

NAUTIX PIONEERS

TECHNICAL DOCUMENTATION

HYDRONAUT

ALEXANDRIA, EGYPT



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27' Mohamed Rezk* Float PM
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29' Heidi Ahmed*
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28' Ibrahim Ahmed*
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Graduation Year

*Denotes New Members

*HS : High School

*PM : Projet Manager

*FM : Fuctional Manager

HYDRONAUT

ABSTRACT

Nautix Robotics Team from Vortex Academy is a group of passionate students dedicated to building underwater robotic systems.

Our main goal is to develop innovative solutions that support ocean exploration, underwater maintenance, and environmental monitoring. By integrating our knowledge in mechanical, electrical, and software engineering, we strive to create practical systems that can be applied in real-world scenarios.

For the MATE ROV 2026 competition, we designed and built our ROV, HYDRONAUT. The name reflects the concept of an underwater vessel, as the robot is engineered to withstand pressure and operate efficiently beneath the surface.

During the development of HYDRONAUT, we focused on creating a practical and user-friendly system. The ROV features a modular design, allowing for easy adjustments and maintenance, along with a control system that enhances the operator's experience. It is capable of performing a variety of tasks, including shipwreck inspection, buoy maintenance, environmental monitoring, and water sampling.

Our journey involved multiple stages, starting from initial concepts to prototyping, testing, and continuous improvement. Throughout the process, we prioritized stability, safety, and reliability to ensure the system performs effectively in real underwater conditions.



Figure 1. Nautix Pioneers Photo By AHMED REZK

Abstract

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TEAMWORK

Company & Personal Overview

Nautix Robotics is a team of passionate students working together to develop and enhance underwater robotic systems.

Corporate Structure & Leadership

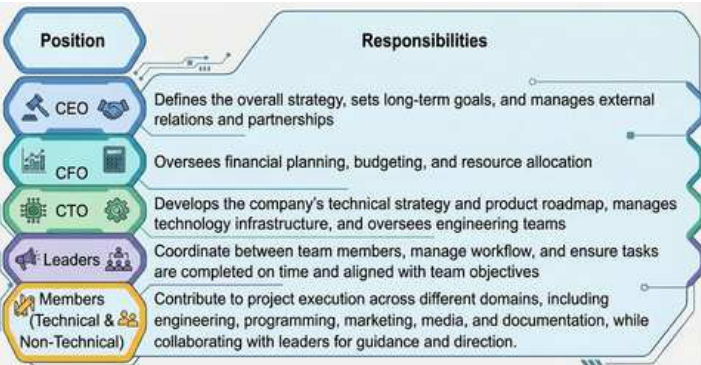


Table 1: Corporate Structure

Schedule

In October and November, the team began with a training phase, where members developed essential technical skills and built a strong foundation across different departments. This was followed by the design phase in November, where initial ideas were explored and the general concept of the ROV was defined.

During December and early January, the team moved into initial prototyping, translating concepts into early physical and functional models.

In January, the focus shifted to iterative prototyping, where designs were refined through multiple cycles of testing and improvement.

By February, the team entered the continuous testing phase, ensuring that all subsystems performed reliably and efficiently under expected conditions.

In March, efforts were directed toward final planning and prototyping, where the system was finalized and prepared for full integration.

This was followed by document preparation, where all technical documentation and reports were completed.

In late March to early April, the team worked on document revision and submission, ensuring all deliverables met competition standards.

Finally, in April, the project reached its peak with mission testing, followed by pilot testing and participation in the regional competition, where the full system was evaluated under real competition conditions.

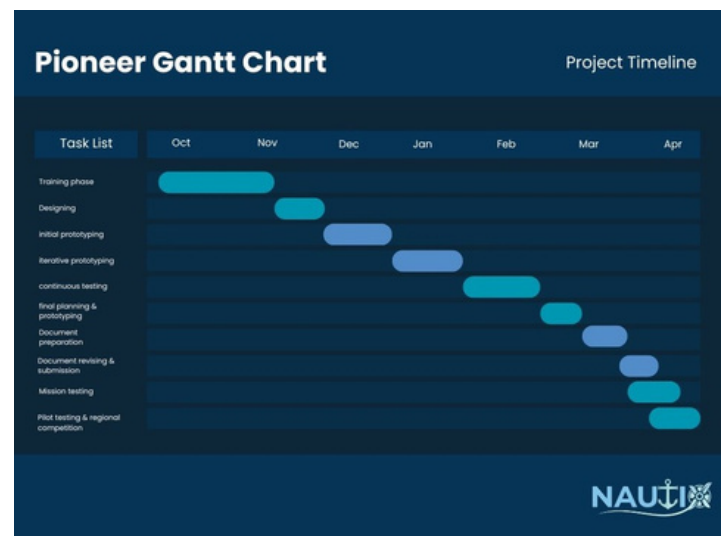


Figure 1: project timeline

Milestones

Milestone 1: MATE Regional Competition (April 22–25, 2026)

This stage represents a full-system validation under real competition conditions, allowing the team to evaluate performance, identify final improvements, and qualify for the international level.

Milestone 2: MATE International Competition (June 2026)

The ultimate goal, where the team competes on a global stage against top ROV teams worldwide, showcasing the final optimized version of the system.

Resource, Procedure, & Protocol Management
Nautix Pioneers operate at a high pace using a framework built in August, driven by agility, traceability, and data-informed decisions.

Design Rational

Engineering Design Rationale

Under the guidance of "Vortex robotics" which competed several times in MATE ROV competition & after thoroughly reviewing the tasks required by our client, HYDRONAUT came to life.

Our goal was to create an ROV that was stable, lightweight, compact, easy to assemble, adaptable and cost-effective.

HYDRONAUT's ultimate design was achieved through a series of processes where members of the team were instructed to brainstorm ideas of their proposed ROV's systems conception. Mechanical team members freehand sketched their proposed designs, then discussed and modified these designs to establish the outlines of the final design.

Electrical and software team members targeted a robust integrated electrical and control system that complies with the required missions and decided on the key components needed.

Then, the space needed for the electrical system was estimated and upon receiving the dimensions of the electronic components, solid modeling Computer Aided Design (CAD) and Computer Aided Engineering (CAE) programs - as SolidWorks- were used to create and test our ROV.

In-parallel our software team started to research on the best controller, cameras and companion computer that provides all the needed tasks and still be cost efficient, afterwards they started using each of those components, running testing codes on every component, testing their compatibility and ways of communication with one another until the full software was finalized based on the given tasks and missions.

Vehicle Structure

Our frame consists of a top deck, made of two 8mm-thick HDPE wings and a 6mm-thick laser-cut transparent PMMA base.

HDPE was used over PMMA for the wings for its higher ductility which is the determining factor as the wings are the bearing point of the eight of the ROV when carried from the handles.

Although heavier, PMMA was used for the base over HDPE for its rigidity; to prevent any bending that might occur, and its higher density shifts the center of gravity downwards.

Openings were cut from the PMMA base to decrease the ROV's weight and reduce the drag force in vertical movement.

8 10mm-thick HDPE supports -where each 2 are tangentially fixed together- hold the upper deck and the base together, mounted at the corners of the frame, at an angle 45° to hold the thrusters at the desired orientation, along with two Aluminum supports.

The two wings are connected by four 10 mm-thick HDPE parts that are fixed to the top deck wings by L-shaped metallic parts, where the main electronics enclosure rests on them.

Two Aluminum Alloy handles were added to the top deck wings for the ROV to be easily held.

U-shaped 3D-printed PLA parts were used to mount the thrusters on the inclined HDPE parts and on both Aluminum extrusion profiles.

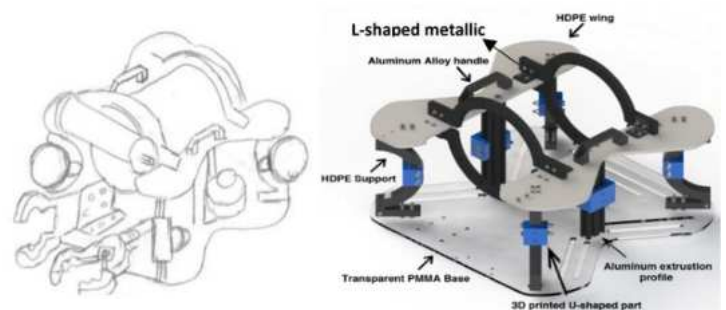


Figure 2: Vehicle Structure

Propulsion

In Hydronaut, the aim was to utilize an optimal number and type of thrusters to maintain all necessary degrees of freedom for smooth maneuvering. After multiple tests using different thruster configurations and numbers, six thrusters were selected as the most suitable solution to support Hydronaut's size and weight underwater. The chosen configuration is a vectored setup, consisting of four horizontally mounted thrusters at 45° angles, along with two vertically mounted thrusters. This arrangement allows for stable horizontal movement and ensures even force distribution across the frame, while the vertical thrusters enable effective heave control.

Thruster Configuration

The use of six thrusters allows Hydronaut to achieve the required degrees of freedom: surge, sway, heave, yaw, and roll. The vectored configuration was selected after comparison with an alternative layout consisting of two forward-facing thrusters, two lateral thrusters, and two vertical thrusters. Testing showed that this alternative configuration resulted in semi-stable movement, especially with the relatively large size of Hydronaut, as the vehicle experienced positional drift along unintended axes. In contrast, the vectored configuration provided significantly improved stability, as thrust forces are distributed across the corners of the frame. This results in better control, reduced drift, and smoother horizontal motion. The two vertical thrusters were retained in the design, as vertical movement is required but represents a lower operational demand compared to horizontal maneuvering.

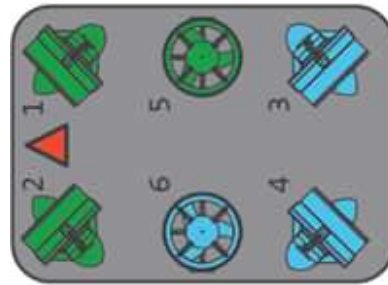


Figure 3 : Thruster Configuration

Buoyancy and Ballast

HYDRONAUT has a displaced volume of 702,484 cm³ and weighs 19 kg in air. The largest component contributing to this displacement is the electronics enclosure, which occupies a volume of 7,755 cm³. This enclosure is strategically positioned at the top to elevate the center of buoyancy, thereby enhancing HYDRONAUT's stability. To further achieve stability, weights and heavier payloads are positioned at the bottom, lowering the center of gravity. Since HYDRONAUT's body is positively buoyant in water, small weights are added evenly at the bottom to balance the weight with buoyancy, ensuring neutral buoyancy. Additionally, foam is distributed evenly along the tether to counteract its buoyancy, thus maintaining the vehicle's balance and stability.

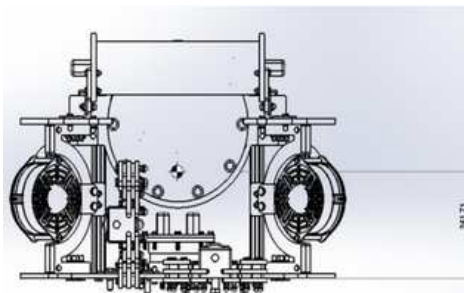


Figure 4: hydronaut's center of gravity 241.71 mm from base

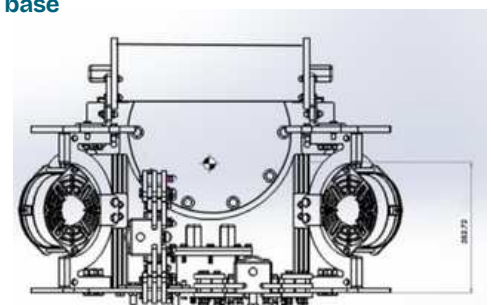


Figure 5 : hydronaut's center of buoyancy 262.72 mm from base

System Approaches

Virtual Integration & Task-Specific Design: Before physical assembly, we modeled the ROV and the specific MATE competition props in SolidWorks. This electromechanical CAD integration allowed us to verify camera visibility and manipulator reach digitally. By simulating the ROV interfacing with the 2-inch PVC coral props, we accurately scaled our custom HDPE horizontal grippers. Furthermore, to support our specific Computer Vision (CV) architecture, we integrated an OAK camera positioned behind a flat, transparent faceplate. This planar geometry is a critical systems-level decision; it prevents the refractive distortion inherent in domed enclosures, ensuring the OAK camera's stereovision can generate accurate and reliable depth maps for autonomous tasks.

Structural-Control Integration (Hydrodynamic Stability): To ensure reliable maneuvering and provide a highly stable platform for our Pixhawk flight controller, the Pioneers designed an optimized, multi-material frame. Rather than using a single material, we made calculated choices based on structural and control requirements:

- **Material Ductility vs. Rigidity:** The top deck utilizes two 8mm-thick HDPE wings, chosen for their high ductility to safely bear the ROV's weight when lifted via the dual aluminum alloy handles. Conversely, the base is constructed from 6mm-thick laser-cut transparent PMMA. While heavier, PMMA provides the necessary rigidity to prevent structural bending.
- **Passive Stability (Center of Gravity):** The heavier PMMA base intentionally shifts the ROV's center of gravity (CG) downwards. This lower CG works directly with the Pixhawk controller to maintain passive pitch and roll stability underwater.
- **Hydrodynamic Drag Reduction:** To optimize vertical translation, strategic openings were cut into the PMMA base, drastically minimizing drag forces when the ROV dives or ascends.

- **Precision Vectored Propulsion:** The upper deck and base are connected by eight 10mm-thick HDPE supports (tangentially fixed in pairs) and two aluminum supports at the corners. Using custom U-shaped 3D-printed PLA mounts, these supports hold the thrusters at an exact 45° orientation.

Mission and problem solving and innovation

Organization

In Nautix team, we believe that organization is the key to reaching our goals and achieving mission objectives. After completing the training phase and fully understanding the tasks, we started assigning roles to each team member, taking into account their strengths and weaknesses, while setting proper deadlines to ensure work efficiency.

We followed a daily schedule to make sure tasks were completed on time. We also held daily updates with all team members to track progress, boost team morale, and handle any unexpected problems taking them into consideration for future improvement

Handling day to day problems

During the project, we faced various day-to-day challenges that required efficient problem-solving and continuous communication among team members. To address these challenges, we followed a clear protocol:

First, tolerance and patience among team members were very important. When facing any problem, we avoided blaming each other and instead worked together to find a solution.

Then, we broke down the problem into smaller parts to identify the root cause and solve it effectively. This protocol was applied to all types of challenges we faced, including team-related issues, problems during building or testing, and time constraints

Issues during testing and how we solved them

During the testing phase, we encountered several issues; however, through teamwork and structured problem-solving, we were able to resolve them effectively.

One of the main problems we faced was that one of the motors was not functioning, although it had been previously tested and worked properly.

To address this issue, we followed a systematic approach by breaking the problem down into smaller parts and troubleshooting step by step. First, we verified that all components were properly connected, including the connections between the laptop, the esc, the motor, and the power supply.

Next, we ensured that the motor itself was not damaged. After that, we examined the electrical components more closely and discovered that the ESC was faulty and not operating correctly.

Once the issue was identified, we managed to fix the ESC, and the system returned to normal operation

Innovation

In Nautix team, we ensure that we gain experience from our previous ROV models. We strive to avoid the problems we faced in earlier designs and take advantage of the successful aspects of our previous models. For example, we reused the T200 Blue Robotics thrusters from last year's project. This helped reduce the overall budget and gave us the opportunity to invest in new components while still maintaining cost efficiency

payload and tools

Manipulators

After several iterations, the current design has achieved the desired performance. The first prototype, made from PMMA (acrylic), lacked sufficient structural strength. The second prototype, constructed from polyethylene, still did not provide the necessary rigidity under operational loads. Finally, the third prototype, made from high-density polyethylene (HDPE), proved durable and effective.

HYDRONAUT features two grippers—one horizontal (axial) and one vertical—designed for improved accessibility. This setup allows it to handle multiple objects simultaneously, enhancing efficiency and saving time.



Figure 6: Gripper

Cable tool

A lightweight modular mounting system uses a durable metal carabiner with a T-joint interface for quick and easy deployment and removal. A cylindrical extension ensures proper alignment and distributes loads evenly for improved stability. Instead of rigid fasteners, heavy-duty cable ties are used to reduce weight, simplify assembly, and provide corrosion resistance along with shock absorption. Overall, the design offers a cost-effective, low-maintenance solution with minimal added weight while maintaining reliable performance.

Spinning tool

The camera-cleaning system for the Holyrood subsea observatory uses a motorized rotation setup driven by a bilge pump. A Cytron controller manages both the rotational direction and speed. Motion from the motor shaft is transferred through a copper connector to a specially designed 3D-printed U-shaped component, which engages the internal plastic layer and turns it. This movement allows the target color segment to cycle past the viewing area three times, fulfilling the required completion condition.

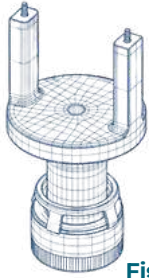


Figure 7: Bilge Pump

Vision System

HYDRONAUT's vision system is engineered to deliver reliable situational awareness, accurate spatial perception, and real-time object detection using a streamlined multi-camera setup consisting of one primary OAK stereo camera and three auxiliary Rapoo USB cameras.

At the core of our architecture is the OAK camera, which serves as the main depth-sensing and measurement unit. Equipped with three lenses (stereo pair + RGB) and an onboard processing chip, it enables real-time depth estimation, spatial tracking, and efficient 3D perception without heavily loading the main onboard computer. This makes it the primary driver for our measurement mission and spatial understanding pipeline.

Each camera position was carefully selected based on task requirements, pilot visibility, and system coverage. This configuration ensures full operational awareness while dedicating specific viewpoints to critical task zones. It allows the pilot to confidently handle navigation, inspection, and manipulation tasks, while also providing the software team with clear visual data for detection and analysis.

Camera Configuration & Strategic Placement

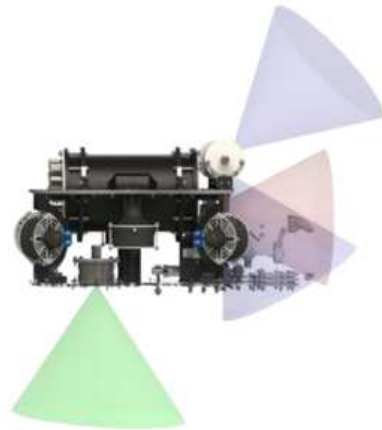


Figure 8: Vision System Camera Cone

Each camera position was selected through deliberate analysis of task geometry, pilot visibility requirements, and subsystem coverage. The resulting configuration provides broad operational awareness while assigning dedicated sensors to the most critical task zones. This layout allows the pilot to maintain control during navigation, seabed inspection, reversing maneuvers, and manipulation, while also ensuring that the software team receives high-quality visual input for detection, measurement, and reconstruction.

OAK Camera (Forward / Measurement & Navigation)

The OAK camera is mounted at the front of the vehicle and acts as the primary vision sensor. Its stereo capability allows accurate depth perception and distance measurement, which is essential for tasks requiring precision.

With its adjustable orientation, it supports both forward navigation and close-range inspection, while also giving visibility over the front grippers during manipulation. Its onboard processing enables efficient real-time inference and reduces latency in the system.

Rapoo USB Camera 1 – Bottom-Facing

This camera is positioned downward to support seabed observation and object detection tasks. Its near-vertical angle minimizes perspective distortion, improving detection accuracy and consistency with training data.

It also provides the pilot with a stable reference for bottom-aligned navigation and inspection.

Rapoo USB Cameras 2 & 3 — Front & Front-Down

The Front camera provides a forward-facing view from a different perspective than the OAK-D camera, offering an additional angle of the workspace. The second camera is angled downward and serves as the primary camera for monitoring the grippers, as it provides the most optimal view of their operation.

Video Streaming

To ensure smooth and reliable video streaming, the system was designed with two independent pipelines, each tailored to a specific camera type. The OAK camera processes both depth and RGB data internally, reducing the computational load on the main system while maintaining fast, low-latency performance. Its video output is then streamed to the main system using GStreamer, ensuring efficient transport with minimal delay. On the other hand, the Rapoo USB cameras continuously stream video to the onboard computer via GStreamer, supporting real-time monitoring and piloting. By distributing the workload this way, the system avoids bottlenecks and maintains stable performance under different operating conditions.

Image Processing & Color Restoration

One of the main challenges in underwater imaging is the gradual loss of color due to light absorption, particularly affecting warmer tones like red and yellow. To enhance visual clarity, a real-time color correction method based on the Gray World Assumption is applied to the frames captured by the OAK-D camera. While the camera's built-in Auto White Balance (AWB) helps correct color casts, the Gray World algorithm ensures consistent results in dim underwater conditions, avoiding the noise amplification or distortions sometimes caused by Histogram Equalization. This approach preserves a natural appearance while improving overall visibility for underwater scenes.

Camera Calibration

Accurate depth perception in underwater imaging depends heavily on precise camera calibration, especially when using a stereo camera system like the OAK-D. To achieve this, the stereo cameras were carefully calibrated underwater using a standard chessboard pattern. This calibration process serves multiple purposes: it determines the intrinsic parameters of each individual camera, such as focal length, optical center, and lens distortion, and it also establishes the extrinsic parameters that define the precise spatial relationship between the two cameras in the stereo pair. Performing this calibration underwater is particularly important because the refractive properties of water can slightly alter the effective focal lengths and distortions compared to air, potentially affecting depth measurements if uncorrected.

During calibration, multiple images of the chessboard were captured at different positions and angles throughout the camera's field of view. These images were then processed to compute a set of calibration matrices, which accurately model how the cameras perceive three-dimensional space. Once calculated, these parameters are stored and automatically applied in real-time during operation, ensuring consistent and reliable depth estimation. By performing this meticulous underwater calibration, the system can generate precise depth maps and 3D reconstructions, which are critical for applications such as underwater navigation, object detection, and environmental monitoring.



Figure 9: Calibration

Crab Detection

Detecting European green crabs in underwater environments is inherently challenging due to unpredictable object orientations and complex seabed backgrounds.

Traditional detection approaches struggle in such conditions, as axis-aligned bounding boxes often include excessive background when objects appear at an angle, reducing both accuracy and confidence.

To address this issue, the system adopts Oriented Bounding Boxes (OBB), which align each detection with the actual orientation of the crab.

This alignment minimizes background interference and leads to more precise localization.

For training, a dedicated dataset was constructed entirely from real underwater footage captured using HYDRONAUT's onboard cameras.

In addition, data augmentation techniques were applied to increase variability and simulate different orientations and environmental conditions, enhancing the model's robustness.

The detection model, based on YOLOv26, was optimized for real-time performance.

As a result, the system achieved an accuracy of 99%, maintaining strong performance even in low-visibility conditions and highly cluttered underwater scenes.

Model performance Comparison

The following table summarizes the benchmark results across all evaluated YOLO architectures:

YOLOv11(Small)		YOLOv26(Small)	
Precision (P)	99.9%	Precision (P)	99.2%
Recall (R)	100.0%	Recall (R)	98.4%
mAP50-95	0.937	mAP50-95	0.964
Parameters	9.41 M	Parameters	~5.4 M
Inference Time	13.2 ms	Inference Time	13.8 ms

Table 2: Evaluation Metrics

Depth Measurement Approach

Accurate spatial perception is accomplished using a dual-panel interface that combines high-resolution RGB visuals with live depth mapping. This setup enables the operator to clearly detect objects, while the underlying system computes precise 3D positions through stereo disparity analysis.

To maintain reliable measurements in difficult underwater environments, a Confidence Thresholding Filter is employed. This mechanism automatically discards depth data compromised by turbidity (such as disturbed sediment) or reflective interference, allowing only dependable samples to be used in calculations. In addition, a Window-based Spatial Averaging technique is applied to reduce sensor noise. This method was chosen for its ability to smooth fluctuations while retaining well-defined edges, which are essential for accurate structural assessment. The processed data is then passed through a Euclidean Distance Transform to produce measurements with centimeter-level precision. Acting as a "digital ruler," this system keeps results within the required 5 cm tolerance, giving the operator dependable measurements for complex three-dimensional operations.

Coral Garden 3D Modeling

Reconstructing the coral garden in Task 1.2 requires a method that preserves true metric scale, captures all eight measurement targets within a single unified coordinate frame, and produces a point cloud dense enough to support accurate height and length estimation. After evaluating available reconstruction approaches, we selected the Tripo 3D Generator as our primary solution.

The Tripo 3D Generator enables fast and practical 3D reconstruction from visual inputs, making it well-suited for field conditions where time, accessibility, and hardware limitations are critical factors. Its ability to generate detailed meshes from a relatively small set of images simplifies data collection and accelerates the overall workflow. However, this approach introduces several trade-offs. While it performs well in terms of speed and usability,

It may not consistently achieve high-precision metric accuracy, particularly in underwater environments where lighting distortion and turbidity can affect reconstruction quality. Additionally, ensuring all eight targets are accurately aligned within a single coordinate frame may require extra post-processing steps, increasing complexity.

Another trade-off lies in the balance between reconstruction detail and control. While Tripo automates much of the modeling process, it offers less flexibility for fine-tuning reconstruction parameters compared to more traditional methods. Furthermore, reliance on AI-driven reconstruction can sometimes result in smoothing or loss of fine geometric details, which may impact precise measurements. Despite these limitations, the use of Tripo 3D Generator provides a strong balance between efficiency, deployment simplicity, and acceptable reconstruction quality, making it a practical and mission-ready solution for this task.

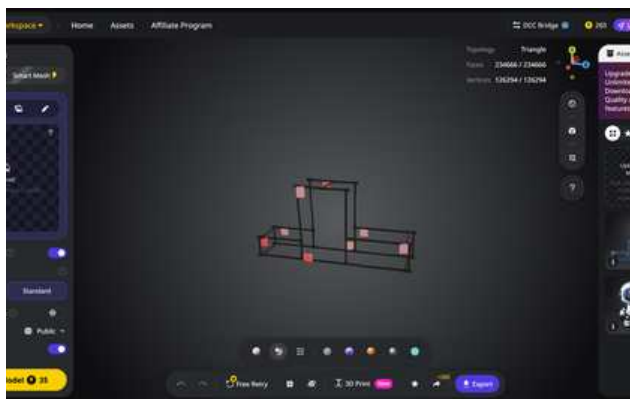


Figure 10: Tripo 3D Generator

At Nautix, safety is not an afterthought it is a core value embedded in every aspect of our work. We believe that innovation and safety must go hand in hand to achieve sustainable excellence. Our team adheres to industry best practices, international safety standards, and MATE ROV competition regulations, with a strong emphasis on proactive risk management and continuous preventive measures. Every team member is empowered and expected to take ownership of safety by identifying hazards, proposing mitigations, and maintaining compliance across all activities. We foster a culture of accountability through regular assessments, collaborative reviews, and open communication. This approach ensures that our work environment remains secure, efficient, and conducive to high-performance engineering

Electric System

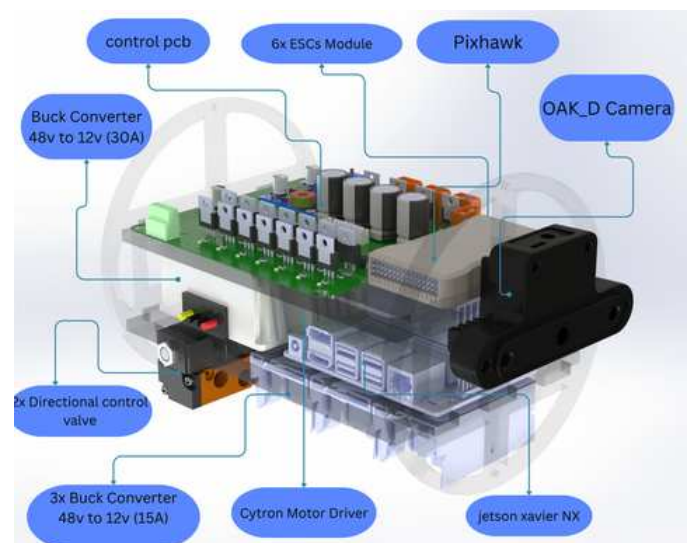


Figure 11: Electrical System Diagram

The electrical system of our ROV is built around a central PCB that houses the control system and the power rails that drive the thruster, creating a compact, integrated system that reduces wiring and space requirements. To prevent the electromagnetic interference (EMI) between the sensitive control parts and the power-hungry components like the thrusters .

Power Distribution

power is distributed among 3 48V to 12V 15A buck converters, and 1 48V to 12V 30A buck converter, powering all our components. We dedicated one 15A converter to power the NVIDIA Jetson NX, DCVs, and bilge pump, effectively eliminating voltage instability and reducing wiring complexity. The remaining converters are connected to the 6 T200 thrusters that move our vehicle, and here we found a problem. To make each thruster move at a pulse width of 1850s, each draw about 14A, and that means to power all 6, we need 84A.

To solve this issue, we manipulated our Pixhawk software to make the ROV move horizontally or vertically at means, which means that in the worst-case scenario, only 4 thrusters will work simultaneously, which needs only about 56A. This configuration fully leverages the advanced thruster stabilization capabilities provided by the Pixhawk flight controller, and this optimization ensures high-speed maneuverability while maintaining a 4A safety margin.

	quantity	voltage (V)	current (A)	power (W)	total (W)
T200 thruster	6	12	13.7	164.4	657.6
ESC	6	12	0.15	1.8	10.8
bilge pump	1	12	7	84	84
Jetson nx	1	12	4	48	48
pixhawk	1	5	0.125	0.625	0.625
DCV	2	12	0.3	3.6	7.2
OAK camera	1	5	0.8	4	4
rapoo camera	3	5	0.4	2	6
					836.225

Table 3: Power Calculation

Power protection

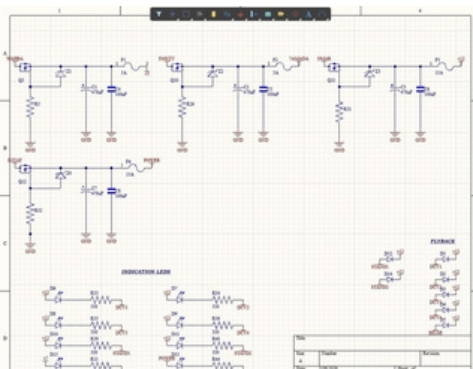


Figure 12: Safety circuit

Power distribution and protection circuitry showing fused supply lines, filtering capacitors, and MOSFET switching stages used to safely distribute power to propulsion and auxiliary loads.

The power distribution design includes filtering capacitors, current-rated fuses, and protection elements to maintain stable voltage levels across the system and prevent electrical faults.

Control System

MOSFET Control Approaches

We implemented two possible approaches for controlling the MOSFETs in our system:

1. Optocoupler-Based Gate Driver Circuit

In this approach, the MOSFETs are controlled using optocoupler-based gate driver circuits, which serve as an interface between the Pixhawk and the power electronics.

Since the Pixhawk's output signals are not sufficient to directly drive the MOSFETs, optocouplers provide both:

- Electrical isolation
- Signal amplification

These MOSFET-based circuits act as switching units for controlling critical auxiliary components, including:

- 2 DCVs for gripper operation
- A bilge pump

This solution was successfully tested and implemented in last year's system to overcome the limitations of direct Pixhawk control.

2. Embedded Arduino Nano Control

In the second approach, an Arduino Nano is integrated directly into the PCB to handle low-level control tasks.

The Arduino Nano was selected due to its:

- Compact size
 - High reliability
 - Ease of integration with custom PCBs
- Embedding the microcontroller on the PCB provides several advantages:

- Reduces wiring complexity
- Improves signal integrity
- Simplifies troubleshooting during testing and competition.

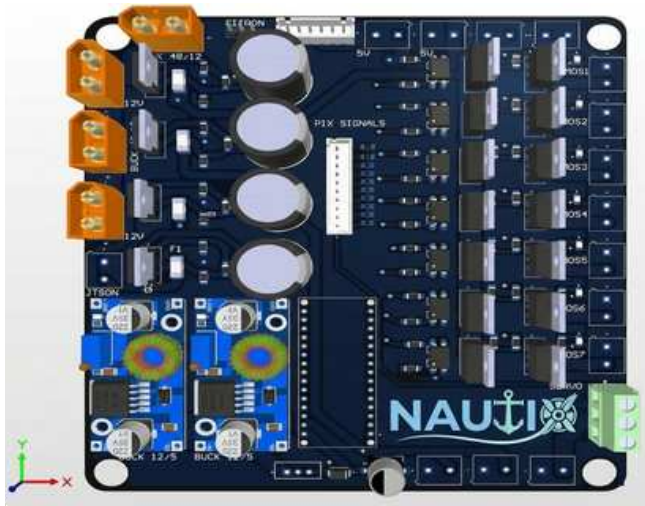


Figure 13: Control PCB

Actuation and Motor Control

Hydronaut uses multiple electric actuators, including thrusters and auxiliary motors, to achieve full maneuverability and mission capability. Thrusters are controlled through Electronic Speed Controllers (ESCs), enabling precise control of speed and direction. A brushless DC (BLDC) motor is integrated to drive mission-specific tools and payload mechanisms. BLDC motors were selected due to their high efficiency, reliability, and compatibility with electronic control systems.

Tether

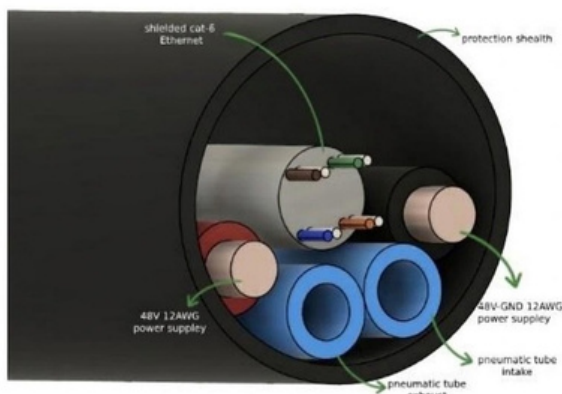


Figure 14: Tether

The tether serves as the ROV's critical lifeline, enabling power delivery, high-speed data transmission, and pneumatic control while maintaining the flexibility, buoyancy, and robustness required for effective underwater operation. Its design was developed to meet MATE's RFP specifications while ensuring safe, efficient, and streamlined operation under competition conditions. The tether consists of the following components:

Power Cable: A 11 AWG two-core power cable (4mm² in diameter) delivers 48V DC to the ROV. This choice is based on the current carrying capacity of the cable (up to 45A) and minimal voltage drop (approximately 0.4% over 25 meters), ensuring stable power delivery throughout the mission.

Data Cable: one Cat6 Ethernet cable (23 AWG) is used for high-speed communication. It is used to communicate between our laptops and the NVIDIA Jetson by a special switch that connects it to multiple laptops.

Pneumatic Tubes: Two 6mm polyurethane tubes, rated for 10 bar, one delivers air to the pneumatic grippers. The other is to provide a "push back" effect to seal the internal pod that contains all of our electrical components to ensure that no water can enter and fry our components.

The tether is 25 meters long, chosen to meet the 5.5-meter pool depth and the 10-meter horizontal distance from the poolside specified by MATE. The additional length provides extra slack, allowing the ROV to move freely without risk of entanglement or excessive tension. All cables are organized and protected within a braided cable sleeve to prevent abrasion and mechanical damage. The sleeve maintains flexibility and reduces tangling, ensuring the tether remains organized and secure during operation.

A strain relief mechanism is implemented at the ROV side to absorb movement cable damage. This strain relief system minimizes mechanical stress, ensuring the tether's integrity and reducing the risk of operational failure. To maintain neutral buoyancy, sections of the tether are covered with closed-cell foam at strategic intervals along its length. This ensures that it remains manageable during ROV operations, reducing drag and minimizing potential entanglement or tension-related issues.

Tether System Management

The Tether Management System is designed to ensure efficient and safe handling of the Tether during deployment, operation, and retrieval.

Pre-Deployment: The tether is carefully inspected for wear or damage. It is coiled and stored in a manner that minimizes tangling, ensuring a smooth deployment process.

During Operation: A tether manager actively monitors the tether, ensuring that it remains untangled and has adequate slack for unrestricted ROV movement. The manager adjusts the length as needed to prevent the tether from becoming taut or tangled, reducing the risk of snagging or damage.

Post-Operation: After mission completion, the tether is carefully retrieved, inspected for any signs of wear, and stored in a clean, dry environment to preserve its longevity. Proper storage ensures the tether's durability for future missions.

Flautix Autonomous Float: System Overview
 Representing three years of iterative design and competition experience, Flautix is an advanced autonomous float engineered for high-efficiency vertical profiling and precise depth control. The vehicle seamlessly integrates mechanical, electrical, and communication subsystems into a highly reliable, constant-volume platform.

Mechanical Design & Buoyancy Engine

Vertical Profiling: Buoyancy is managed by a precise pneumatic cylinder mechanism. A stepper motor, connected via a flexible coupling to accommodate minor misalignments, drives a lead screw that actuates a piston inside a sealed chamber.

Volume Displacement: By strictly controlling the displacement of up to 153.66 mL of fluid, the float efficiently achieves and holds neutral buoyancy with minimal energy consumption.

Structural Stability: Built around a modular aluminum extrusion chassis, the enclosure is piston-sealed against water ingress and features a pressure relief valve for overpressure safety.

Passive Hydrodynamics: The heavy 12V lead-acid battery intentionally serves as ballast to lower the center of gravity. Combined with a streamlined, constant-volume external profile, this ensures stable and drag-reduced vertical translation.

Electrical Architecture

Power Management: Powered by a 12V AGM lead-acid battery (safeguarded by a 3A fuse), the system isolates voltage requirements for stability. A 5V/3A buck converter supplies the core logic (ESP32, RTC, logic-level converter), while a dedicated 3.3V regulator supplies the IR and pressure sensors.

Precision Actuation: A TMC stepper motor driver manages the buoyancy engine, providing the high precision and efficiency required for accurate piston adjustments.

Timing & Navigation: A Real-Time Clock (RTC) module handles exact operational scheduling, while an IR sensor provides feedback to maintain accurate positioning within targeted depth ranges.

Communication & Telemetry

ESP-NOW Network: Telemetry relies on a dual-ESP32 architecture utilizing the ESP-NOW protocol. This establishes a robust, low-latency, peer-to-peer wireless link between the float and the base station without requiring external internet infrastructure.

Real-Time Processing: The onboard ESP32 continuously polls sensor arrays, processes mechanical feedback, and transmits critical diagnostic data to the surface for seamless monitoring and control.

GUI

The Nautix GUI serves as the primary command bridge between the pilot and the ROV, integrating high-level vision from the NVIDIA Jetson Xavier NX with the precision flight control of the Pixhawk. This interface is designed to reduce pilot cognitive load during the high-pressure 15-minute MATE competition trials.

Key Interface Features

Mission Timer: A prominent 15:00 digital countdown with manual Start/Pause controls to track mission progress in real-time.

Stability & Depth Control: * **Depthhold:** Locks the ROV at its current vertical position using the Pixhawk's pressure sensors.

Stabilize: Engages active IMU feedback to keep the chassis level against underwater currents.

Navigation & Telemetry: * **Propulsion Feedback:** Displays real-time Speed and Gain (100%), allowing the pilot to scale thruster sensitivity for delicate tasks.

Visual Indicators: Dedicated icons for vertical thrust, rotation, and gripper states provide instant spatial awareness.

Integrated Vision: The central workspace displays a low-latency HD camera feed processed by the NVIDIA NX, optimized for object detection and navigation.

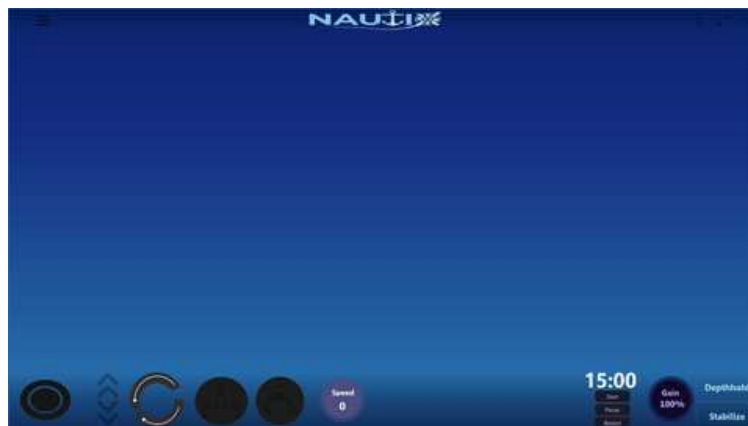


Figure 15: Nautix GUI

Build vs. Buy, New vs. Used

We developed our system by mixing old reliable parts and new ones. This helped improve efficiency and performance. We reused parts like the Nvidia NX, Pixhawk and Thrusters. They have worked before for control and processing. This saved us time and effort in testing core systems.

We use new smaller DCV for grippers instead of the big one, we chose it to make control more precise. It is also smaller and lighter on the ROV. This helps us handle objects more accurately. We bought cameras to replace damaged ones. We also built custom grippers that can rotate. This improves how we handle and align objects. Other new parts, like buck converters and the bilge pump were chosen carefully. We made sure they are reliable and suitable for tasks. Using a mix of new parts helps us get the best performance. It also helps with cost and testing time. We make sure all parts meet the missions requirements.

SIDs

Pneumatic SID

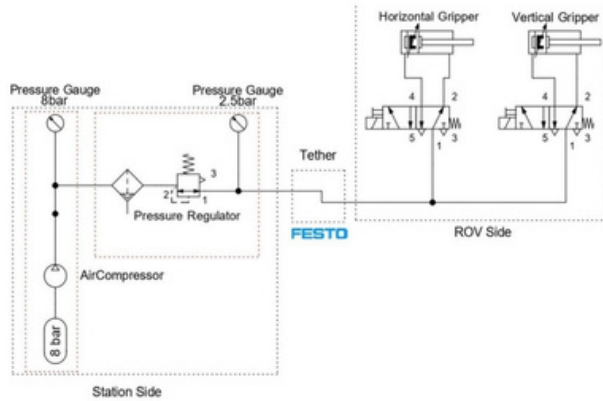


Figure 16: Pneumatic SID

ROV SID :

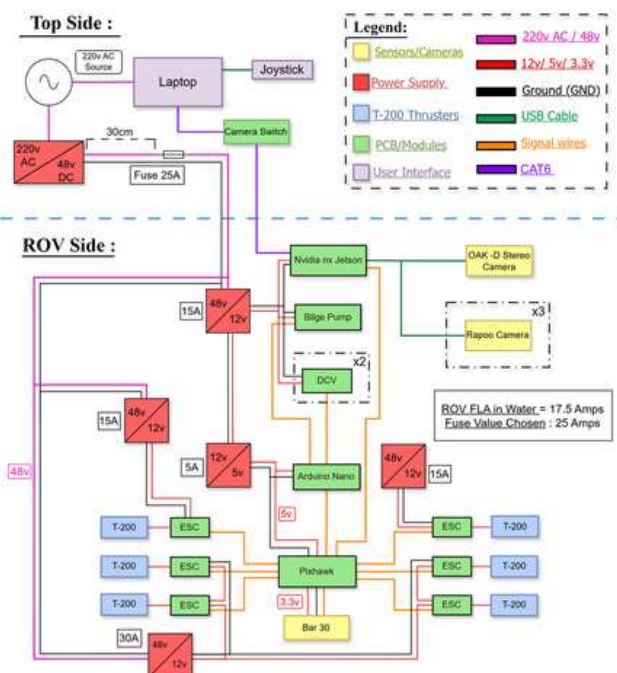


Figure 17: ROV SID

Float SID

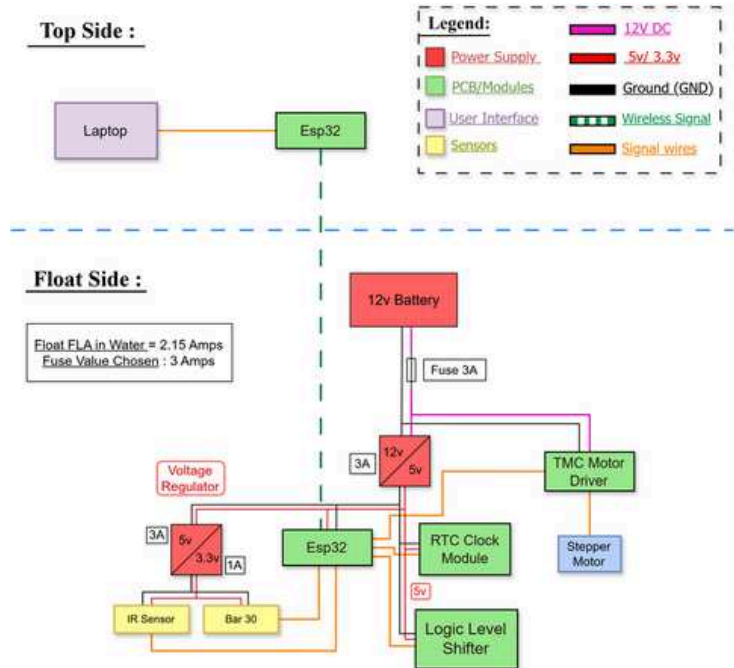


Figure 18: Float SID

Software SID :

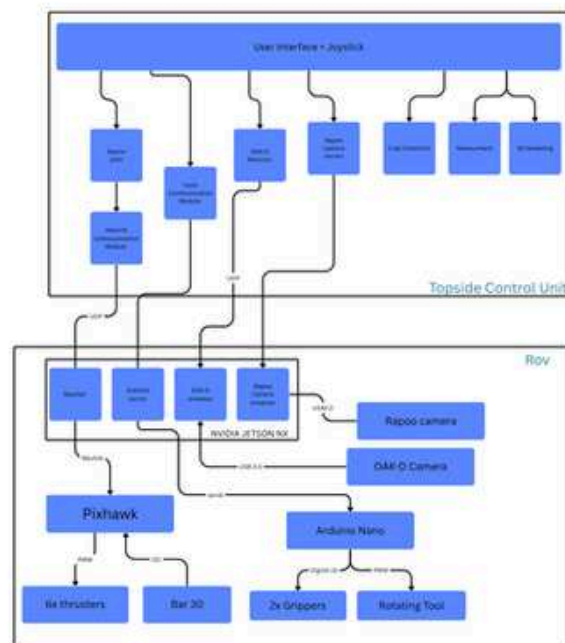


Figure 19: Software SID

Safety

Our Safety Philosophy

Safety is our top priority at our company. Our philosophy is to provide a safe environment and ROV; to ensure the safety of the members debugging on the ROV and the ROV assistant during the product demonstration. A non-safe environment and ROV are unusable, so we are strictly following our safety protocols.

Safety Training

Before we even started building or working on the ROV, we had safety training. All team members got trained to use the equipment safely and follow safety rules. Training started with an introduction about risks, emergency steps, and how to use the tools. After that, we practiced under supervision to learn safe habits in real situations. We also regularly review safety and do drills to make sure everyone stays prepared and informed.

Our Task Handling Safety Protocol

Each task has a hazard rating from 1 to 3, where 1 is a hazardous task that requires following the safety measures: The functions that have this rating are (drilling, pneumatic testing, cutting using the Grinder, soldering electronics, cables, etc). These Tasks are done in a certain room specialized for hazardous tasks. No one is allowed to enter this room when performing these tasks except the members required to perform them. This room is equipped with the required tools and the safety equipment (Safety gloves and goggles) that must be used in this room. In addition, there is an emergency aid kit in case of any emergency.

Tasks with a hazardous rating of 2, like debugging the ROV, opening the internal structure, and making electrical or mechanical modifications to the ROV, all similar tasks, are done on the operation table.

The only members who can stand by the table are the members assigned these tasks. The power supply is far from the table and disconnected, while debugging to ensure nothing happens to the ROV, and to provide a safe environment for the members.



Figure 20: Nautix employee wearing safety gloves during soldering

hazardous rating of 3 are mainly software and non-technical work, which is done in a separate room far from the hazardous tasks room and the operation table. To ensure a safe environment.

The Mechanical Safety of the ROV To ensure the ROV is safe for the mechanical team when performing certain tasks on the ROV and the ROV assistant during the product demonstration, mechanical safety measures are taken in consideration, any sharp edges should be covered like the head of the nylon cable ties should be covered by glue, a capnut should cover any screw end and the terminals of the aluminium extrusion is covered by a 3d part as the terminals are sharp. Moving parts should be covered. We have two major moving parts: the T200 thrusters and the bilge pumps motor housing. The T200 thrusters are covered with an aluminium mesh, and the bilge housing is covered with a 3D printed mesh.

The Electrical Safety of the ROV. We use Anderson SBS50 connectors on our ROV because they can withstand high current loads, lock with a secure latch, and withstand harsh environments. To guard the power system, we employed fuses designed for a maximum estimated current of 17A with a 1.5× safety margin, so we had a 25A on the main tether and 15A on the PCB, which protected the more sensitive parts, ensuring component safety. This configuration defends against overcurrent and short circuit simultaneously. We selected a minimum of 12 AWG cables to contain the heat and current safely. Along with marine electrical grade fuse boxes and waterproofing the vessel, our design provides unparalleled electrical safety intended for submerged applications.

Critical Analysis

To ensure safe and reliable systems as well as operational efficiency, NAUTIX assess the ROV's performance across three categories: mechanical, software, and electrical. So we emphasize systematic testing and troubleshooting throughout all departments during the development process. Our goal of this phase is to identify any technical issues and apply strategies to resolve them efficiently.

1. Mechanical Testing:

Structural Integrity Assessment:
to ensure the ROV frame is strong and stable under operational loads. Physical load testing is also done to validate structural durability, especially in underwater environments.

Dry Tests :

Evaluate thruster performance, and ensure hardware safety through operating the ROV on land and monitor all movements and functions. This test helps us at early detection of mechanical issues and reduce risks in water tests.

Sealing:

Through the hydrostatic pressure tests, we test the ROV's sealing by gradually increasing the water pressure and detecting air bubbles, which would indicate any leaks in the seal.

pool test (Buoyancy and stability characteristics) :

Pool Tests We conduct three times a week for four hours in an indoor pool for a neutral buoyancy assessment, through analyses how well the ROV maintains its position in water. We fine-tune buoyancy, ensure stable performance.

This step simulates the ROV's efficiency in navigation, object manipulation, and data collection.

The testing process is done step by step to challenge the ROV with operational scenarios, enabling adjustments and driver training to control the ROV better. This test evaluates the ROV's capabilities in all the testing stages; we ensure that it is well prepared for real-world applications and environmental protection missions.

2. Electrical System Testing:

Power supply and Distribution :

We need to ensure reliable and stable performance of the ROV under all operating conditions, using oscilloscopes and multimeters to control voltage regulation and current draw, also ensuring consistent power delivery even under peak load.

Component Verification :

Individual electrical components testing to confirm their functionality. We test wiring, connections, continuity, and resistance and PCB to validate the system design. After testing all of this, all components are integrated and evaluated into the full system to check power flow, data transfer, and response time in real conditions.

3. Software testing :

System Integration Testing:

Also we test the software system using an organized and systematic approach to ensure reliability and real-time performance. We test it using hardware-in-the-loop (HIL) simulation to validate synchronization between sensors, actuators, and control algorithms.

Fault Injection Testing:

In this phase the team decide to make failures to evaluate the system's ability to detect and handle errors. for example disconnections, data corruption, camera feed loss ,and communication issues , also Communication protocols were tested including TCP and UDP to ensure safety , stable, and low-latency data transmission. The goal of this step was to evaluate the ROV's overall efficiency and performance.

Component Validation and Simulation:

finally , each component was tested individually before integration, including Jetson NX , Pixhawk under controlled conditions using QGroundControl. This enabled early issue detection and ensured optimal system performance before hardware deployment . Jetson NX commands were tested to control all thrusters correctly,The ROV is tested under high load to confirm it can handle difficult conditions,perform its tasks reliably and to ensure all components work together smoothly

Troubleshooting:

Troubleshooting is a key part of the ROV development, to ensure reliable operation under various conditions. Sure the team have a plan for fault detection .

Problem Identification:

we observe the roV behavior during pool test to ensure that all is good instead of the baseline data that quickly detect any failure .

To resolve last year's thruster issues—sudden brownouts, and erratic spinning— NAUTIX initiated a systematic troubleshooting process. This strategy has been crucial in preventing similar problems .

Root Cause Analysis:

After detecting a problem, the team brainstorm to discover the root cause and classifies it as mechanical, electrical, or software. We work together to fix it. For example Electrical problems are checked using multimeters and oscilloscopes, mechanical faults are tested physically, and software issues are debugged by tracing the code.

an additional test is performed on the system to ensure that the issue is fixed without affecting other systems.

prototype:

At the beginning, we focused on designing an ROV that is efficient and able to complete all required tasks. We watched the fly-through video to understand what we need, especially in terms of thrusters and cameras to give us flexibility and good performance.

After building the first prototype, we found some problems. The gripper was not performing well, and the thrusters were not stable. The main issue was in the 3D printing, as the part was printed horizontally, which created a weak point at a 90-degree angle and made it easy to break

In the second prototype, we printed the part vertically to solve this issue, but it was still not stable enough. So, we redesigned the system to achieve better thruster fixation and stronger gripper performance. We also fixed the thrusters at a 45-degree angle to improve movement flexibility

For the vision system, we used four cameras (3 Rapoo and 1 OAK). Two are placed in the front, one is facing upward from below, and one is near the gripper. The Rapoo cameras are used for crab detection by collecting datasets and training the model. The output is a bounding box around the object with a counter.

For safety, we first used an aluminum sheet on the thrusters based on the IB20 standard (12.5 mm spacing) to prevent fingers from entering. However, it reduced water flow and affected the thruster speed. So, we replaced it with a 3D-printed mesh that keeps safety while allowing better flow, which helped the thruster reach the full speed without loss.

Budget

Our budget covers all subsystems and logistics for the season, ensuring that each component from mechanical fabrication to electronics and software meets the required performance and reliability standards.

We carefully managed our financial resources, prioritizing essential components and optimizing costs without compromising quality or performance.

Through strategic planning and efficient allocation, we minimized waste, maximized value, and ensured that every expense directly supported our technical goals and competition readiness.

Budget Allocation

Budget divided across each subsystem. Projected costs include the market value of reused parts to show the full worth of the build.

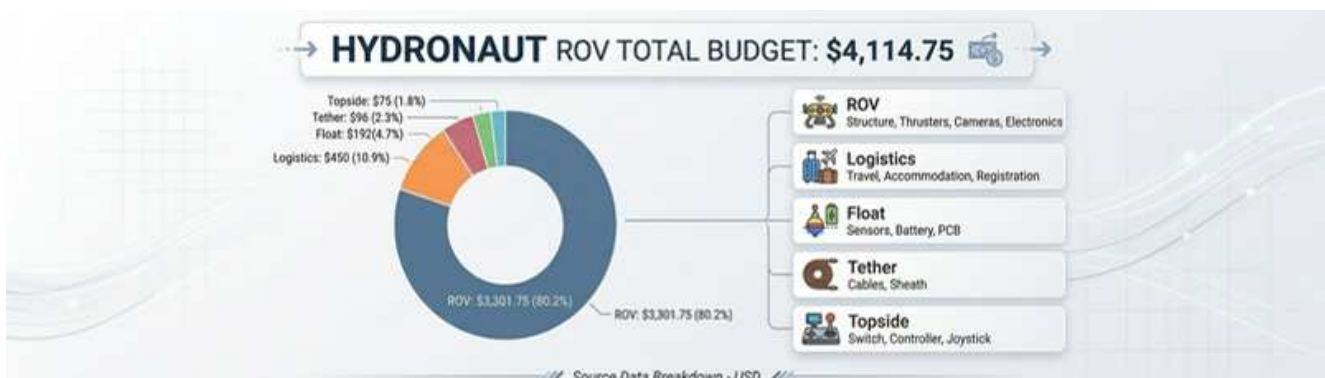


Table 4: Budget Breakdown

Acknowledgements

We would like to extend our sincere appreciation to the MATE Center and the Marine Technology Society for organizing and sponsoring the MATE ROV Competition, an event that continues to inspire innovation and excellence in marine robotics. We are also deeply grateful to Arab Academy for Science, Technology & Maritime Transport and AASTMT Stadium for hosting the regional competition in Egypt and providing a motivating and well-equipped environment that supported our team throughout this journey.

Our heartfelt thanks go to Vortex Company for their valuable contribution in providing high-quality hardware equipment, which played a crucial role in the development and performance of our ROV system. Their support significantly enhanced our ability to implement reliable and efficient solutions.

We would also like to express our deepest gratitude to our dedicated mentors, whose continuous support, technical expertise, and encouragement were instrumental in guiding us through every stage of this project: Omar Tabouna (PM), Abdelrahman AbouKlila, Nouraldeem Hassanien, Youssef Emara, Ali Sherif, Abdullah Fawzy, and Seif Tabouna. Their mentorship not only strengthened our technical capabilities but also inspired teamwork, problem-solving, and innovation.

We proudly acknowledge the following companies and platforms for their impactful contributions to our project: Pixhawk, Blue Robotics, Hikvision, NVIDIA, and Stereolabs for providing cutting-edge hardware and robotics technologies. We also extend our appreciation to GitHub, ANSYS, SolidWorks, Visual Studio Code, Qt, ArduPilot, and Ultralytics for supporting our software development, simulation, and engineering workflows. Additionally, tools such as Flaticon and GStreamer played an important role in enhancing our system design, visualization, and integration processes.

We are equally thankful to Makers Electronics, Ampere Electronics, and Morphiq for providing essential resources, technical support, and facilities that enabled us to successfully design, build, and test our ROV system.

This project has been a remarkable journey of learning, collaboration, and innovation. Through challenges and successes alike, we have developed not only a competitive ROV but also valuable skills in engineering, teamwork, and problem-solving. We take great pride in what we have achieved and remain motivated to continue advancing in the field of marine technology and robotics.



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APPENDIX A : SAFETY CHECKLIST

Pre-Operational Safety Checklist

General Workspace Safety
Confirm clean and clutter-free workspace
Remove all trip hazards
Ensure no personnel are in launch/recovery zone

Communication

Establish communication protocol (pilot, supervisor, deck crew)
Test all communication systems

Power Verification

Verify correct voltage to ROV system
Test power supply and backup systems

Leak Tests

Perform leak test on pressure housings.

Equipment Inspection

Inspect ROV frame and structure
Check sealing of electronics housings
Verify thrusters are unobstructed
Confirm power source is securely connected
Inspect tether for damage points
Ensure tools and spares are available

Thruster Testing

Test all thrusters for full movement
Confirm controller inputs match ROV response

Camera and Sensor Checks

Verify all cameras are operational
Check video feed clarity and positioning
Test sensors (depth, temp, IMU, etc.).

Pre-Dive Preparations

Prepare dive site and clear hazards
Confirm weather and water conditions

Post Operation Safety Checklist

ROV Retrieval

Safely recover ROV from water
Inspect for damage or debris

System Power Down

Power down system safely
Disconnect tether and power

Post-Dive Inspection

Check for leaks or water ingress
Inspect thrusters and moving parts

Completion

Announce: "Dive Complete"

Pre-Water Safety Checklist

Connect tether to control station
Set pressure ratings for enclosures
Perform full system test (thrusters, sensors, cameras)
Verify controller input response
Confirm readiness with team
Announce: "Water Ready"
Deploy ROV into water safely

During Operation Safety Checklist

Operation Monitoring

Continuously monitor system status
Track depth, orientation, and power usage.

Tether Management

Maintain proper tether handling
Avoid entanglement or excessive tension

Communication Continuity

Maintain clear communication with surface team.

Tool Operation

Follow procedures for tool usage
Monitor manipulator/tool performance

APPENDIX B : COST ACCOUNTING

4500\$			Income		
Expense	udgeted va	Projected cost	Description	Type	project
8\$			Pneumatic Cable 25m	Reused	Tether
80\$			Cat 6 Cable 25m x2	Reused	
5\$			Tether Sheath	Reused	
60\$	60\$	60\$	12AWG Power Cable 25m	Purchased	TCU
72\$			Xbox Joystick	Reused	Flautix
12\$			Nema 17 Stepper Motor	Reused	
3\$	\		DS3231 RTC Module	Reused	
85\$			Bar30 Pressure Sensor	Reused	
25\$			I2C level Converter	Reused	
10\$			Underwater Switch	Reused	
7\$	4\$	4\$	5 Port Gigabit Switch	Purchased	
8.5\$	8.5\$	8.5\$	Esp32	Purchased	
4\$	4\$	4\$	TOF050C IR Sensor	Purchased	
5\$	3\$	4\$	TMC2209 Motor Driver	Purchased	
20\$	20\$	18\$	40X50 Pneumatic Piston	Purchased	
117.75\$	119.\$	120.\$	Materials and Fabrication	Purchased	
29\$	29\$	29\$	2-layer PCB	Purchased	
21.5\$	21.5\$	21.5\$	LP7-12 Lead Acid AGM B	Purchased	
1.8 \$	1.8 \$	1.8 \$	elbow 1/8	Purchased	
0.9\$			bress silencer 1/8	Reused	
10.44\$	11\$	11\$	wa valve 5/2	Purchased	
3.76\$	3\$	3\$	puch-in elbow fitting 1/8*6	Purchased	
1.56\$	2\$	2\$	PCB Float - component	Purchased	hydron
19\$	19\$	19\$	Rapoo camera x3	Purchased	
17.87\$	17.\$	17.\$	PCB Components	Purchased	
2.87\$	3\$	3\$	aluminum face	Purchased	
3.10 \$	5\$	4 \$	soldering Iron Tip - compone	Purchased	
17.07 \$	15\$	15\$	3D Parts For Motors	Purchased	
23.6 \$			Nails _ comp	Reused	
8.4 \$			Frame Nails _ comp	Reused	
22.3 \$			Gripper Nails _ comp	Reused	
13.1 \$			Nails	Reused	
14.6 \$			Acrylic Parts	Reused	
107 \$			Plastic worm gear	Reused	
76\$	76\$	76\$	Camera Boxes (Face Seal)	Purchased	
60\$	70\$	55\$	Grippers Material and Fabr	Purchased	
45\$	47\$	47\$	Aluminium Extrusion	Purchased	
5.6\$	7\$	7\$	O-Rings	Purchased	
23.5\$	25\$	25\$	3D Printed Parts	Purchased	
24\$	24\$	24\$	Thruster Guards X12	Purchased	
24\$	25\$	23\$	Cameras and Tools Fixatio	Purchased	
62\$	65\$	63\$	Control PCB	Purchased	
6\$	7\$	5\$	8A DC-DC Buck Converte	Purchased	
7\$	5\$	5\$	1100GHP Bilge Pump	Purchased	
720\$			T200 Thruster X6	Reused	
20\$			48V 30A Power Supply	Reused	
85\$			Bar30 Pressure Sensor	Reused	
228\$			BlueRobotics ESC X6	Reused	
193\$			Pixhawk 2.4.8	Reused	
90\$			30A DC-DC Buck Convert	Reused	
25.75\$			15A DC-DC Buck Convert	Reused	
35\$			Camera Boxes (Piston Seal	Reused	
450\$			Nvidia Jetson NX	Reused	
177\$			AGRO Glands X 40	Reused	
45\$			DCV X2	Reused	
88\$			Pneumatic Piston X2	Reused	
200\$			Main Enclosure Material (I	Reused	
135\$			Compressor	Reused	
450\$	500\$	450\$	Customs and Shipping for	Purchased	
4500\$			Total Income		
4,114.97 \$			Total Expenses		
3649.65\$			Total Re-used		
465.32\$			Total Expenses – Reused		
4034.68\$			Final Balance		

Table 5: Cost