behind the development of a capable and mission-ready ROV.



Figure 2: AUR's Team.

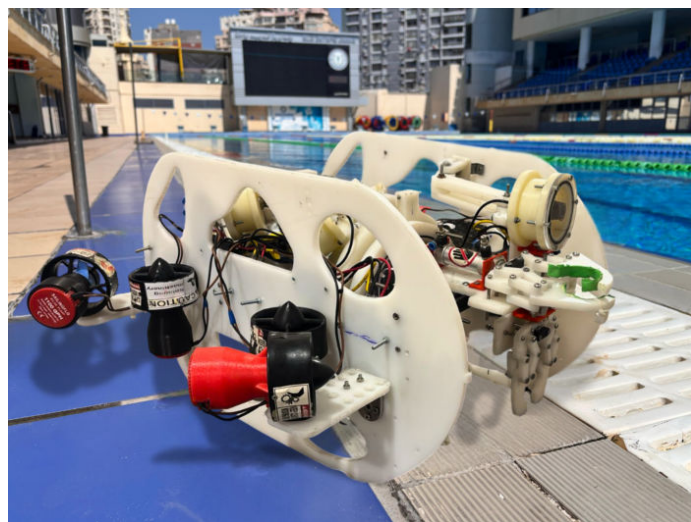


Figure 3: AUR's 2026 ROV, Aurora.

2 Design Rationale

2.1 Innovations

This year's innovations are built on two foundations: the hard-earned experience our former members gained building and competing with *Giulietta*², "last year's ROV", and the fresh perspectives of our current team members. Every design decision on Aurora was guided by a simple philosophy: maximize efficiency while keeping the system as simple and robust as possible. The result is an ROV that honors the lessons of the past while being driven forward by the ideas and effort of our present member. In this section, we discuss the key innovations that define Aurora and the thinking behind them.

- **In-House Motor Drivers:**

To drive the six thrusters on *Giulietta*², we relied on commercially available Cytron MD10A motor drivers. While performant, they were neither space nor cost efficient. With Aurora requiring eight thrusters plus a DC manipulator, we would have needed five of those drivers, impractical given our size constraints and budget. So this year, we designed our own motor driver board from scratch using TA6586 ICs. A single board, roughly the size of two Cytron drivers, now drives all nine motors at once. This gave us complete control over form factor, significantly reduced cost, and freed up valuable space inside our electronics enclosure.

- **Leakage Sensor:**

In strict alignment with MATE ROV competition safety guidelines³ and our team's core commitment to operator and equipment protection, we designed our own leakage detection system from scratch. The sensor triggers a magnetic latch that instantly cuts power to the ROV the moment water is detected inside any enclosure. This ensures that both the environment and our electrical components are immediately protected in the event of a breach.

- **Network Architecture:**

The tech stack used for the GUI for Aurora allowed for a perfect balance of high performance, rapid iteration and testing, and elevated user-experience. This year, we decided to expand the modularity of the software subsystem by introducing changes to our network stack that cater to multi-tasking competitions like MATE ROV while still being flexible enough for use elsewhere. We now use a central router

which takes on the responsibility of relaying the information streams to all pilots in the station, without putting more load on the on-board computer.

- **Real-Time PID Tuning:**

PID gains are configurable in real time through the GUI, with Testing Mode transmitting step response data directly to enable iterative tuning without firmware reflashing.

- **Remote DFU Updates:**

A DFU (Device Firmware Update) mode allows firmware to be flashed to the STM32 remotely through the Raspberry Pi, eliminating the need to open the pressure enclosure or physically reboot the microcontroller.

- **Unified API Surface:**

Both Normal and Testing modes share a unified API surface, ensuring that validated lab behavior transfers directly to competition conditions.

- **Rotating Gripper Mechanism:**

Previous ROV designs used two static grippers, which created two problems: increased hydrodynamic drag and limited operational flexibility. To solve this, Aurora introduces a single rotating gripper mechanism, which improves maneuverability while reducing drag. Smooth rotation is achieved through a gland packing shaft seal, an industrial sealing solution adapted to maintain waterproofing under dynamic conditions.

2.2 Design Process

During the design phase of our ROV, we aimed to fully utilize the engineering capabilities of our team members. To achieve this, the system was divided into several subsystems so that each part could be designed and developed efficiently. The ROV was therefore broken down into the following main components:

- Frame
- Thrusters
- Grippers (Manipulator)
- Rotating Mechanism
- Enclosures

The overall design process was divided into stages:

- **Research:**

In this stage, we began by studying the requirements outlined in the MATE ROV 2026 rulebook³ to identify the key design constraints and objectives. We also reviewed designs from previous teams to understand common challenges and effective solutions that could guide our design decisions.

• Designing:

During this phase, the actual design work began. Each subsystem was designed while ensuring early compatibility checks between components to confirm that the different systems could integrate properly.

• Assembly Planning:

Here, we ensured that all subsystems could be assembled together efficiently. Special attention was given to avoiding mechanical interferences, ensuring proper mounting locations, planning screw fixing points, and maintaining accessibility for maintenance. System balance and buoyancy were also considered to ensure stable underwater operation.

• Simulation and Prototyping:

In this phase, structural stress simulations were performed on critical components, and pressure vessel calculations were conducted for the enclosure. Furthermore, prototypes were developed for the manipulator mechanism to verify functionality and ensure reliable operation before final manufacturing.

The cylindrical shape of our electronics enclosure presented the same space constraint as it previously did in *Giulietta*². Rather than fight it, we optimized for it. After multiple layout iterations and careful calculations, we settled on an octagonal PCB design, shown in Figure 4, which offered the best space efficiency for our components.

Maintainability was another priority carried forward from last year's experience. We designed every connection to be easily detachable XT60 connectors for power, JST terminals for data, and rosettes that make assembly and troubleshooting quick and painless.

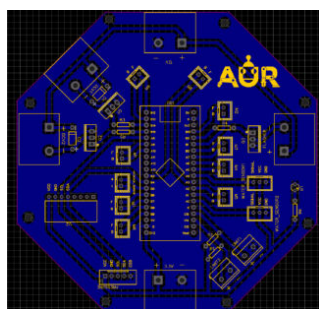


Figure 4: Octagonal PCB Design

2.3 Manufacturing Process

2.3.1 Build vs Buy

Our build vs buy policy was simple: manufacture in-house whenever possible without compromising functionality, reliability, or performance. This aligns

with our goal of maximizing hands-on engineering experience while maintaining strict budget control.

• Thrusters:

We evaluated each thruster component individually. For the propeller and nozzle, the trade-off was clear: building them would save money but required precision beyond our capabilities. 3D printing tests produced uneven surfaces that degraded performance significantly. Since propulsion efficiency directly impacts mission success, we prioritized performance over learning experience and purchased these components. For the coupler and stator, simpler geometries, the trade-off favored in-house manufacturing, which saved cost, and met performance requirements.

• Frame and Grippers:

These were designed specifically for 2026 mission requirements, and no commercial products matched our exact needs. Building was not just about cost, it was the only path to achieving the precise dimensions and integration features our design required. In-house manufacturing from HDPE gave us full design flexibility, rapid iterations, and perfect integration with other subsystems.

• Rotating Gripper:

No off-the-shelf solution existed for our specific competition tasks, so building was the only option. Within that decision, we faced material trade-offs. The enclosure's complex geometry made traditional machining difficult, so we traded structural strength for manufacturing speed by choosing 3D-printed PLA+. For the coupler, where precision and strength were critical, we invested time in lathe machining from aluminum. The mounting bracket was laser-cut from sheet metal, trading manual finishing for precise geometry. Each decision balanced time, complexity, and performance.

• Hardware Enclosure:

Commercial enclosures are readily available and waterproof, but none matched our required internal dimensions. Building in-house required significant machining time but gave us optimized internal space, perfect O-ring sealing, and exactly the mounting points we needed. We traded the convenience of a proven commercial product for the benefits of a custom one designed specifically around our electronics.

• Electrical Hardware:

Most of Aurora's electrical hardware, including our motor driver board, power distribution board, leakage sensor, and main control board, was designed and manufactured entirely in-house, following the

same approach that served us well last year. However, we also made a deliberate decision to purchase certain components commercially. After careful consideration, we chose to buy the internal buck converters since building them from scratch would not have been time efficient for us .

• Reused Components:

From Giulietta², we inherited the external buck converters and several bilge pumps. The buck converters were validated by connecting two motors at maximum current draw to their outputs and monitoring performance under load. The bilge pumps were tested during underwater trials to verify their efficiency remained within specifications. Both performed reliably, allowing us to allocate budget toward new components.

2.3.2 Mechanical

We implemented various manufacturing processes to expand our learning opportunities while maintaining a cost-efficient design, as shown in Table 1. By utilizing different fabrication techniques, we were able to manufacture multiple components effectively according to their functional and structural requirements.

Method	Components
Lathe Machining	Hardware enclosure, Camera enclosure, Caps, Thruster coupler, Rotating gripper coupler, Rotating gripper gland
3D Printing	Thruster stator, Rotating gripper enclosure
CNC Router	Cap gland holes, Frame
CNC Laser Cutting	Fixing brackets

Table 1: Manufacturing methods

The choice of manufacturing method for each component was driven by geometry complexity, required precision, and material properties. For example, 3D printing enabled the complex shape of the rotating gripper enclosure, while lathe machining ensured precise tolerances for couplers and seals.

2.3.3 Electrical

Like last year, all of Aurora's PCBs were fabricated in-house at our workshop. We chose this approach not out of tradition, but because it proved significantly more time-efficient than ordering from external manufacturers, which typically takes weeks. By handling the entire process ourselves, from material selection to production to testing, we maintained full control over quality while being able to iterate and produce new boards in days instead of months. This end-to-end capability meant we could catch issues early, implement fixes, and keep moving forward without waiting on shipments.

2.4 Vehicle Structure

Frame

Constructed from 10mm CNC-machined HDPE sheets that were chosen for corrosion resistance, low weight, and strength. Two side plates connected by cross-braces create an open, rigid architecture with integrated mounting points for all subsystems. The 10mm thickness balances structural rigidity against weight, while the open-frame design minimizes drag without sacrificing mounting flexibility, a trade-off we accepted in favor of manufacturing simplicity and maintenance access.

Enclosures

Electronics are housed in custom-machined HDPE cylinders with O-ring seals and laser-cut acrylic end caps. The main enclosure sits centrally for balanced weight distribution, while 3 camera enclosures are positioned to allow full situational awareness.

Thruster Configuration

Eight thrusters provide full 6-DOF control. 4 angled horizontals handle surge, sway, and yaw, and 4 verticals manage heave, pitch and roll. All are shrouded and protected within the frame footprint. This layout increases power consumption and cost compared to a simpler configuration, but the gains in precision and stability justify the trade-off for mission-critical tasks.

Manipulator System

Aurora is equipped with two manipulators: a rotating gripper mounted forward and a static gripper positioned for complementary task handling. The rotating gripper uses a 3D-printed PLA+ claw on a gland-sealed rotating shaft, enabling 360° positioning without moving the vehicle. The static gripper provides a fixed reference point for stabilization during fine manipulation tasks. This dual-configuration allows the pilot to choose fre based on mission requirements.

Buoyancy and Ballast

Upper flotation blocks and lower ballast weights allow fine-tuning of center of gravity, ensuring stable operation and passive self-righting.

Tether Interface

The tether enters through a rear strain-relief gland with internal routing secured against snagging.

Dimensions and Weight

The complete vehicle measures 75cm in length, 75cm in width, and 40cm in height, with a total weight of 21kg. These dimensions strike a balance between stability in the water and ease of transport and handling during launch and recovery.

2.5 Core Systems

2.5.1 Mechanical

Frame

- **Design Rationale and Overview:**

Shown in Figure 5, the chassis serves as the skeleton, balancing structural integrity with maneuverability. An open-frame architecture ensures unobstructed water flow for thrusters, minimizing drag, while protecting internal components from collisions.

- **Material Selection (HDPE):**

HDPE was chosen for four reasons:

- Near water density provides near-neutral buoyancy
- Excellent corrosion and chemical resistance
- Highly recyclable with low environmental impact
- Affordable and readily available locally

- **Modularity and Portability:**

Standardized mounting points allow rapid reconfiguration of manipulators and sensors. The double-decker structure enables independent servicing of individual frames, and the frame disassembles into smaller components for easy transport and storage.

- **Technical Specifications:**

The frame measures 75cm × 75cm × 40cm, constructed from 10mm machined HDPE sheets secured with stainless steel screws. A symmetrical layout ensures stable, predictable underwater performance.

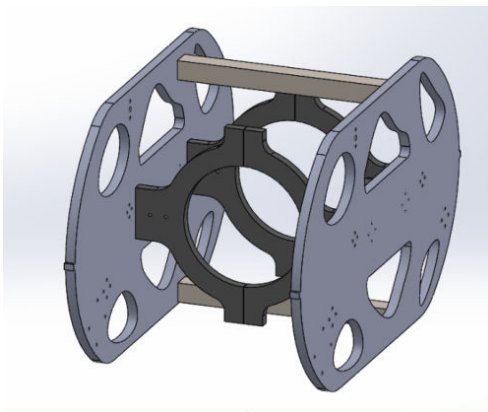


Figure 5: HDPE Frame Design

Propulsion

To achieve full maneuverability underwater, the ROV utilizes an 8-thruster configuration, shown in Figure 6, designed to provide control in all six degrees of freedom. This arrangement ensures precise motion, stability, and efficient thrust distribution, allowing the vehicle to perform complex movements required during competition tasks.

The horizontal thrusters are placed symmetrically around the vehicle's center of mass and oriented to generate forces in the forward/backward and lateral directions. The thrusters are angled at 45 degrees to provide equal thrust in both surge and sway. By varying the speed and direction of these thrusters, the vehicle can produce rotational motion about the vertical axis (yaw).

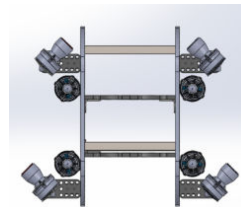


Figure 6: 8-Thruster Configuration

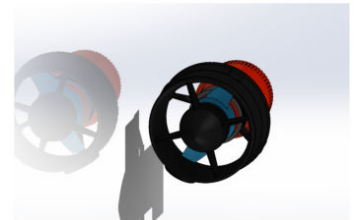


Figure 7: Thruster Assembled

The four vertical thrusters are positioned at different corners of the frame to control vertical motion and orientation. When all vertical thrusters produce equal thrust, the vehicle moves vertically (heave). By adjusting the thrust difference between the front and rear vertical thrusters, the vehicle can generate pitch, while varying the thrust between the left and right pairs produces roll.

High-speed electric motors adapted originally from the bilge pump assembly are utilized. Operating at 6600 RPM, it delivers stable torque suitable for underwater propulsion with reliable performance in submerged environments. A direct coupling to a T100 propeller converts rotational energy into thrust by accelerating water through a controlled flow path. A T100-style nozzle optimizes fluid direction and efficiency, enhancing thrust generation and maintaining navigational stability. A nozzle holder, shown in Figure 8 secures the nozzle assembly to the bilge pump housing, completing the propulsion unit.

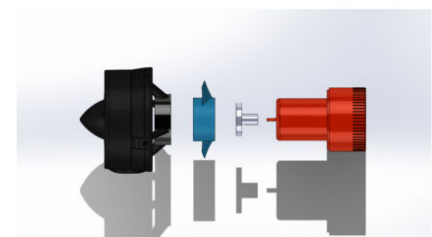


Figure 8: Thruster Parts Separated

Canisters

- **Material and Manufacturing:**

The main, solenoid, and camera canisters are all machined from HDPE using a lathe, allowing precise shaping for accurate fits and effective sealing.

• Main Canister:

Houses all electrical components and is open from both sides:

- **Front Side:** Sealed with a transparent plexi-glass plate using an O-ring and silicone gasket for radial sealing. The transparency allows easy visual debugging of internal components.
- **Back Side:** Sealed with four O-rings (three axial, one radial) plus a silicone gasket for robust protection against water ingress. Houses all insulated cable glands for safe cable entry.

- **Camera Canister:** Follows the same material and manufacturing process, sealed radially to protect the internal camera board.

Mission Tools

• Overview:

Aurora is equipped with two custom-designed grippers, purpose-built for the 2026 MATE ROV competition tasks³. Each manipulator is optimized for specific mission requirements, one static for support, one rotating for dexterity, maximizing ability to handle diverse underwater objectives efficiently.

• Material and Fabrication:

The grippers are fabricated from HDPE using CNC routing for precision and cost efficiency. Complex structural parts were 3D printed where necessary.

• Manipulator Design:

- **Static Gripper:** Positioned horizontally at the top, it serves as a support and backup, designed to hold cylindrical objects. Shown in Figure 10.
- **Rotating Gripper:** A key innovation, a DC motor-powered rotating gripper that enables complex tasks without moving the entire vehicle. Its elliptical jaw design accommodates a wide range of object diameters with improved self-centering. Shown in Figure 9.

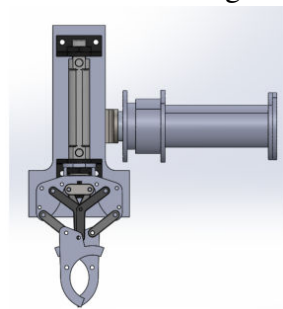


Figure 9: Dynamic Arm

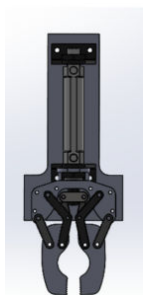


Figure 10: Static Arm

• Task-Specific Applications:

- **Task 1.1:** Both grippers handle large-diameter objects for coral garden collection.

- **Task 2.4:** Static gripper holds the recovery rope mechanism while the rotating gripper performs other tasks.

- **Task 2.5:** Static gripper aligns with the ROV's rotation axis, moving in sync for intuitive observatory servicing.

• Actuation:

A pneumatic system using an MLA 20×20 air cylinder provides gripping force, controlled by two-way DC solenoid valves for fast, responsive operation.

• Rotating Mechanism:

- **Sealing:** A gland packing system creates a dynamic seal around the rotating shaft—packing compressed by the gland expands radially against the coupler and enclosure wall.
- **Components:** Gland, packing, enclosure, aluminum coupler, DC motor, and end cap. Shown in Figure 11.
- **Motor Selection:** Torque requirement $T = m \times g \times r$ was minimized by aligning the gripper's center of gravity with the bracket, allowing a compact, efficient motor.
- **Coupler:** Custom aluminum coupler increases shaft diameter for reliable sealing while minimizing mass.
- **Packing:** 10×10mm greased braided packing balances sealing effectiveness and rotational friction.
- **Enclosure:** Designed for component alignment and packing compression. Stress simulations confirm safe operation at 1.5 bar, three times the competition depth requirement.

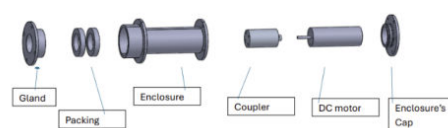


Figure 11: Rotation mechanism Parts

Buoyancy & Ballast

Achieving near-neutral buoyancy was a critical aspect of our ROV design and fabrication process. The initial step involved calculating the buoyant force acting on each major component, including the enclosure, grippers, and other structural elements. This provided a baseline understanding of the overall buoyancy characteristics of the system.

The enclosure contributed positively to buoyancy due to the presence of internal air volume. However,

other components exhibited varying buoyancy effects, making it difficult to achieve perfect balance through calculations alone. As a result, practical testing played a significant role in fine-tuning the system.

During testing, it was observed that the ROV had a forward tilt caused by the higher weight concentration of components located at the front. To compensate for this imbalance, buoyancy foam was strategically added in specific locations to counteract the excess weight and restore equilibrium.

Through iterative testing and adjustment, we were able to achieve a well-balanced system with near-neutral buoyancy, ensuring stable and efficient underwater operation.

2.5.2 Electrical

Aurora's underwater electrical system consists of four custom PCBs: the power distribution board, main control board, motor driver board, and leakage sensor board. Our objectives remained the same as last year, to create an electrical system that is highly efficient, yet simple and easy to maintain.

Main Control Board

At the heart of Aurora's control system is the STM32 microcontroller, commonly known as the Black Pill. We selected this MCU over last year's ESP32 for several mission-critical reasons:

- **Performance:**

With an 84 MHz ARM Cortex-M4 processor, it provides the computational overhead required for running real-time PID control loops without latency.

- **Peripheral Density:**

The abundance of hardware PWM timers allows us to control all nine motors simultaneously with precise timing and no software jitter.

- **Communication:**

Dual I2C and multiple UART buses enable high-speed data acquisition from our sensor suite, including the MPU9250 IMU and pressure transducers.

Our control board is a custom PCB designed and fabricated in-house that serves as the central hub for all command signals within Aurora. As shown in Figure 13, it houses the STM32, which handles:

- PWM signals to all nine motors (eight thrusters plus the DC manipulator)
- Signals to 2 solenoid valves in the pneumatic system
- Data from the IMU for attitude telemetry (yaw, pitch, and roll) through its built sensor fusion
- Acquiring depth data from pressure sensors for closed-loop altitude control

Power

As per competition requirements³, Aurora is powered by a single 48V source. This input feeds directly into our custom power distribution board, which routes power for every electrical component in the system.

The board houses input terminals for the incoming 48V and distributes it to 4 external waterproof buck converters, which handle the high-current demands of our thrusters and manipulator. Additional internal converters on the board step down power for lower-voltage components such as the control board, sensors, and leakage detection system. With this architecture, our power board ensures that every part of Aurora receives stable sufficient power as it needs.

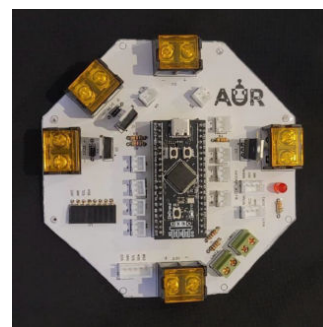
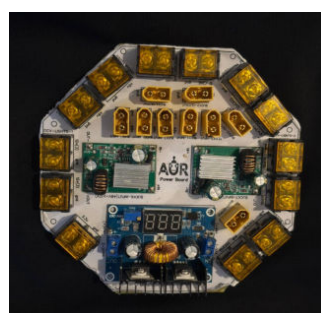


Figure 12: Power Board. Figure 13: Main Board.

In any ROV, the thrusters are by far the most power-consuming components, and Aurora is no exception. Ensuring they received stable, sufficient power was our top priority when designing the overall power system. To meet this demand, we used four external waterproof buck converters, each stepping down 48V to 12V with a 20A maximum current draw. Rather than pushing them to their limits, we stayed well within the safe side by connecting only two thrusters per buck converter. This approach guarantees that even under full load, each thruster gets the power it needs without risking voltage drops or overloading any single converter. Table 2 shows the theoretical power calculations and assumptions for our system's electronic components:

Component	V	I	Qty	Power
DC Motors	12V	6A	9	648W
Raspberry Pi 4	5V	3A	1	15W
DCVs	12V	0.33A	2	8W
STM32	5V	0.5A	1	2.5W
Total				673.5W

Table 2: Power Consumption Calculations

However, we could not depend solely on theoretical calculations for a matter such as our ROV's safety, so we tested the total ROV current draw on maximum power consumption conditions underwater, and

the max current came out to be around 13A, Which of course, is a close number to what we had expected it to be theoretically.

With a factor of safety of 1.5, the maximum current draw came out to be around 20A, Therefore, we used a 20A fuse as per MATE ROV safety specifications, which will be further discussed in the safety section.

To protect our Raspberry Pi from power faults, we designed a dedicated protection board using a crowbar circuit, as shown in Figure 14. The board sits between the 5V buck converter and the Pi itself, and the moment any voltage exceeds safe thresholds, it instantly shorts the excess to ground. This compact solution adds a critical safety layer without compromising power delivery efficiency or the Pi's operational integrity. It's a small board with a simple job: make sure the central communication hub of our ROV stays safe, no matter what.



Figure 14: Overvoltage Protection Board.

Motor Driving Board

As introduced in the Innovations section, driving nine motors, eight thrusters plus a DC manipulator, required a deliberate approach to motor control. Rather than purchasing multiple commercial drivers, we designed and built our own custom motor driver board from scratch as shown in Figure 15.

The board houses nine TA6586 ICs, each driving a single motor. To ensure consistent operation under maximum load, we added dedicated heatsinks to each IC, a necessary precaution given the sustained current draw during missions. Filtering capacitors were integrated throughout the board to protect against power spikes and smooth voltage fluctuations. Every connector type was chosen with intention:

- **JST connectors** handle data input from the STM32, providing secure signal connections
- **XT60 terminals** serve as power inputs from the distribution board, chosen for their current capacity and quick disconnect capability
- **HB9500SS terminals** deliver motor power output, selected for durability and ease of wiring

It wasn't just about saving cost or space, though we achieved both. Every component balances three priorities: electrical performance, physical footprint, and ease of maintenance. That resulted in a single compact board equivalent to five commercial drivers, freeing up space and simplifying our electrical architecture.



Figure 15: Motor Driver Board.

Tether

Our tether serves as the main power and data link between the surface station and Aurora. For power, we used high-quality copper cables to minimize voltage drops over the 30-meter length. A CAT6 Ethernet cable handles noise-resistant data transmission for video, telemetry, and control signals. A separate pneumatic tube supplies air to our dual gripper system. The entire bundle is encased in a protective sheath for durability and easy handling. In figure 16, a cross section of our tether cable is illustrated.

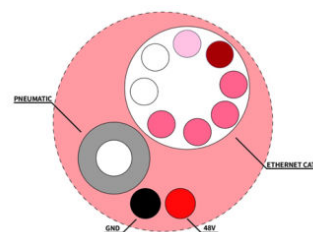


Figure 16: Cross Section Of Tether.

Effective tether management is critical to mission success, as uncontrolled tether can snag on obstacles, drag on the vehicle, or interfere with task execution. During operation, a dedicated tether tender monitors the cable at the surface, maintaining slight tension to prevent slack from tangling while avoiding excessive pull that could affect the ROV's stability.

Communication between the tender and pilot is maintained throughout dives to coordinate movement and anticipate tether behavior during complex maneuvers. Underwater, the tether enters the vehicle through a rear strain-relief gland with internal routing secured against snagging. To minimize drag, the tether is kept neutrally buoyant through the use of foam floats attached at regular intervals along its length, ensuring it

trails behind the ROV without sinking or floating into the work area. Before each dive, a pre-mission checklist confirms tether integrity, connector security, and proper strain relief attachment.

Cameras

Aurora is equipped with 3 waterproof USB HD cameras featuring 108° wide-angle lenses, providing real-time visual feedback to the pilot's interface. Each camera is housed in a custom-engineered waterproof enclosure made from pressure-resistant HDPE with polished plexiglass windows, ensuring both durability and clear visibility underwater. The cameras are strategically placed to give wide coverage of the ROV's surroundings and manipulator workspace, allowing for precise navigation and tool operation during missions.

Video transmission is handled by the onboard Raspberry Pi, which encodes and compresses the feeds to reduce bandwidth requirements while maintaining high frame rates and low latency.

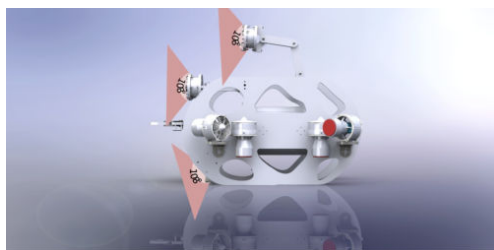


Figure 17: Cameras' FOVs.

2.5.3 Software

Station

The graphical user interface (GUI) is the central hub for telemetry and control, enabling the main pilot to maneuver the ROV effectively and monitor sensor and safety information like depth, orientation, and leakage levels. Our GUI is designed as a desktop app for maximum portability, with the chosen framework being Qt. We selected the Qt framework through PySide, the Python bindings for the library, achieving a balance of high performance, rapid iteration, and tight integration with other open-source libraries like OpenCV, Py-Serial, and PyGame.

The visual design of the GUI is intentional but flexible. The main viewing mode, shown in Figure 18, is laid out as follows:

- **Camera feed widgets:** Display the live video stream from the ROV's cameras
- **Orientation widgets:** Show IMU data in a responsive way to aid the pilot's movement

- **Thrusters' speeds widget:** Display transmitted speed to each thruster and projected motion of the ROV for piloting aid and communications debugging

Pilots with different responsibilities can change the default view to focus more on MATE-specific tasks, such as the crab-counting task, which requires more camera and computer-vision controls.

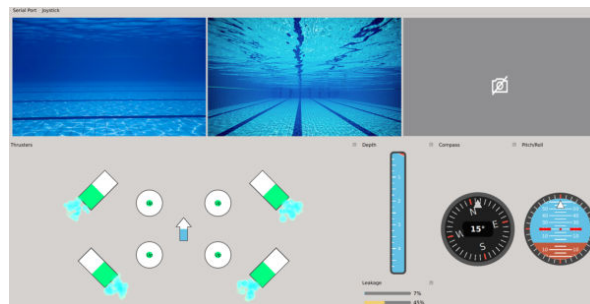


Figure 18: GUI overview.

Communication

To facilitate high-frequency telemetry and low-latency piloting, our communication stack includes a mix of protocols and robust networking to maintain scalability and a cost-effective hardware footprint^{5,7}. The architecture is composed of the following layers:

• Physical Layer & Network:

For high-throughput over the extended tether length, Ethernet was chosen as the medium for data transfer. The tether terminates at a central router on the station, serving as a distribution hub for the pilots' devices. Onboard the ROV, a Raspberry Pi 4 acts as the primary communication gateway, interfacing the three USB cameras and microcontroller with the pilots' devices onshore.

• Telemetry & Control (Serial-over-IP):

The onboard microcontroller connects to a single pilot device responsible for controlling the ROV and viewing the high-frequency telemetry stream. We opted for industry-standard software: VirtualHere USB server, running on the Raspberry Pi, serves the microcontroller's connection over the network instead of using rigid, specialized devices. The team's customized serial communication protocol utilizes the CDC protocol, ensuring efficiency in transmission and processing.

The GUI sends control commands serially to the microcontroller, which are processed and translated into motion and manipulator activation. The microcontroller returns a constant stream of telemetry, including sensor readings, manipulator states, and other information, to be displayed on the GUI at the station.

• Multicast Video Streaming:

To allow pilots at the station to view feeds from the three onboard USB webcams, the cameras are connected to the Pi, which serves the video streams over Ethernet. Streaming is optimized with Ethernet's bandwidth and the Pi's computational power taken into consideration. The raw video feeds are encoded by the Pi's hardware-accelerated H.264 encoder to conserve bandwidth over the Ethernet line, then served using UDP Multicast to the station's router, which distributes them to each pilot.

This system keeps the network load on the Raspberry Pi constant regardless of the number of connected viewers, focusing processing power toward encoding the high-resolution streams necessary for MATE's computer-vision-intensive missions and underwater exploration. This efficient pipeline is enabled by the open-source software GStreamer.

Firmware

The firmware developed for Aurora is designed to manage critical low-level operations, including sensor data processing, motor control, communication protocols, and safety features. Aurora's firmware runs on bare-metal architecture, ensuring fully deterministic, real-time execution with no operating system overhead.

The system continuously reads from an MPU9250 IMU and MS5611 pressure sensor, both over I2C, to maintain a real-time picture of Aurora's orientation and depth. GUI messages are received asynchronously via interrupts, ensuring pilot commands are captured immediately without blocking the main loop, keeping the ROV responsive to the operator. Each iteration, incoming commands are routed either through PID controllers or passed directly to a mixer that translates the commands into precise, coordinated thruster outputs.

Communication between the STM32 and Raspberry Pi is established via a CDC Virtual COM Port, selected for its higher throughput and built-in data integrity guarantees, eliminating the need for additional validation logic. A ready-message protocol is used where the STM32 signals the Pi when ready to receive a new command, avoiding constant interrupt handling. Sensor readings and thruster speeds are transmitted at 20 Hz, providing the pilot with real-time state feedback essential for tasks requiring precise positioning.

• Operation Modes:

Aurora operates in two modes:

- **Normal Mode:** The ROV receives pilot commands and uses PID controllers to hold position or navigate to a specified setpoint.

- **Testing Mode:** Activated during lab validation and pre-dive checks. Allows individual DOF testing without triggering full mission execution. PID parameters can be tuned directly through the GUI with no hardcoding required.

Both modes share a single, unified API surface. Hardware abstraction, sensor interfaces, and operations are identical regardless of which mode is active. What you test is exactly what you deploy.

• Safety Mechanisms:

Water leakage detection, gripper limit switches, and a communication watchdog that halts all motors upon timeout are continuously monitored throughout operation to ensure Aurora fails safe under any fault condition. This architecture ensures it remains responsive, stable, and safe throughout all phases of operation, while its modular design allows for straightforward integration of future updates and enhancements.

• Sensor Data Processing:

MPU9250:

To measure Aurora's orientation, an MPU9250 was selected because it combines a magnetometer, gyroscope, and accelerometer on a single chip. Data from all three sensors is fused using a Madgwick filter, which operates on quaternion representations to yield accurate, drift-resistant estimates of roll, pitch, and yaw in real time.

These readings are fed directly into Aurora's PID controllers, enabling autonomous attitude stabilization and ensuring Aurora remains level and balanced underwater without continuous pilot input.

The MPU9250 requires one-time calibration to ensure accurate data. This process involves measuring each sensor's offsets, the gyroscope's resting noise, the accelerometer's response to gravity, and the magnetometer's reaction to the local magnetic environment and applying these corrections through software. For an ROV where magnetic interference from motors and power cables is substantial, proper magnetometer calibration is crucial for dependable heading information.

MS5611:

The MS5611 pressure sensor is interfaced via I2C to measure the ROV's depth. On initialization, six factory-calibrated coefficients (C1–C6) are retrieved from the sensor's internal PROM and applied to compensate raw ADC readings for temperature and pressure, yielding accurate pressure measurements in Pascals.

A surface baseline is established at startup by averaging five consecutive readings, so depth is derived as:

$$\text{Depth} = \frac{P - P_{\text{surface}}}{\rho g}$$

This real-time depth estimate is fed directly into the heave PID controller, enabling autonomous depth hold, critical for maintaining stable survey altitude during photogrammetry transects and for precise depth measurement.

Motion and Control

At the core of Aurora's manoeuvrability is a robust software-based motion control system that translates pilot commands into precise thruster outputs. This capability is critical for operations requiring stable hovering and precise manipulation, such as specimen collection (Task 1.1) and sensor installation (Task 2.5).

Software Development Process & System Modelling

Development utilized Git for version control, enabling firmware and software sub-teams to work in isolated branches while ensuring stable module integration. Core control logic was incrementally validated through modular bench tests before full integration.

The control software is founded on a rigid-body dynamic model based on the Newton–Euler 6-DOF framework^{4,8}, linearized around the vehicle's primary operational envelope: a low-velocity hovering state. This linearization decouples the axes, enabling computationally efficient classical control theory. However, control authority degrades at high velocities or extreme pitch/roll angles.

Cascaded PID Feedback Controller Design

To handle dynamic underwater disturbances such as tether drag and water currents, a cascaded PID architecture is employed for depth, roll, pitch, and yaw⁶. The system isolates the kinematics into 2 nested loops:

- **Outer Loop (Angle/Position):** Compares the desired setpoint angle (from the pilot or auto-heading) against the actual angle measured by the IMU, producing a target angular rate rather than a direct motor command.
- **Inner Loop (Rate/Velosity):** Compares the target angular rate with the actual angular rate measured directly from the gyroscope, producing the final control effort sent to the thruster mixer.

The inner rate loop detects and corrects high-frequency disturbances instantly via the gyroscope, long before the ROV's physical angle changes enough to trigger the outer loop. This significantly improves reaction speed and stability. Two additional features further optimize system performance:

- **Integral Clamping (Anti-Windup):** Prevents indefinite integral accumulation when thrusters saturate, avoiding violent overshoot when disturbances are removed.
- **High-Pass Derivative Filtering:** Attenuates high-frequency mechanical noise from thruster vibrations, preventing erratic PWM spikes.

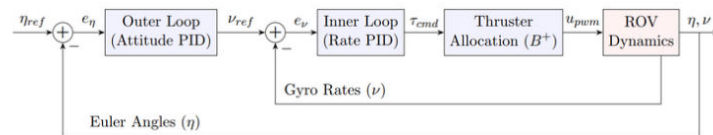


Figure 19: Cascaded control architecture separating slow attitude tracking from fast stabilization.

Control Logic & Operator Features

To improve operator performance and reduce pilot cognitive load, the software manages seamless transitions between manual control and autonomous feedback loops using a software multiplexer (MUX). The MUX parses the 1-byte control packet received from the GUI to toggle specific control loops.

When the pilot engages a semi-autonomous mode (e.g., *Depth Hold*), the MUX captures the current sensor reading at that exact instant and feeds it as the new setpoint to the outer PID loop. This ensures a *bumpless transfer* with zero erratic motion.

If the autonomous loop is disabled, the system flushes the PID integrators and safely returns raw GUI force vectors directly to the thruster mixer.

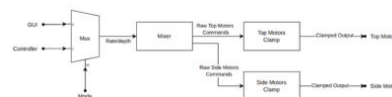


Figure 20: Control logic architecture showing the MUX routing between pilot and autonomous inputs.

Thruster Allocation Mixer

The cascaded PID controllers output a generalized six-degree-of-freedom force/torque command vector. To translate this into physical action, the software utilizes a custom thruster allocation mixer.

Based on the mechanical geometry of the 8-thruster vectored configuration, an 8×6 inverse kinematic matrix $\mathbf{B}_{inv}$ was derived. This matrix determines the proportional effort each thruster must exert to achieve the desired force and torque vector:

$$\mathbf{B}_{inv} = \begin{bmatrix} 0.2500 & -0.2500 & 0.0000 & 0 & 0 & -0.2500 \\ 0.2500 & 0.2500 & 0.0000 & 0 & 0 & 0.2500 \\ -0.2500 & 0.2500 & 0.0000 & 0 & 0 & -0.2500 \\ -0.2500 & -0.2500 & 0.0000 & 0 & 0 & 0.2500 \\ 0 & 0 & -0.2500 & -0.2500 & 0.2500 & 0 \\ 0 & 0 & -0.2500 & 0.2500 & 0.2500 & 0 \\ 0 & 0 & -0.2500 & -0.2500 & -0.2500 & 0 \\ 0 & 0 & -0.2500 & 0.2500 & -0.2500 & 0 \end{bmatrix}$$

Saturation and Scaling Algorithm

Following matrix multiplication, computed values can theoretically exceed hardware limits during aggressive maneuvers. Hard clipping these values would distort the force vector and cause uncommanded rotations.

Instead, a saturation algorithm evaluates horizontal and vertical thrusters independently. If any thruster exceeds its limit, the entire subgroup is proportionally scaled down. This preserves the intended force distribution and maintains trajectory and attitude even at maximum throttle.

System Identification & Controller Tuning

Rather than relying solely on theoretical hydrodynamic coefficients, empirical system identification (System ID) was performed. In a controlled pool environment, the ROV was subjected to open-loop step inputs along each axis. By recording the resulting angular rates and absolute angles through telemetry, accurate state-space models of the vehicle were constructed.

Using the MATLAB PID Tuner Toolbox, these models were imported to simulate the vehicle's dynamics. Optimal K_p , K_i , and K_d gains for both the inner rate and outer angle loops were calculated offline.

Finally, these baseline gains were deployed to the ROV firmware and empirically fine-tuned in water to account for unmodeled factors such as tether drag and buoyancy. This process resulted in a critically damped and highly stable control system.

Mission Algorithms

Keel Depth Measurement

By utilizing the on-board pressure sensor and aligning it properly with one of the cameras, the control code calculates the depth at the pressure sensor. This approach trivializes the mission down to a task of aligning the pressure sensor vertically with the point in the iceberg for which depth is being measured. An on-screen algorithm can be used to insert the offset of the sensor relative to the bottom of the ROV.

Invasive Crab Species Counting

A YOLOv8 model was trained using a pre-annotated dataset of the 3 crab species, generated in an automatic process we developed using filters in the industry-standard Blender for simulating an underwater environment and using OpenCV scripts for introducing a wide range of distortion and sticker placement. A simple button on this mission's specific tab in the GUI allows the copilot to take a screenshot to highlight and count the invasive crab species. An example of the workflow in Blender can be seen in Figure 21.

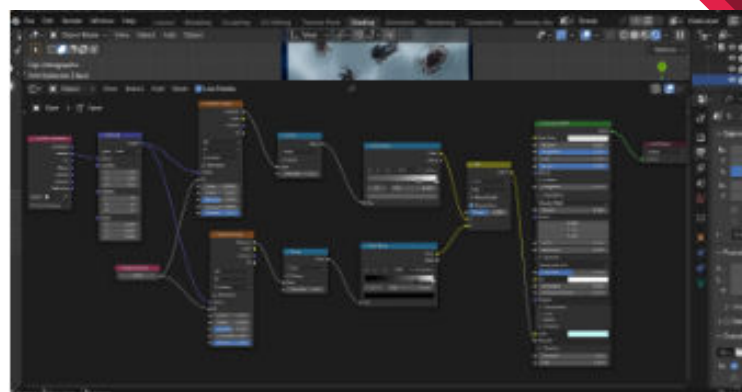


Figure 21: Blender Workflow

Different underwater lighting environments were simulated and inculcated into the dataset, as shown in Figure 22.



Figure 22: Underwater Lighting Environments

This training approach was found to be more time and cost-effective than trying to obtain a dataset by taking pictures of mock-props and manually annotating the dataset, and the model training approach in general is more widely preferred over other computer-vision approaches like template matching and color detection, all of which were tested.

Photogrammetry & Length Measurement

Most approaches to photogrammetry make use of periphery information like IMU readings, motion, and stereophotogrammetry to restructure models from images. The most basic working principle is tracking similarities between every two images with about a 40% difference, and pinning them to a 3D plane while projecting the dissimilarities relative to the similarities¹.

While we did trial integration of IMU readings and SfM (structure from motion) in the open-source program Meshroom with good results, ultimately, perfect results would not have been achieved without usage of a stereo camera or machine learning to aid the process. To keep our solution cost-effective and avoid the difficulty of emulating a stereo camera with two cameras, we chose to use the open-source AI-powered Hunyuan 3D and to keep the Meshroom workflow with AI-aided noise reduction as backup.

After the model is constructed and exported as a .obj file, it is opened in Blender to complete the length

measurement task using the app's Measure Tool. A reference object with known length should be used regardless of the approach, in order to provide the most accurate measurements. We will use cues from the prop itself, which has fixed-length parts, but in other settings, a permanently attached ruler onboard may help.

3 Non-ROV Device

3.1 Mechanical Design

The non-ROV device is housed in a durable, waterproof PVC Pipe (shown in Figure 24) and utilizes a buoyancy engine (shown in Figure 23), comprising a motor-driven linear power screw and four parallel 60 mL syringes, to control depth. By retracting to intake water (increasing density) or extending to expel it (decreasing density), the system manages ascent and descent, while internal support disks keep the assembly axially aligned to prevent lateral movement and leaks, ensuring mechanical reliability.



Figure 23: Buoyancy Engine



Figure 24: Non-ROV Device Design

3.2 Electrical Design

The float's electrical system is built around the ESP32 microcontroller, which handles sensor data acquisition, motor actuation, and communication.

A key component is the GY-63 MS5611-01BA03 Barometer Pressure Sensor, installed externally to directly measure water pressure, enabling depth determination. The ESP32 communicates with the sensor over I2C, periodically reading pressure values and timestamping each measurement using its internal Real-Time Clock (RTC). These readings are stored locally throughout the dive. Once the float surfaces and reestablishes wireless connectivity, the ESP32 transmits the logged data to the station via MQTT requests.

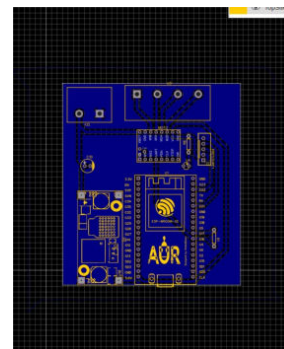


Figure 25: PCB Design

A compact printed circuit board (PCB) hosts all components (as shown in Figure 25), including the fuse holder and power input. The system draws power from a 3S 18650 battery pack (12V nominal), which supplies the buoyancy engine motor directly. An integrated buck regulator steps the 12V down to 5V to power the ESP32 and MS5611 Pressure sensor.

Power Calculations

The device has a maximum power consumption of **36W** (Table 3), drawing around **3A** from the **12V** power supply. Taking in a safety factor of 1.5x for in-rush currents, the system is protected by a **5A** fuse.

Table 3: Power Consumption Summary

Component	Power
Motor	30W (12V×2.5A)
Pressure Sensor	1W (5V×0.2A)
ESP32	3W (5V×0.6A)
Total	36W

Current Calculation (12V Supply):

- Base Current: $\frac{36W}{12V} = 3A$
- With Safety Factor (1.5x): 4.5A
- Fuse Installed: 5A

System Interface Diagram (SID)

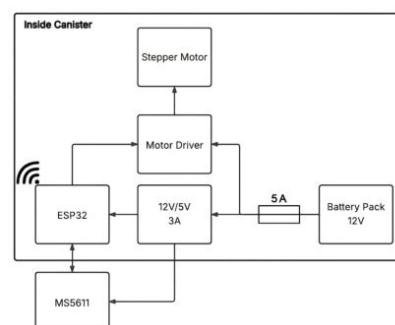


Figure 26: System Interface Diagram (SID).

4 Safety

At AUR, safety is more than a checklist; it's a mindset embedded in everything we do. From their first day, team members are trained in safety principles that protect both people and equipment. These principles guide us through every phase: design, build, and test.

4.1 Safety Features

One of our top priorities is keeping Aurora safe to operate throughout all development phases. Electrical and mechanical components incorporate multiple protective layers:

- **Fused Electrical System:** Appropriately rated fuses protect all major circuits from over-current damage. A 20A fuse is placed 30 cm from the Anderson Powerpole connectors per MATE specifications.
- **Waterproof Enclosures:** All electrical components are sealed in protective housings to prevent water ingress, even under pressure.
- **Strain Relief:** Both ends of the tether are secured with strain relief techniques, preventing connectors from pulling or damaging during operation and minimizing the risk of accidental disconnection.
- **Shrouded Thrusters:** All propeller blades are fully enclosed within shrouds, eliminating accidental contact during testing and handling.
- **Smoothed Frame Edges:** The frame is deburred and polished to remove sharp edges that could injure team members or damage sensitive surfaces.
- **Warning Labels:** Visual warnings are placed on hazardous areas (eg: thrusters and main power unit).

Together, these features enhance safety, simplify maintenance, and ensure reliable operation during testing and deployment.

4.2 Safety Procedures

We follow strict operational procedures to ensure the safety of every team member at all times:

- **Safety Training:** All new members receive a guided introduction to workspace safety rules and work under close mentor supervision until they demonstrate a solid understanding of safety measures.
- **Personal Protective Equipment (PPE):** Members, particularly in the mechanical subteam, are required to wear appropriate safety gear, including goggles, gloves, and face masks when working with high-speed tools, soldering stations, or heavy equipment as shown in Figure 27.



Figure 27: Applying Safety Procedures

- **Workshop Clean-Up:** At the end of each session, members return equipment to its proper place. Additionally, the entire team participates in a monthly deep-clean day to maintain an organized, hazard-free workspace.
- **Safety Checklist:** A comprehensive safety checklist is followed before any testing or deployment step (see Appendix 8.1). It confirms that all systems are functioning properly and all risks are accounted for.

By applying these procedures consistently, the team maintains a safe environment where everyone can work confidently and efficiently.

5 Testing & Troubleshooting

5.1 Testing Methodology

Aurora's electrical system underwent a rigorous multi-level testing process before ever touching water:

- **Component Level:** Every individual component was tested for basic functionality before assembly. This immediately caught several faulty buck converters from our inventory, components that would have caused headaches if we'd soldered them in blindly.
- **PCB Level:** Each custom board went through a series of validation steps, short circuit testing, track-to-pad continuity checks, and power delivery verification. Here we discovered a few soldering issues and disconnected tracks that were easy to fix before moving forward. Only after passing these did we proceed to full functional testing of the board itself. Figure 28 illustrates our complete PCB testing workflow.
- **System Level:** With all PCBs verified, we connected every component together and tested the integrated system as a whole, confirming that communication, power distribution, and control signals all worked as intended.

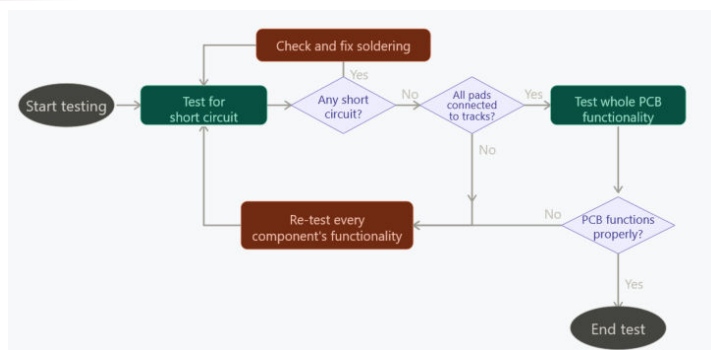


Figure 28: PCB Testing Flow Chart

Thanks to this layered approach, by the time we reached the third level of testing, nearly every board was functioning smoothly. The methodology saved us countless hours of troubleshooting downstream, because we caught problems when and where they actually happened.

Only after passing every stage of bench testing did we move to underwater trials, where we validated performance under real operating conditions.

After this entire process was over, we held multiple underwater tests to ensure every part of our system worked efficiently under real-life conditions.

Before Aurora ever touched water, we needed absolute confidence that our enclosures would keep water out. The stakes are simple: leaks destroy electronics.

We used compressed air at 2 bars to pressure-test every sealed compartment, the main electronics canister, each camera housing, and the pneumatic valve enclosure. The process is straightforward: seal everything up, pressurize to 2 bars, and monitor for any pressure drop over time. If the gauge moved, we had a leak.

This method proved invaluable. It let us verify that every cable gland was properly seated and that our end plates were sealing correctly without risking a single component. We caught tiny leaks, fixed them, and retested until every enclosure held pressure perfectly at 2 bars.

It's not glamorous, but it's effective. We know that if an enclosure can hold 2 bars of air, it will hold back water at depths far beyond what we'll encounter in competition. And we'd much rather find a leak on the workbench than at the bottom of a pool.

5.2 Troubleshooting Strategies

Electrical Troubleshooting

When electrical issues arose, we followed a systematic multi-stage strategy:

- **Visual Inspection:** Examined for burnt components, loose connections, or tripped breakers. This step alone often solved the problem.

- **Diagnostic Testing:** Used multimeters and clamp meters to measure voltage, current, and resistance, comparing readings against expected values.
- **Isolation:** Isolated suspected sections and tested individual components to avoid chasing issues through the entire system.
- **Logic Verification:** Reviewed wiring diagrams and control logic to ensure correct sequencing.

Once faulty components were identified, they were repaired or replaced and the system retested.

Real-World Case: During pool testing, a sudden Raspberry Pi power warning appeared. Visual inspection showed no damage, but diagnostic testing revealed a 5V buck converter outputting only 4.2V instead of 5V. Isolation confirmed the issue was localized to that converter, and logic verification showed correct wiring. Replacing the worn converter fixed the problem in 20 minutes, hours faster than guesswork.

Mechanical Troubleshooting

When mechanical issues arise, we follow experience-based approaches:

- **Leaks:** Compressed air test at 2 bars identifies leaks quickly. Pressure drops pinpoint exactly where to look, usually loose cable glands or seals, without getting electronics wet.
- **Frame and Structure:** Regular inspection of stress points, glued joints, and ballast weights catches hair-line cracks early, turning potential catastrophes into five-minute repairs.
- **Thrusters:** First check nozzles for debris, then inspect 3D-printed mounts for cracks. Spares are kept on hand for preemptive replacement when wear appears.
- **Pneumatic Manipulator:** Soapy water sprayed on pressurized lines reveals leaks instantly through bubbles, saving hours of disassembly.

Our philosophy: check obvious stuff first, catch problems early, and keep spares for what breaks most often.

6 Logistics

6.1 Company

6.1.1 History

Founded in **May 2021** by a group of ambitious engineering students from various departments at **Alexandria University**, **AUR** emerged from a shared

passion for robotics and a desire to create opportunities for hands-on learning, and technical exploration.

From the very beginning, AUR has been fully dedicated to the field of robotics. Through intensive training, collaborative projects, and national and international competitions, we have empowered students to become not only skilled engineers but also confident problem-solvers and innovators.

In just a few short years, our initiative has reached remarkable milestones. To date, we have trained more than **350 students**, equipping them with strong foundations in **mechanical design, electronics, and programming**. Many of these students have gone on to lead and contribute to competitive robotics teams, research projects, and engineering initiatives.

• Competition Achievements

1. **All Egypt Micromouse 2021** – Dominated the podium, earning **1st, 2nd, and 3rd place** at **EJUST University**.
2. **ORCE Innovation Challenge** – Secured **3rd place** with an original project competing against top teams across Egypt.
3. **IEEE Victoris 1.0 (2022)** – Finished in the **Top 10** in the **Micromouse category** at **Mansoura University**.
4. **IEEE Victoris 2.0 (2023)** – Returned with stronger designs and teamwork, taking **1st place**.
5. **Minesweepers 2023 (Alamein University)** – Competed for the first time in minefield navigation, gaining key insights and experience.
6. **IEEE Mutex Summit (2024)** – Earned the award for **Best Mechanical Design** in the **Firefighting Robot Challenge** held at **Zagazig University**.
7. **ANNMMC'24 (Hungary)** – Reached the **final round** of the international **All Nations Micromouse Competition**, competing among the world's best.
8. **IEEE Victoris 3.0 (2024)** – With stronger designs and teamwork, taking **1st place** again.
9. **IEEE Victoris 4.0 (2025)** – For the third year in a row, **1st place** again.

6.1.2 Structure

AUR's executive board consists of:

- **CEO - Chief Executive Officer:** Responsible for all high-level decision-making to ensure that the goals and vision are realized with established timelines.
- **CTO - Chief Technology Officer:** Supports the CEO and oversees all technical divisions.

- **CFO - Chief Financial Officer:** Manages the financial planning and strategy.

The organizational structure is divided into three primary departments: **Mechanical, Hardware, and Software**. Each department is led by a **department head** and supported by a **vice head** to ensure efficient management and coordination. A full hierarchical structure diagram is shown in the Appendix **8.2**.

Additionally, we have a dedicated **Media Team** that manages social media, creates visual content, and collaborates with sponsors to ensure consistent branding and promotional outreach.

6.1.3 Management

• Strategic Framework:

To meet 2026 mission demands, AUR adopted a hybrid management framework merging Systems Engineering with Agile development. Our objective was building a comprehensive schedule while establishing clear protocols to manage resources and solve day-to-day operational problems.

The project lifecycle, shown in Figure **29**, began in December 2025 with cross-disciplinary architectural reviews led by the CTO and Department Heads. After multiple design iterations evaluating subsystem trade-offs, a baseline architecture was locked in, ensuring every mechanical housing, electrical layout, and software pipeline was designed with full-system integration in mind from day one.

• Agile Work Breakdown:

Once architecture was established, the CTO translated it into an Agile framework. Development phases were categorized into Epics, broken into Stories, and fragmented into actionable Tasks, as shown in Figure **30**. Each task included a Task Directive document defining name, description, objectives, requirements, and testing protocols. **Discord** served as our centralized communications hub, structured by subsystem and sprint cycle.

• Training & Sprint Execution:

Before fabrication or development began, each sub-team completed three intensive training modules to bridge knowledge gaps. Firmware, for example, conducted sessions on ROV dynamics, PID theory, and tuning methodologies.

Development ran in weekly Agile Sprints. The CTO led macro-level Sprint Reviews to track progress and allocate resources. Department Heads held micro-level stand-ups multiple times weekly to troubleshoot daily challenges and monitor task velocities.

• Integration & Validation:

The final ROV assembly, the Integration Phase, was our highest-risk period. The CTO shifted from macro-oversight to daily operational command. A day-by-day Integration & Validation Plan reorganized personnel into cross-functional strike teams focused on daily objectives. Structured testing plans coordinated firmware telemetry checks with mechanical structural tests and hardware thermal stress testing.

Internal Directives with strict deadlines enforced accountability. The protocol mandated zero tolerance for integration failures: all bugs required immediate debugging and re-testing, and no fix was complete until independently verified twice. This systematic approach ensured operational anomalies were isolated and resolved long before the vehicle touched water.

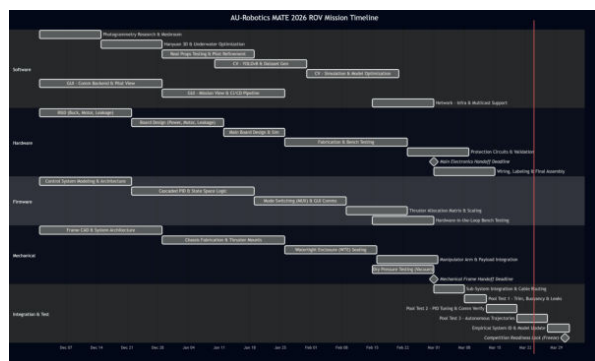


Figure 29: AUR's 2026 ROV timeline

■ Epic A — Sensor Drivers

Story A1 — IMU Driver (BNO055)

Goal: MCU can read Euler angles + body rates reliably at required frequency.

Tasks

- A1.1 Implement low-level PC communication abstraction (if not already in HAL).
- A1.2 Implement BNO055 register map in a dedicated driver (.cpp/.h).
- A1.3 Implement initialization sequence (config mode → IMU mode → fusion mode).
- A1.4 Implement calibration routine:
 - Trigger calibration
 - Read calib status from BNO055
 - Store calibration offsets in flash
- A1.5 Implement read functions:
 - `getEulerAngles()`
 - `getBodyRates()`
- A1.6 Test driver on hardware (unit test + real sensor test).
- A1.7 Logging for debugging (print orientation & rates via UART).

Acceptance Criteria

- Reading angles/rates at ≥ 100 Hz
- Calibration persists across resets
- No bus lockups / timeout recovery implemented

Figure 30: Sample of firmware's epics and tasks

6.2 Accounting

6.2.1 Budget

• Budget Overview:

Financial planning for Aurora was approached as a detailed resource allocation strategy, ensuring each

subsystem received sufficient funding based on system impact while maintaining strict expenditure control. The project operated under a total allocated budget of **2,260.45 USD** (based on 1 USD = 51.76 EGP), covering design, fabrication, electronics, testing, and competition requirements.

• Budget Distribution:

Funds were allocated across key areas:

- **Structural & Mechanical:** \$517.97 — Frame fabrication, sealing mechanisms, mounting structures
- **Electronics & Control:** \$528.99 — Embedded systems, power management, sensors, PCB fabrication
- **Registration & Fees:** \$627.07 — Competition participation fees
- **Transportation & Logistics:** \$79.35 — Safe transport of ROV and equipment
- **Testing & Validation:** \$33.06 — Testing environments and trial runs
- **Tools & Consumables:** \$121.23 — Workshop tools, fabrication aids, expendables
- **Media & Representation:** \$220.41 — Documentation, promotional materials
- **Reserve Margin:** \$132.37 — Buffer for design changes or component failures
- **Cost-Efficiency Strategies:**

Selected components were planned for reuse from previous projects where compatibility and performance were not compromised, reducing overall expenditure. The budget also accounted for potential PCB redesign iterations, preventing disruptions during later development stages.

– Funding Sources:

The project was supported through competition prizes, team contributions, and external sponsorships, summarized in table 4. The overflowing funds were used to support the team's participations in other competitions.

Source	Amount (USD)
Micromouse 2025 Prize	386.4
Team Contributions	2260.45
Makers Electronics	36.1
Nori Solutions	154.5
Total	2837.45

Table 4: Funding Sources

• Detailed Analysis:

For a complete budget breakdown, see Appendix 8.3.

6.2.2 Costing

- **Costing Methodology:**

Expenditures were categorized by subsystem and systematically tracked for individual components, materials, and services. Providing clear cost distribution and enabled identification of optimization areas.

- **Financial Documentation:**

All transactions were recorded in a centralized Google Sheet with continuous updates throughout the project lifecycle. Invoices and receipts were archived to validate recorded costs.

- **Costing Structure:**

Each component was documented with unit cost, quantity, and total cost contribution, ensuring traceability, accountability, and consistency between planned and actual expenditures.

- **Financial Outcome:**

Total expenditure amounted to **1,809.8 USD**, while total income reached **2,008 USD**, resulting in a remaining balance of approximately **198.2 USD**, indicating effective budget management and controlled spending.

- **Detailed Analysis:** For a complete costing breakdown, see Appendix 8.4.

7 Conclusion

7.1 Future Improvements

At AUR, our engineering philosophy is rooted in continuous, iterative development. Post-mission analysis has identified several critical areas for strategic improvement, focusing on transitioning from a pilot-reliant platform to a highly autonomous, dynamically adaptable subsea worker while maintaining cost-efficiency.

- **Variable Buoyancy Engine (VBE):**

Currently, neutral buoyancy trimming requires manual deck-side adjustments, and heavy payloads force vertical thrusters to drain battery power, fighting induced negative buoyancy. We propose a low-cost electromechanical VBE using a stepper motor, reversible pump, and internal bladder. This allows dynamic density adjustment mid-flight—for heavy lifts, the ROV can pump water out, using buoyancy physics rather than thrusters to lift objects, extending mission dive times.

- **Full Autonomous 6-DOF Motion & Velocity Control:**

Our current architecture excels at attitude and depth hold, but planar translations remain open-loop, force-commanded. Next iteration will feature closed-loop velocity control across all 6 DOF using optical flow sensors and upgraded IMUs with an Extended Kalman Filter (EKF). Pilots will command exact speeds (e.g., "0.5 m/s forward"), enabling stable visual transects for pipeline scanning or mapping.

- **Global Localization & Trajectory Generation:**

The ROV currently relies on visual dead-reckoning through camera feeds. We intend to implement global localization by fusing IMU data, flow sensors, and surface GPS into a topside ground station for real-time coordinate mapping. Paired with spline-based trajectory generation, pilots will click waypoints on a map for autonomous 6-axis flight path execution, with auto-return capability if communication is lost.

- **Advanced Multi-Function Robotic Arm:**

Our current end-effector is effective for simple grasping but requires maneuvering the entire vehicle for precise positioning. We will develop a 3–4 DOF robotic manipulator using low-cost waterproof servos with Inverse Kinematics (IK) computed topside. This enables a "grab-and-work" paradigm—one arm stabilizes the ROV against currents while the second performs delicate tasks, reducing pilot fatigue and completion times.

7.2 References

- [1] **SIFT Algorithm.**
- [2] **MateROV 2025 Julietta Technical Documentation**, 2025.
- [3] **MATE ROV Competition Pioneers Manual**, 2026.
- [4] T. I. Fossen and O. E. Fjellstad. Nonlinear modelling of marine vehicles in 6 degrees of freedom. *Mathematical and Computer Modelling of Dynamical Systems*, 1(1):17–28, 1995.
- [5] A. Ghilezan and M. Hnatiuc. The roV communication and control. In *2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging (SIITME)*, pages 336–339. IEEE, 2017.
- [6] R. G. B. Sangalang, D. J. S. Masangcay, C. M. R. Torino, and D. J. C. Gutierrez. Design of a control architecture for an underwater remotely operated vehicle (rov) used for search and rescue operations. Technical report, Unknown Institution, 2020.
- [7] S. Siregar, M. I. Sani, M. M. Kurnia, and D. Hasbiallyoh. Low-cost communication system for explorer-class underwater remotely operated vehicle. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 17(2):593–600, 2019.
- [8] C.-J. Wu. *6-DoF Modelling and Control of a Remotely Operated Vehicle*. PhD thesis, Flinders University, College of Science and Engineering, Engineering Discipline, 2018.

8 Appendices

8.1 Safety Checklist

Operational Safety Checklist				Workshop Construction Safety Checklist
Preparations Pre-operation	Powering Up	Launching & In-Water Operations	Retrieval & Post-Mission Checks	
- Remove any obstructions around the poolside - Tether is free of knots & firmly secured to both the station & the ROV - All electronic housings are properly sealed - Appropriate fuses are installed & rated - Inspect for exposed wires or unstable electrical connections - Proper safety measures are followed, including wearing PPE - The station, & necessary software, is fully operational	- Confirm that LEDs are functioning when ROV is turned ON - Dry test of thrusters, manipulators, and payload systems - Verify all video feeds and sensor data are working correctly	- Perform unit testing before full system integration - Tether man must maintain control of the tether at all times - Only designated team members are allowed to handle the ROV - Visual inspection for leaks or air bubbles - Continuously monitor ROV communication and system responsiveness - Be prepared to troubleshoot in any case needed - Confirm mission objectives through feedback analysis	- Pilot must surface the ROV and power off all thrusters - Only assigned team members retrieve the ROV safely - Place the ROV securely & safely on the poolside - Completely power off the ROV - Fully inspect for leaks, loose connections, & tether condition - All tools, and equipment used must be collected from station - Coil and store the tether properly to prevent damage	- A tidy & well-organized work area is maintained before beginning any task - Access to the workshop during operations is limited to designated team members only - Usage of specialized or hazardous tools is permitted only if properly trained and authorized - Wearing suitable PPE whenever working with equipment, soldering, or chemicals - All electrical systems are OFF prior to any maintenance or handling - Smooth out or clearly mark any sharp edges on fabricated components to prevent injury - Properly return all tools and leftover materials in their designated areas once work is finished - Conduct routine deep cleaning to sustain a safe and efficient working environment
	Loss of Communication - Immediately power down the ROV to prevent potential damage - Conduct a full inspection for any visible issues or faults - Perform troubleshoot procedures to identify the cause of failure			

Table 5: Safety Checklist

8.2 Company Structure & Job Description

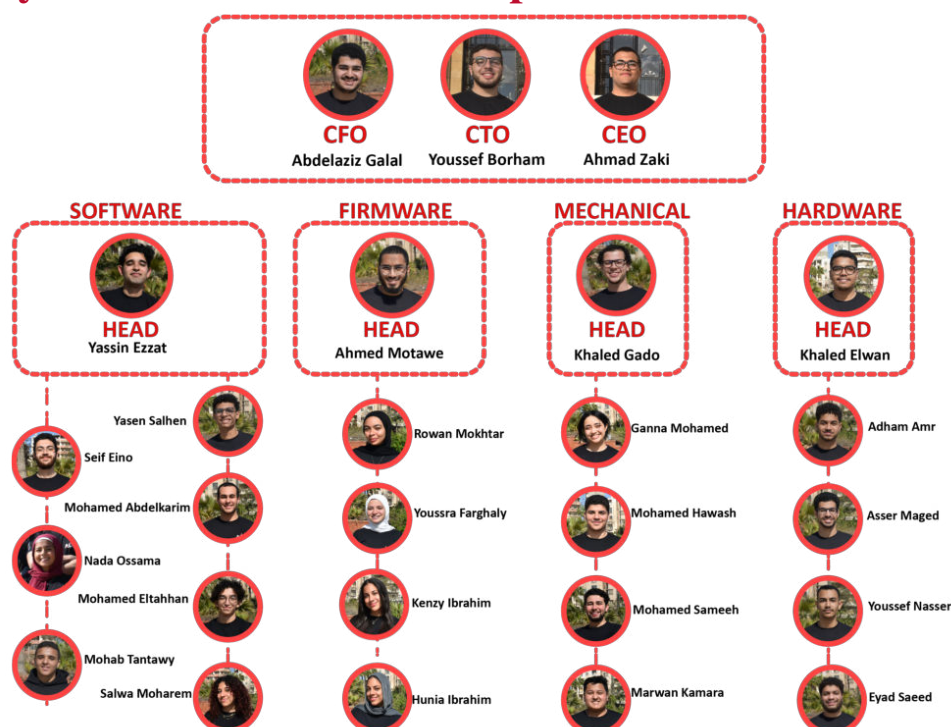


Figure 31: AUR's Team Structure

8.3 Project Budget

	Category	Item	Description	Status	Quantity	Unit Price (USD)	Total Cost (USD)
Mechanical	Thruster System	Bilge Pumps	Main propulsion motors	Purchased	8	19.6	156.8
		Kort Nozzle	Flow optimization nozzle	Purchased	2	5.31	10.62
		Kort Nozzle	Flow optimization nozzle	Donated	6	5.31	31.86
		Propellers	Thruster propellers	Purchased	6	5.41	32.46
		Propellers	Thruster propellers	Purchased	2	5.41	10.82
		3D Printed Stators	Motor flow stabilization	Purchased	10	3.09	30.9
	Pneumatic system	Pistons	Mechanical actuators to control the gripper movement.	Purchased	1 set	23.54	23.54
		Solenoid Valve	Pneumatic control	Purchased	1	50	50
		Hose	Tubing used for air transmission	Purchased	1 set	15.8	15.8
		Flow control valve	To adjust and regulate airflow rate.	Purchased	1 set	1.49	1.49
		Service unit with pressure control valve	To regulate and maintain consistent air pressure.	Purchased	1	12.13	12.13
		Safety valve	Protective component	Purchased	1	0.81	0.81
		Non return valve	Ensures one-directional airflow	Purchased	1	2.46	2.46
		Fittings	Join pneumatic components securely	Purchased	1	19.87	19.87
	Gripper & Actuation System	Compressor	Air source that generates pressurized air for the pneumatic system	Purchased	1	81.8	81.8
		Pneumatic Tubing & Fittings	Air distribution	Purchased	1 set	15	15
	Structure & Enclosure	Aluminum Rods/Rolls	Couplers & rotating gripper	Purchased	1 set	20	20
		Hardware Enclosure	Waterproof electronics housing	Purchased	1	24.6	24.6
	Sealing & Assembly	Camera Enclosure	Waterproof camera housing	Donated	1	20.2	20.2
		Acrylic Sheets	Camera + PCB enclosure	Purchased	1	14.2	14.2
		Artillon Roll	Gripper structure material	Purchased	17 kg	3.63	61.71
		Gland Packing	Motor sealing/isolation	Purchased	0.5 kg	4.84	2.42
		Screws & Fasteners	Assembly hardware	Purchased	2 kg	4.1	8.2
	Total in USD						
Electrical	Control & Electronics	Raspberry Pi 4 (4GB RAM)	High-level processing unit for video streaming and system communication	Purchased	1	102.4	102.4
		STM32F401RCT6	control unit for sensors, motors, and communication	Purchased	1	8	8
		TA6586	Motor driver IC	Purchased	9	1.5	13.5
		TP1205	Transistor	Purchased	3	0.7	2.1
	Power System	Passive Components	Resistors, capacitors	Purchased	30	0.0097	0.29
		PCB Fabrication	All boards	Purchased	4	8	32
		XL4016 Buck	DC-DC module	Purchased	1	5	5
		48V to 12V Buck	Power modules	Purchased	2	4	8
	Wiring & Integration	Waterproof converters	Protected modules	Purchased	4	12	48
		12V Power Supply	Main supply	Purchased	4	20	80
		XT60 connectors	Power connectors	Purchased	10	1.5	15
		Terminal blocks	HB9500	Purchased	20	0.5	10
	Sensors	JST/PH connectors	Signal & motors	Purchased	20	0.3	6
		Ethernet cable	Tether communication	Purchased	1	12	12
		Electrical wires	Internal wiring	Purchased	1	5	5
		Heat shrink	Insulation	Purchased	1	3	3
	Total in USD	Solder wire	Assembly	Purchased	1	3	3
		Headers	PCB pins	Purchased	80	0.003	0.17
		BNO055	IMU	Purchased	1	6	6
		BMP280	Pressure sensor	Purchased	1	3	3
		Water sensor	Leakage detection	Purchased	2	2	4
		Limit switches	Position sensing	Purchased	2	1	2
		Camera (USB)	Visual feedback	Purchased	1	27	27
		Total in USD					
Contingency	Uncertainty margin			—	—	90	
	Total in USD						
Workshop & Tools	Workshop	Workspace / Workshop Access	Workspace for fabrication and testing	Donated	—	—	0
		Electricity Consumption	Power usage during manufacturing and testing	Purchased	1	1	29.32
	Tools	Soldering Iron	PCB assembly tool	Purchased	1	5	5
		Multimeter	Electrical measurement tool	Donated	2	8.12	16.25
		Wire Stripper & Cutter	Cable preparation tool	Purchased	1	3	3
		Screwdriver Set	Assembly tools	Purchased	1	4	4
	Drill & Drill Bits	Mechanical fabrication tools	Purchased	1	6.7	6.7	
	Total in USD						
General Costs	Registration Fees	Competition Regional Registration	Participation fees regional competition	Purchased	1	214	214
		Competition Global Registration	Participation fees in the global competition	Purchased	1	355	355
	Transportation	Transportation & Logistics	Transport of ROV and equipment	Purchased	1	199	68.06
		Total in USD					
Media & Representation	Media	T-shirts	Team uniforms	Purchased	1 set	4.45	178.05
		Banner	Team identification	Purchased	1	13.54	13.54
		Stickers	Branding materials	Purchased	1 set	3	3
Total in USD							194.59 USD
Research & Development (R&D)	Mechanics R&D	Waterproofing Experiments	Seal testing materials	Purchased	1 set	5	5
		ESP32 Dev Board	Development/testing board	Purchased	1	9.35	9.35
		Breadboards & Jumper Wires	Circuit prototyping	Purchased	1 set	4.5	4.5
	Electrical R&D	Sensor Testing Modules	IMU and pressure testing	Purchased	1 set	8	8.02
		Total in USD					
Total Expenses (USD)							2055.95

8.4 Project Costing

	Category	Item	Description	Status	Quantity	Unit Price (USD)	Total Cost (USD)
Mechanical	Thruster System	Bilge Pumps	Main propulsion motors	Purchased	8	19.6	156.8
		Kort Nozzle	Flow optimization nozzle	Purchased	2	5.31	10.62
		Kort Nozzle	Flow optimization nozzle	Donated	6	5.31	31.86
		Propellers	Thruster propellers	Purchased	6	5.41	32.5
		Propellers	Thruster propellers	Purchased	2	5.41	10.8
		3D Printed Stators	Motor flow stabilization	Purchased	10	3.09	30.9
	Pneumatic system	Pistons	Mechanical actuators to control the gripper movement.	Purchased	1 set	23.54	23.54
		Solenoid Valve	Pneumatic control	Purchased	1	50	50
		Hose	Tubing used for air transmission	Purchased	1 set	15.8	15.8
		Flow control valve	To adjust and regulate airflow rate.	Purchased	1 set	1.49	1.49
		Service unit with pressure control valve	To regulate and maintain consistent air pressure.	Purchased	1	12.13	12.13
		Safety valve	Protective component	Purchased	1	0.81	0.81
		Non return valve	Ensures one-directional airflow	Purchased	1	2.46	2.46
		fittings	Join pneumatic components securely	Purchased	1	19.87	19.87
	Gripper & Actuation System	Compressor	Air source that generates pressurized air for the pneumatic system	Purchased	1	81.8	81.8
		Pneumatic Tubing & Fittings	Air distribution	Purchased	1 set	15	15
		Aluminum Rods/Rolls	Couplers & rotating gripper	Purchased	1 set	20	20
	Structure & Enclosure	Hardware Enclosure	Waterproof electronics housing	Purchased	1	24.6	24.6
		Camera Enclosure	Waterproof camera housing	Donated	1	20.2	20.2
	Sealing & Assembly	Acrylic Sheets	Camera + PCB enclosure	Purchased	1	14.2	14.2
		Artillon Roll	Gripper structure material	Purchased	4 kg	3.63	14.52
		Gland Packing	Motor sealing/isolation	Purchased	0.5 kg	4.84	2.42
		Screws & Fasteners	Assembly hardware	Purchased	2 kg	4.1	8.2
	Total in USD						
Electrical	Control & Electronics	Raspberry Pi 4 (4GB RAM)	High-level processing unit for video streaming and system communication	Purchased	1	102.4	102.4
		STM32F401RCT6	control unit for sensors, motors, and communication	Purchased	1	8	8
		TA6586	Motor driver IC	Purchased	9	1.5	13.5
		TIP120G	Transistor	Purchased	3	0.7	2.1
		Passive Components	Resistors, capacitors	Purchased	30	0.0097	0.29
		PCB Fabrication	All boards	Purchased	4	8	32
	Power System	XL4016 Buck	DC-DC module	Purchased	1	5	5
		48V to 12V Buck	Power modules	Purchased	2	4	8
		Waterproof converters	Protected modules	Purchased	4	12	48
		12V Power Supply	Main supply	Purchased	4	20	80
		XT60 connectors	Power connectors	Purchased	10	1.5	15
		Terminal blocks	HB9500	Purchased	20	0.5	10
	Wiring & Integration	JST/XH connectors	Signal & motors	Purchased	20	0.3	6
		Ethernet cable	Tether communication	Purchased	1	12	12
		Electrical wires	Internal wiring	Purchased	1	5	5
		Heat shrink	Insulation	Purchased	1	3	3
		Solder wire	Assembly	Purchased	1	3	3
		Headers	PCB pins	Purchased	80	0.009	0.17
	Sensors	BN0055	IMU	Purchased	1	6	6
		BMP280	Pressure sensor	Purchased	1	3	3
		Water sensor	Leakage detection	Purchased	2	2	4
		Limit switches	Position sensing	Purchased	2	1	2
		Camera (USB)	Visual feedback	Purchased	1	27	27
	Total in USD						
Contingency	Uncertainty margin			—	—		87
	Total in USD						
Workshop & Tools	Workshop	Workspace / Workshop Access	Workspace for fabrication and testing	Donated	—	—	0
		Electricity Consumption	Power usage during manufacturing and testing	Purchased	1	1	29.32
	Tools	Soldering Iron	PCB assembly tool	Purchased	1	5	5
		Multimeter	Electrical measurement tool	Donated	2	8.12	16.25
		Wire Stripper & Cutter	Cable preparation tool	Purchased	1	3	3
		Screwdriver Set	Assembly tools	Purchased	1	4	4
		Drill & Drill Bits	Mechanical fabrication tools	Purchased	1	6.7	6.7
	Total in USD						
General Costs	Registration Fees	Competition Regional Registration	Participation fees regional competition	Purchased	1	214	214
		Competition Global Registration	Participation fees in the global competition	Purchased	1	355	355
	Transportation	Transportation & Logistics	Transport of ROV and equipment	Purchased	1	193	68.06
	Total in USD						
Media & Representation	Media	T-shirts	Team uniforms	Purchased	1 set	4.45	178.05
		Banner	Team identification	Purchased	1	13.54	13.54
		Stickers	Branding materials	Purchased	1 set	3	3
Total in USD							194.59 USD
Research & Development (R&D)	Mechanics I R&D	Waterproofing Experiments	Seal testing materials	Purchased	1 set	5	5
		ESP32 Dev Board	Development/testing board	Purchased	1	9.35	9.35
		Breadboards & Jumper Wires	Circuit prototyping	Purchased	1 set	4.5	4.5
	Electrical R&D	Sensor Testing Modules	IMU and pressure testing	Purchased	1 set	8	8.02
Total in USD							26.87 USD
Total Expenses (USD)							2005.77

8.5 SIDs

8.5.1 Pneumatic

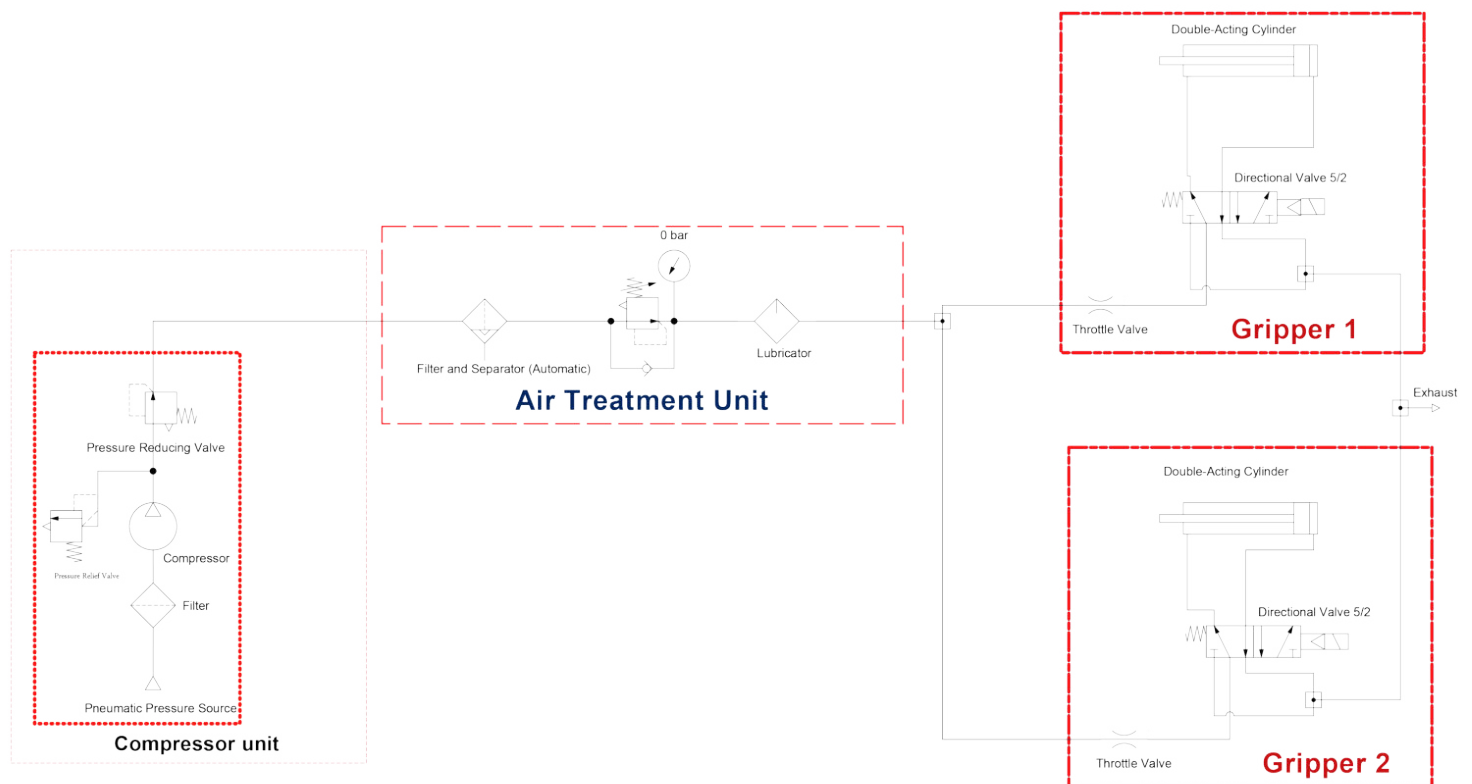


Figure 32: Pneumatic System Interface Diagram (SID).

8.5.2 Electrical

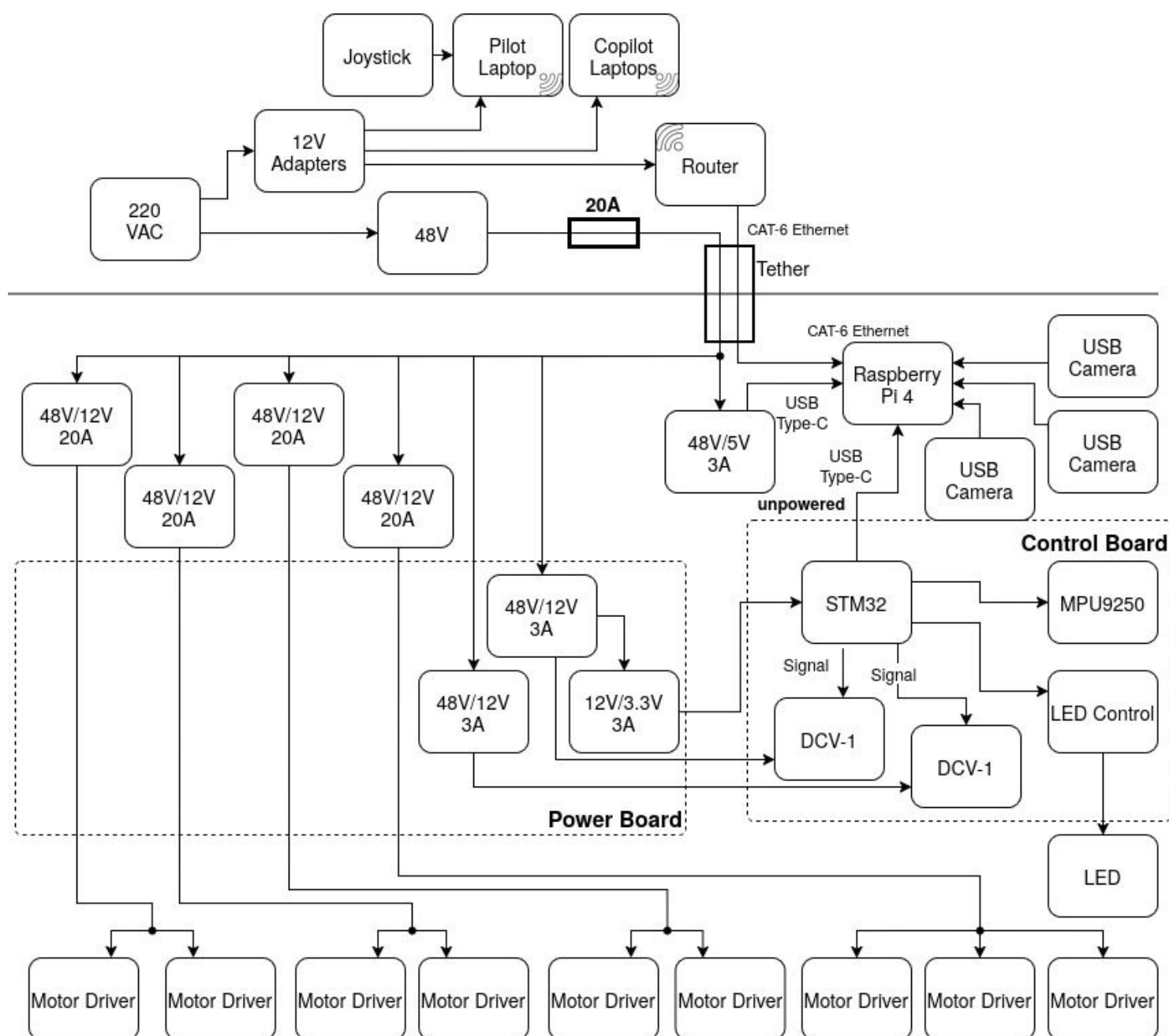


Figure 33: Electric System Interface Diagram (SID).