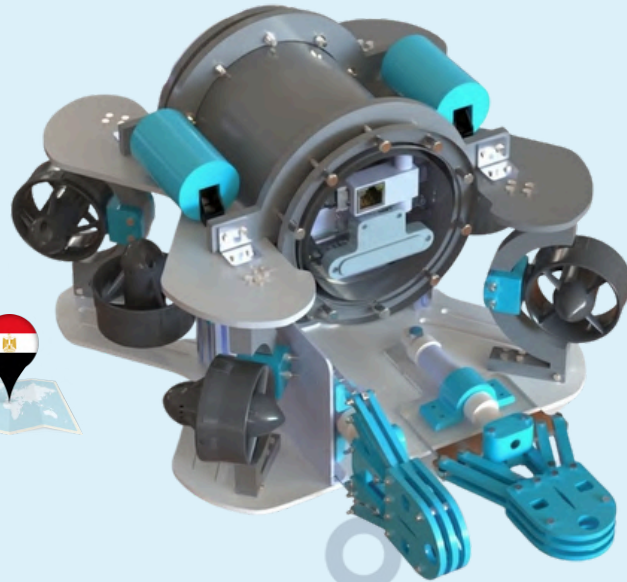


NAUTIX PIONEERS

TECHNICAL DOCUMENTATION

HYDRONAUT

ALEXANDRIA, EGYPT



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- 28' Aly eldin Mohamad* FM
- 28' Youssef Khaled* Control Lead
- 27' Youssef Midhat* Vision Lead
- 27' Mohamed Rezk* Float Lead
- 27' Abdelrahman Ihab*
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- 29' Heidi Ahmed*
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- 28' Ibrahim Ahmed*
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- 27' Serag Mohamed*
- HS' Kareem Ayman*
- HS' Adham Eslam*
- HS' Shahd Ahmed*
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- Ali Sherif
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GRADUATION YEAR

*DENOTES NEW MEMBERS

*HS : HIGH SCHOOL

*PM : PROJET MANAGER

*FM : FUCTIONAL MANAGER

ABSTRACT

We are a team of driven students united by one mission: building cutting-edge underwater robotic systems that solve real-world problems beneath the surface.

From ocean exploration to underwater maintenance and environmental monitoring, we engineer solutions that bridge the gap between innovation and application drawing on our collective expertise in mechanical, electrical, and software engineering.

MEET HYDRONAUT AND FLAUTIX

For the MATE ROV 2026 Competition, we proudly present HYDRONAUT and Flautix a name that embodies what this machine is built to do: navigate, endure, and perform in the depths.

Engineered to withstand underwater pressure while delivering peak operational efficiency, HYDRONAUT is built around a modular architecture that enables rapid adjustments, seamless maintenance, and an intuitive control experience for operators. Its capabilities span a diverse range of mission-critical tasks, including:

- Shipwreck inspection
- Buoy maintenance
- Environmental monitoring
- Water sampling

Our Process

HYDRONAUT didn't happen overnight. From first sketches to functional prototype, every stage of development concept, design, testing, and iteration was driven by a commitment to three core principles: stability, safety, and reliability. The result is a system built not just to compete, but to perform in real underwater conditions.



Figure 1. Nautix Pioneers Photo By Asmaa Aboshady

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• Acknowledgements

We would like to sincerely thank the MATE Center and the Marine Technology Society for organizing and sponsoring the MATE ROV Competition, as well as for providing the official competition manual, which was an essential reference throughout our project development.

We also appreciate Arab Academy for Science, Technology & Maritime Transport (AASTMT) and AASTMT Stadium for hosting the regional competition in Egypt and supporting participating teams.

Special thanks to Vortex Company, Makers Electronics, Ampere Electronics, and Morphiq for their valuable equipment, resources, and technical support. We are equally grateful to our mentors — Omar Tabouna, Salma Hassanien, Jana Houssam, Abdelrahman AbouKlila, Nouraldeem Hassanien, Youssef Emara, Ali Sherif, Abdullah Fawzy, and Seif Tabouna — for their continuous guidance and encouragement.

Our project development also benefited from the use of technologies and references including Pixhawk, Blue Robotics, Hikvision, NVIDIA, Stereolabs, GitHub, ANSYS, SolidWorks, Visual Studio Code, Qt, ArduPilot, Ultralytics, Flatiron, GStreamer, official technical documentation, and online engineering resources.



Teamwork

• Company & Personal Overview

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

• Corporate Structure & Leadership

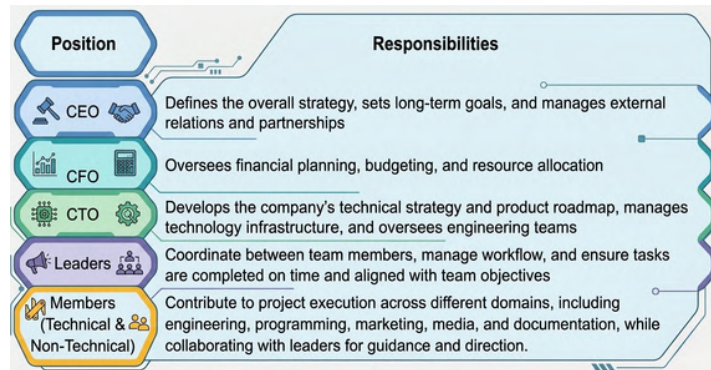


Table 1: Corporate Structure

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.

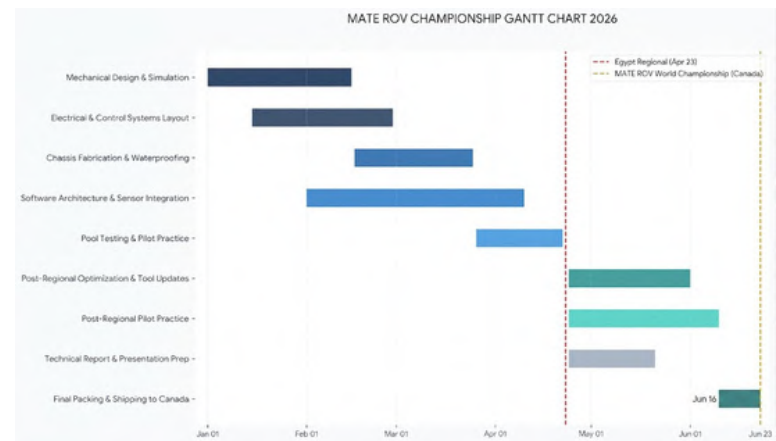


Figure 1: project timeline

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 runs on an agile, data-driven framework to maintain high operational tempo. Alignment is ensured through weekly department syncs, periodic board reviews, and company-wide gatherings — including a full team meeting during Ramadan 2026. The team collaborates using Slack for communication, GitHub for version control, Google Drive for documentation, and Google Photos for media archiving.



Fig 4: Ramadan Gathering

Design Rational

• Engineering Design Rationale

Hydronaut is the product of the enormous efforts and dedication our team members put in. With the guidance of Vortex Robotics, which participated in MATE ROV competition for several years, we were able to reach a satisfactory design that met all the requirements of our client. As shown in **figure 3**, we designed _Hydronaut _to be durable, lightweight, compact, easy to assemble and highly cost effective. To reach that, our team members brainstormed ideas and proposed the concepts they came up with while being instructed throughout the whole process.

Mechanical team members initiated the design process by free hand sketches of their ideas. After several discussions and suggested improvements, the outline of the design's final version was successfully established. Electrical and software team members focused on developing resilient integrated electrical and control systems which met the required missions, and choose the components that satisfied the robot's objectives. After all the components were known, it was time to estimate the space needed for them. This was done upon calculating all the dimensions of the electronic components used. Additionally, solid modeling computer aided design (CAD) and computer aided engineering (CAE) programs such as SolidWorks helped in creating and testing _Hydronaut _before it came to life. Simultaneously, the software team evaluated the most suitable controller, cameras and companion computer. Their target was finding the devices that provide good functionality while still being cost-efficient. Finally, both electrical and software team members individually tested their components, ran validation codes, and verified communication and compatibility until the system was fully finalized for the target missions.

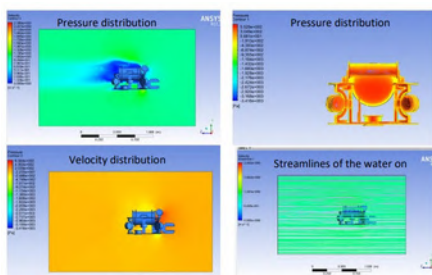


Figure 3: Hydronaut

• Frame

The mechanical design of the ROV frame was developed to maximize strength, stability, and maneuverability while maintaining a lightweight and efficient structure. No material in Hydronaut's frame is accidental.

The structure combines High-Density Polyethylene (HDPE) and transparent Acrylic (PMMA), where each material was carefully selected according to its mechanical advantages and resistance to mechanical stress, enabling the frame to safely withstand the full weight of the ROV during lifting, handling, and deployment operations through the mounted handles.

As visible in figure 4,5, The frame features a dual-layer configuration composed of two 8 mm HDPE wings forming the top deck. HDPE was selected due to its high ductility and toughness, which are critical safety factors since the wings act as the main load-bearing points when the ROV is manually carried.

The lower base was fabricated from 6 mm laser-cut transparent PMMA due to its high rigidity and dimensional stability, allowing the frame to resist bending and maintain structural integrity under operational loads. Its higher density also lowers the ROV's center of gravity, enhancing underwater stability. Additionally, strategically placed cutouts were incorporated to reduce overall weight and minimize vertical hydrodynamic drag.



Figure 4: Vehicle Structure

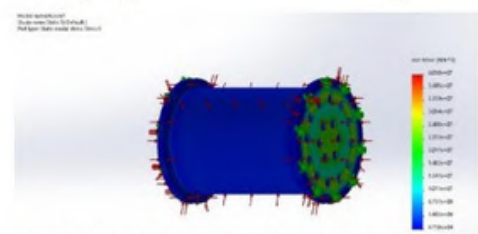


Figure 5: Stress Simulation

To ensure structural rigidity of the assembly, eight 10 mm-thick HDPE supports were used to connect the upper deck and the lower base. Positioned at the frame corners and fixed at 45°, they provide optimal thruster orientation for enhanced maneuverability and motion control. Additional aluminum supports were integrated to further reinforce the structure. The two HDPE wings are interconnected using four 10 mm-thick HDPE cross-members secured with L-shaped metallic brackets, forming a stable platform for the main electronics enclosure. For safer handling and easier deployment, two lightweight aluminum alloy handles were mounted onto the top deck. Moreover, custom U-shaped PLA 3D-printed mounts were designed to securely fix the thrusters onto both the inclined HDPE supports and the aluminum extrusion profiles.

• Propulsion

Tasks such as flying over a transect line and positioning above the coral garden for 3D modeling require smooth throttle response and precise incremental movements, which can only be achieved through an efficient propulsion system that ensures maneuverability, stability, and accurate motion control underwater.

The propulsion system consists of four T-100 and two T-200 thrusters from Blue Robotics, selected for their adequate thrust, reliability, and seamless integration with the Pixhawk controller, which manages thrust distribution to enable precise control and maneuverability.

The four T-100 thrusters are mounted horizontally at 45° to enable stable surging, swaying, and rotation, while the two T-200 thrusters provide vertical motion (heave).

Opposing propeller directions (clockwise and counterclockwise) are used to counteract torque, eliminating unwanted spin and ensuring stable motion.

• Thruster Configuration

The use of six thrusters allows Hydronaut to achieve the required degrees of freedom: surge, sway, heave, yaw, and roll.

As highlighted in the figure 6, 7 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 distributes thrust across the frame corners, significantly improving stability, reducing drift, and enabling smoother horizontal motion. The two vertical thrusters were retained, as vertical motion is required but has lower operational demand compared to horizontal maneuvering.

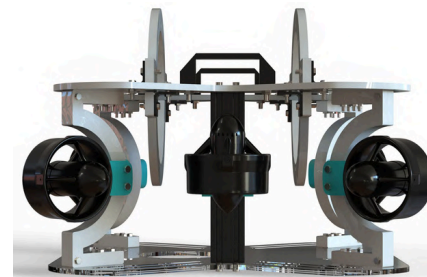


Figure 6 : Thruster Configuration

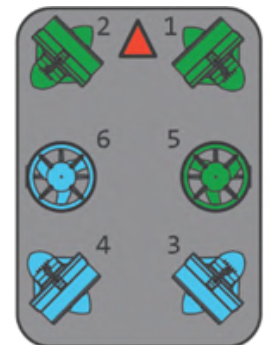


Figure 7: Thruster Configuration

• Buoyancy and Ballast

Hydronaut occupies a transient volume of 702484 cm³ and weighs 14.65kg in air. The electronics enclosure is the component that occupies the largest displacement, occupying a displaced volume of 7755cm³. As a result, it is placed at the top to shift the buoyancy center upwards, which increases _Hydronaut's_ stability. To move the center of gravity downwards, all the weights and the heavy payloads are placed at the bottom, achieving stable maneuvering. The ROV is positively buoyant in water, therefore, small weights were evenly distributed at the bottom to neutralize the weight with the buoyancy. Furthermore, equally spaced foam was added to the tether to provide balance, stability and neutral buoyancy.

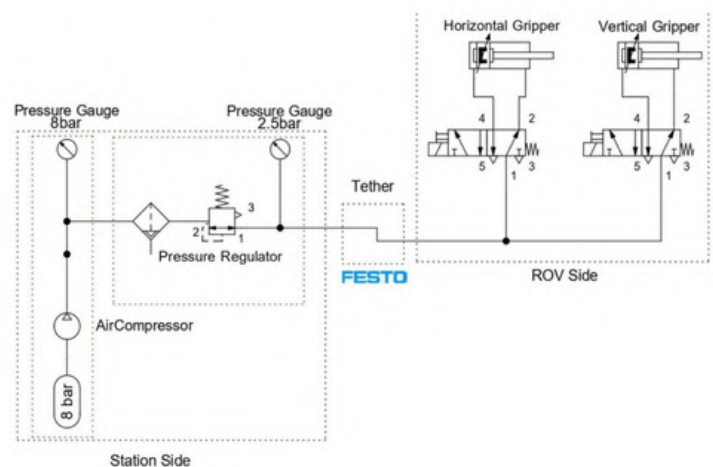
• Electronics enclosure and sealing

Hydronaut contains three sealed enclosures; the main electrical enclosure, one for rapoo first camera that looks down and another one for the other rapoo cameras. The electronics enclosure is a 25cm flanged cylinder with a 15cm inner diameter and 6mm wall thickness. For the material of the enclosure, Polyamide (PA type-6) was our choice due to its non-porous, high strength and shock-resistant material. the front side of the cylinder are capped with a laser-cut PMMA face in order to enable the O-ring compression checking and clear vision for the OAK-D, While the Back side of the cylinder are capped with a laser-cut aluminium face in order to withstand the pressure under the water, Regarding its internal structure, PMMA was chosen for the shelves where the electronic components are fixed. We arranged the PMMA shelves components where the heavy dense components are placed on the lower shelves, whereas the light ones are placed on the upper shelves. As for the rapoo down camera enclosure, HDPE was still considered our first option for the enclosure's material, and each end is sealed using an PMMA cap. Meanwhile, for the lower enclosure we picked a machined Polyamide (PA6) cylinder covered with 4mm PMMA sheet acting as a lens cover. Regular cameras were selected along with a custom-manufactured seal, prioritizing cost efficiency. Now that the enclosures were finalized, sealings were our next focus. The three enclosures use O-rings which were selected in accordance with the Parker Sealing Handbook. We preferred using O-rings for the sealings as they rated for a pressure differential of up to $5 \times 10^5 \text{ Pa}$ which is suitable for our requirements. Additionally, we needed to seal between the cables within the cable holes in the enclosure, so we employed IP-68 nickel-plated brass cable glands, withstanding the same pressure difference as the O-rings. These glands provide cable strain relief which is crucial for the functionality of our system. Prioritizing undersea environmental safety, we preferred using non-toxic sealants such as silicone and epoxy.

• Pneumatic

On deciding how to control grippers, the team agreed that pneumatic-powered grippers would be highly effective, reliable and dependable, unlike the standard motor-powered ones. We started the process by drawing and testing the pneumatic circuits on FESTO software. Our system is designed to contain three main parts; the top side which includes the compressor and the relief valve, two pneumatic pistons that are connected to two DCVs and the cable that provides the enclosures with compressed air.

Each pneumatic actuator is controlled using a 5/2 DCV, which is configured with no neutral position. The cables are connected such that each piston is normally closed. The pneumatic tubing has a diameter of 4mm and an outer diameter of 6mm which can accommodate a maximum pressure of 106 Pa.



• Hydronaut Manipulator System

Hydronaut is equipped with two pneumatic grippers: one horizontally fixed and one vertically fixed. As observed in Figure 8 The horizontal gripper holds objects up to 13 cm in diameter, while the vertical gripper handles smaller objects up to 10.5 cm in diameter.

End-Effector Design

The end-effectors feature multiple curves and rubber coating to securely grip fragile specimens such as basket stars and coral species. PMMA was selected as the primary material for its durability, lightweight properties, and transparency, giving the pilot a clear view during gripping operations.

• Gripper Mounting

The horizontal gripper is fixed directly to the base frame. The vertical gripper is mounted onto two L-shaped aluminium parts, which are also attached to the base. Both grippers have a static side mounted to the base and a dynamic side secured to the pneumatic piston rod via a nut embedded in a 3D printed component.

Regional Competition — Vertical Gripper

In the regional competition, Hydronaut used a vertically mounted gripper as the second manipulator. It was mounted on two L-shaped aluminium parts attached to the base frame, capable of gripping objects up to 10.5 cm in diameter using the same PMMA curved-finger design with rubber-coated pads.

International Competition — Jaw Gripper Upgrade

For the international competition, the vertical gripper was replaced with a 3-jaw claw-style gripper as demonstrated in figure 9. Unlike its predecessor, this jaw gripper is mounted horizontally on the base frame. Three curved PMMA fingers, arranged symmetrically around a central actuating hub, close in unison when the piston rod extends, providing balanced three-point contact for gripping irregularly shaped specimens up to 10.5 cm in diameter. Rubber pads on the inner finger surfaces ensure secure handling of fragile biological samples.

The jaw gripper was specifically designed with a 45° geometry to directly match the EDNA sensor connector orientation, eliminating the need for continuous ROV pitching and complex repositioning during manipulation tasks.

This design significantly improved alignment accuracy and manipulation stability underwater, while reducing control complexity and mission execution time.



Figure 8: The horizontal gripper

Figure 9: jaw gripper

Force Calculations

The pneumatic pistons have a bore diameter of 25 mm and a stroke length of 50 mm, operating at a working pressure P. The maximum theoretical force is calculated using:

$$F = P \times A$$

Where A is the cross-sectional area of the piston bore, calculated from the bore diameter d as:

$$A = \pi(d/2)^2$$

• payload and tools

• The O-Ball Retrieval Tool

The O-Ball Retrieval Tool as illustrated in the image 10 was developed as a lightweight, easy to fabricate, and highly efficient solution for rapid object collection during the mission. Traditional retrieval systems often rely on multiple pneumatic actuators or complex gripping mechanisms, which increase system complexity and slow down operation. As illustrated in the figure, the tool is designed to naturally engage with the perforated structure of the O-Balls once lowered into position. This allows the ROV to collect objects quickly and reliably. A key advantage of this design is its ability to secure multiple O-Balls simultaneously, significantly reducing the number of ascent and descent cycles required.



Figure 10 : The O-Ball Retrieval Tool

• The Rotary Spinner task tool

The Rotary Spinner task required the ROV to descend underwater, securely grasp the tool, and complete three full rotations. However, this presented a significant manipulation challenge. While the horizontal gripper could hold the tool, its fixed structure prevented smooth and continuous rotation, making the task slow and unreliable. To overcome this limitation, we used a DC motor as the main actuation mechanism, allowing direct and controlled rotational motion.

To ensure waterproofing and safe underwater operation, the DC motor was sealed using a multi-layer insulation approach. This included an internal epoxy coating to protect critical components, a custom 3D-printed housing to fully enclose the motor, and a final external epoxy layer to prevent water leakage. Together, these layers created a compact, robust, and fully sealed structure suitable for submerged operation as can be seen in Figure 11 .



Figure 11: DC motor

• Spinning tool

The camera-cleaning system for the Holyrood subsea observatory uses a motorized rotation setup driven by a bilge pump as illustrated in Figure 12. 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.

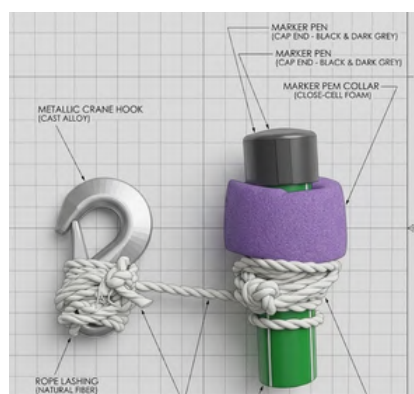


Figure 13: Cable tool

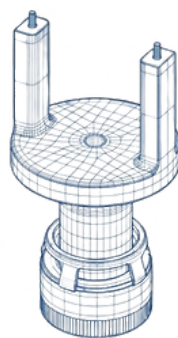


Figure 12: Spinning tool

• Cable tool

A lightweight modular mounting system uses a durable metal carabiner with a T-joint interface for quick and easy deployment and removal as demonstrated in Figure 13. 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.

• Magnetic tool

As can be seen in Figure 14 , the Magnetic Retrieval System was developed to improve the reliability of handling small and lightweight underwater mission objects that are difficult to securely grasp using conventional grippers alone. To overcome this, A magnet was used to create an attractive force that securely holds and stabilizes the pin. This approach ensures reliable pickup of the pin even under challenging underwater conditions.



Figure 14: Magnetic tool

• Vision System

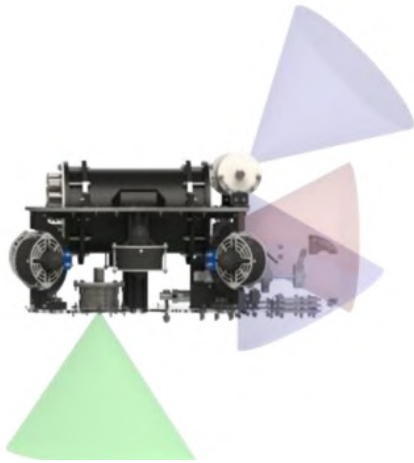
HYDRONAUT's vision system

The HYDRONAUT vision system uses one OAK stereo camera and three Rapoo USB cameras in order to obtain real-time depth information, object recognition, and full coverage of operations. The placement of each camera was determined according to the geometry of the tasks, visibility from the pilot position, and subsystem demands.

Camera	Role
OAK Stereo Camera	Primary depth sensing, 3D perception, spatial measurement
Rapoo USB Camera 1	Bottom-facing seabed observation and object detection
Rapoo USB Camera 2	Forward-facing supplementary workspace view
Rapoo USB Camera 3	Front-down gripper monitoring — primary manipulation view

Table 2 :HYDRONAUT's vision system

• Camera Configuration & Strategic Placement



• OAK Camera (Forward / Measurement & Navigation)

The OAK stereo camera is mounted at the front of the vehicle and serves as the primary vision sensor. It consists of stereo lenses for disparity-based depth sensing, along with an RGB image sensor and an onboard AI chip. ##This configuration enables accurate depth perception and precise distance measurement, which are essential for tasks requiring high levels of accuracy.

With its adjustable orientation, the camera supports both forward navigation and close-range inspection, while also providing clear visibility of the front grippers during manipulation tasks. The onboard AI chip allows for real-time processing and internal analysis of captured data, significantly reducing the computational burden on the main computer and ensuring low-latency performance.

• Rapoo USB Camera 1 – Bottom-Facing

Positioned below to scan the seafloor, this camera features a near-vertical orientation that minimizes perspective distortion and ensures geometric alignment with the training data, improving detection accuracy. In addition, it provides the pilot with a stable reference for hovering and manipulation at the seafloor level.

• Rapoo USB Cameras 2 & 3 – Front & Front-Down

Camera 2 provides a forward-facing view from a different perspective than the OAK-D camera, which reduces blind spots and enhances the spatial perception of the approaching area.

Camera 3 is angled downward toward the manipulator assembly and serves as the primary camera for gripper monitoring. It provides a clear view of manipulation tasks, enabling the operator to precisely observe where the gripper contacts and interacts with objects.

• Video Streaming

To ensure smooth and reliable video streaming, the system was designed with two independent GStreamer pipelines.

The OAK camera processes depth and RGB data onboard, generating pre-processed streams that reduce computational load on the main system while maintaining low-latency performance. These streams are transmitted efficiently via GStreamer.

In parallel, the Rapoo USB cameras stream raw video directly to the onboard computer (via GStreamer) for real-time monitoring. This distributed setup minimizes bottlenecks and ensures stable performance.

Camera	Processing	Transport
OAK Camera	Onboard AI chip	GStreamer
Rapoo USB 1-3	Host onboard computer	GStreamer over USB

Table 3:Video Streaming

• Image Processing & Color Restoration

One of the main challenges in underwater imaging is the gradual loss of color due to light absorption, particularly in red and yellow wavelengths, resulting in a blue-green tint.

To enhance visual clarity, a real-time color correction method based on the Gray World Assumption is applied to OAK-D frames. Compared to other techniques, this approach provides more consistent results than Auto White Balance in underwater conditions and avoids the noise amplification and distortions caused by Histogram Equalization, preserving a more natural scene appearance and improving overall visibility.

• Camera Calibration

Accurate depth perception in underwater imaging depends heavily on precise stereo camera calibration.

This process determines both intrinsic and extrinsic parameters of the stereo pair, ensuring accurate spatial measurements.

Performing this calibration underwater is essential due to light refraction, which alters the effective focal lengths and distortions compared to air, potentially affecting depth measurements if uncorrected.

As can be seen in figure 15 , during calibration, multiple images of a checkerboard pattern were captured at different positions and orientations across 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.

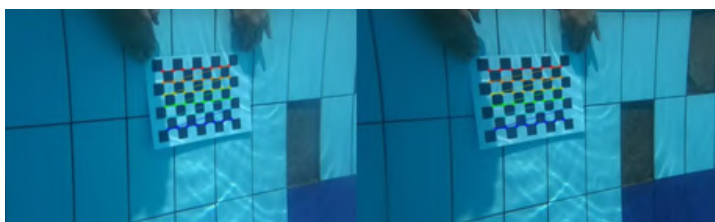


Figure 15: Calibration

• Crab Detection

As shown in Figure 16 , detecting European green crabs in underwater environments is challenging due to camouflage, varying orientations, and complex seabed backgrounds. Traditional methods based on axis-aligned bounding boxes (AABB) often capture excessive background for rotated objects, reducing detection accuracy.

To address this, the system adopts Oriented Bounding Boxes (OBB), which align with the object's orientation, improving localization and minimizing background interference.

The model, based on YOLOv26, was optimized for real-time onboard performance and trained on a dataset of real underwater images captured by HYDRONAUT to avoid domain gap. Data augmentation techniques were applied to simulate variations in orientation, lighting, and turbidity, enhancing robustness.

As a result, the system achieves 99% detection accuracy, maintaining strong performance in low-visibility and cluttered conditions.

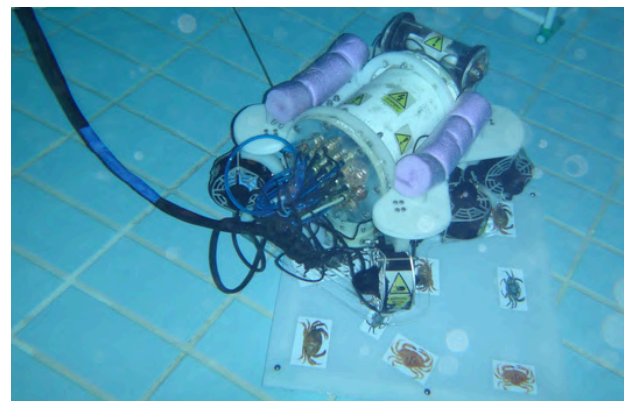


Figure 16: Crab detection

Model performance Comparison

Deployment of the detection model is set to use YOLOv26 (Small) because of slightly shorter inference time by 0.6 ms but a significantly higher mAP50-95 score of 0.964 as opposed to 0.937 in YOLOv11, having 10.5M vs 9.7M parameters respectively.

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 4: Evaluation Metrics

• Depth Measurement Approach

Accurate depth perception is achieved using a dual-view interface that combines RGB imagery with real-time depth mapping. This setup enables the operator to clearly detect objects, while 3D position estimation is computed using stereo disparity. To maintain reliable measurements in challenging underwater environments, three filtering processes are applied:

- **Confidence Threshold Filter:** assigns a confidence value to each stereo depth measurement, and any measurement that does not meet the defined threshold is discarded. This prevents turbidity, suspended sediments, and surface reflections from affecting accuracy.
- **Spatial Window Filtering:** applies window-based averaging to reduce sensor noise while preserving sharp edges for precise boundary detection.
- **Euclidean Distance Transform:** converts disparity values into real-world distances based on camera calibration, resulting in centimeter-level accuracy within a 5 cm operational range.

• Coral Garden 3D Modeling

Reconstructing the coral garden in Task 1.2 as a 3D model requires a method that preserves true metric scale, enabling height and length estimation for eight targets in one coordinate frame. The approach chosen for this task is Tripo 3D Generator as highlighted in figure 17, due to its ability to produce high-quality models from a limited number of overlapping images captured during the ROV survey.

Unlike other methods, the Tripo 3D Generator does not need any special equipment to perform this task and also allows completing the job much faster due to its automation.

- Accuracy may vary depending on underwater conditions such as lighting distortion and poor visibility, which can affect reconstruction quality.

- Since all eight targets should be represented in one coordinate system, additional post-processing may be required to adjust their spatial alignment and positional accuracy.
- The automated pipeline offers limited flexibility for fine-tuning reconstruction parameters compared to traditional methods.
- AI-based reconstruction may introduce smoothing or loss of fine geometric details, impacting precise measurements.

Despite these trade-offs, Tripo provides a strong balance between efficiency, deployment simplicity, and reconstruction quality, making it a practical and mission-ready solution.

*This table compares the main characteristics of Tripo AI, Zephyr, and MAST3R for creating 3D models from images.

Requirement	Tripo AI	Zephyr	MASt3R
Automation	Excellent	Good	Low
No. of Images	Low (1-4)	High	Medium
Accuracy	Good	Excellent	Very High
Speed	Very High	Medium	High
Hardware Requirement	Low	High	Very High

Table 5: software models comparison

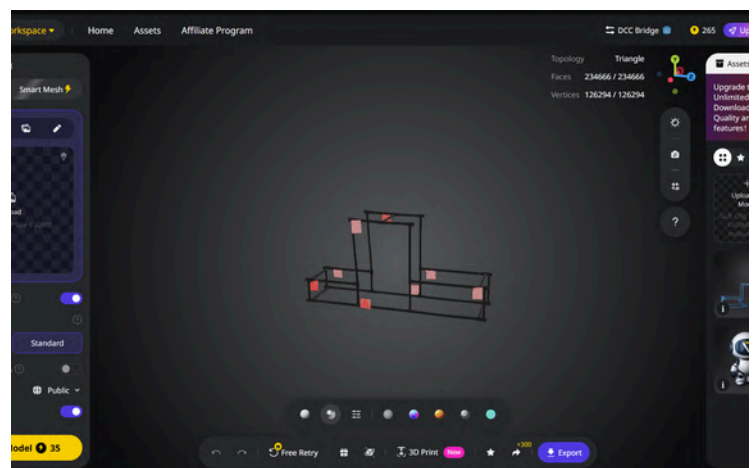


Figure 17: Tripo 3D Generator

- control system

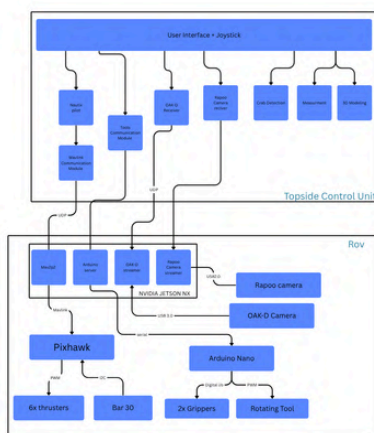
The NVIDIA Jetson Xavier NX was selected as the main onboard computer for HYDRONAUT due to its high computational power, efficient real-time processing capabilities, and suitability for advanced computer vision applications. Since the ROV relies heavily on vision-based tasks such as underwater navigation, object detection, depth estimation, and target tracking, a powerful embedded system was required to process large amounts of visual and sensor data with minimal latency.

The Jetson Xavier NX provides the performance needed to simultaneously handle multiple camera streams, AI inference, and continuous mathematical computations while maintaining stable system operation. Its GPU architecture and Tensor Cores enable efficient execution of deep learning models, allowing real-time object detection directly onboard the ROV without excessive load on the main system.

In addition, its multi-core CPU supports parallel processing for filtering, spatial calculations, and control-related computations, making it highly suitable for HYDRONAUT's integrated control and vision system.

Compared to conventional embedded platforms, the Jetson Xavier NX offers a balance between performance, power efficiency, compact size, and AI acceleration, making it an ideal choice for autonomous and vision-intensive underwater operations.

Figure 18: Software SID



Electric System

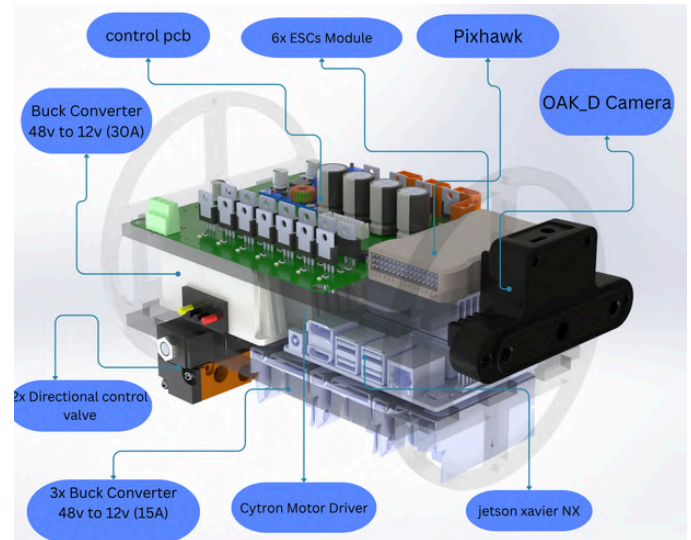


Figure 19: internal

The figure below demonstrates 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 $1850\mu s$, 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
DAK camera	1	5	0.8	4	4
apoo camera	3	5	0.4	2	6
					836.225

Table 6: Power Calculation

- Power protection

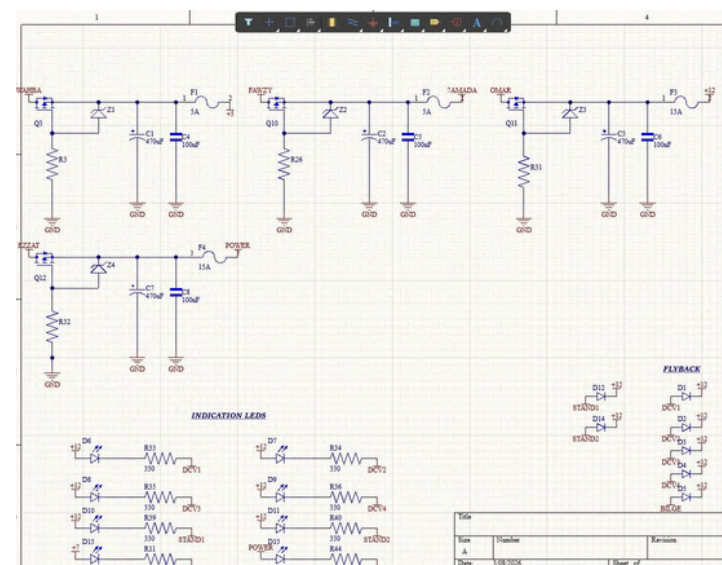


Figure 20: Safety circuit

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 as can be seen in figure 20.

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.

- PCB

PCB supports two MOSFET control approaches as demonstrated in figure 21:

- 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.

- 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.

The MOSFET switching circuits driven by the PCB control critical auxiliary components, including two DCVs for gripper operation and DC motor. Power is distributed through three 48V-to-12V 15A buck converters and one 48V-to-12V 30A buck converter

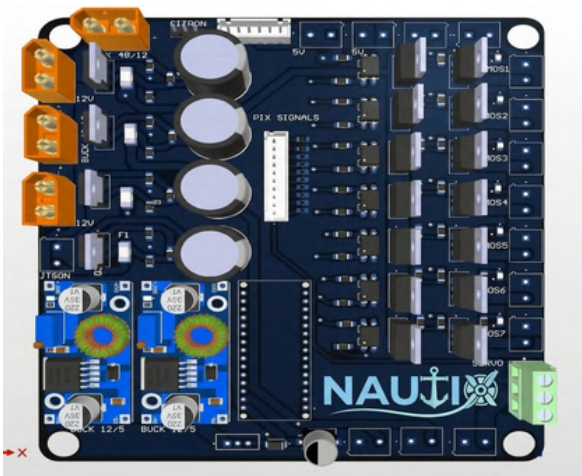


Figure 21: Control PCB

- **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**

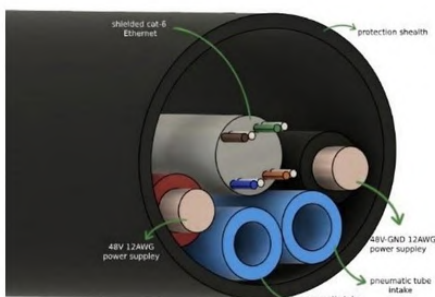


Figure 22: Tether

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 As visible in the figure 22:

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

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.

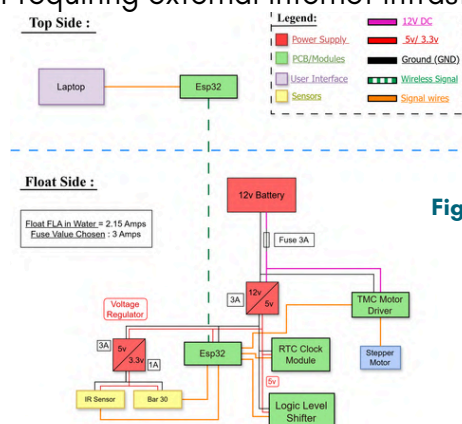


Figure 23: Float SID

GUI

The Nautix GUI serves as the primary human-machine interface between the pilot and the ROV, integrating high-level vision processing from the NVIDIA Jetson Xavier NX with flight control through the Pixhawk. It provides a centralized control environment that combines real-time multi-camera video feeds, telemetry visualization, and operator commands within a unified platform. The GUI was implemented using Python with the PySide6 framework, selected for its object-oriented architecture, cross-platform compatibility, and efficient integration with multithreaded real-time applications, also it supports simultaneous visualization of multiple camera feeds to maximize underwater situational awareness. Video acquisition is handled through dedicated multithreaded processing using QThread. Each UDP camera stream is processed through an independent thread. The system uses OpenCV for frame acquisition and image conversion and GStreamer pipelines for low-latency H.264 UDP stream decoding as shown in Figure 24.

The selected GStreamer pipeline enables, Minimal buffering delay, Reduced frame latency and Efficient decoding of compressed video streams.

To prevent interface freezing and maintain responsiveness, during continuous video streaming, the GUI employs asynchronous multithreading. The GUI also integrates real-time telemetry updates and supports reliable communication with the vehicle.

System robustness is enhanced through automatic fault recovery, including stream monitoring and auto-reconnection, ensuring stable operation under intermittent underwater communication conditions.

The GUI was intentionally created to assist with the software-heavy tasks needed in the competition. Its design allows for effortless incorporation of computer vision and specialized processing units, enabling mission results like object detection, target identification, and environmental assessment to be presented directly to the pilot in real time as presented in Figure 25

The GUI was intentionally created to assist with the software-heavy tasks needed in the competition. Its design allows for effortless incorporation of computer vision and specialized processing units, enabling mission results like object detection, target identification, and environmental assessment to be presented directly to the pilot in real time. For tasks like crab detection and classification, the GUI offers real-time visual feedback with camera overlays, allowing detected objects to be highlighted directly on the video feed for quick operator understanding instead of manual detection. This aids in precise identification and shortens decision-making time while executing missions. As highlighted in Figure 26 the GUI features a measurement tool based on computer vision, aimed at analyzing coral gardens and icebergs. The system calculates dimensions by utilizing a reference object with a known length to create a pixel-to-distance scale. The software determines real-world measurements by contrasting the target's pixel length with the calibrated reference and presents these measurements directly to the pilot, facilitating quick and precise evaluation during mission operations.

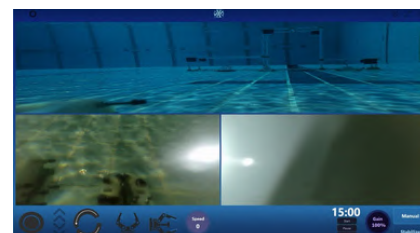


Figure 24: GUI

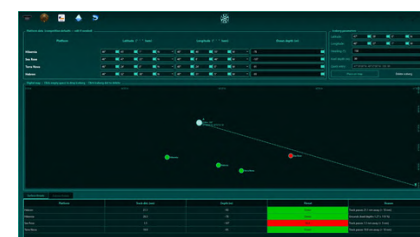


Figure 25 : SW CO Pilot GUI

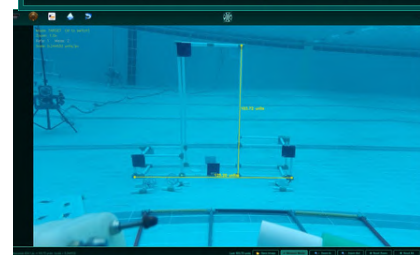


Figure 26 : SW CO Pilot GUI

- Build vs. Buy, New vs. Used

System	Justification
Pixhawk 4 (reused / purchased)	Meets requirements:ArduSub Compatibility, Communication Interfaces, Companion Computer Integration, Sensor Suite
Nvidia Jetson NX (reused / purchased)	Meets requirements:sufficient processing power, Camera & Vision Support, Compact & Low Power, Linux-Based OS, Networking
T200 Thrusters (reused / purchased)	Meets requirements:provides sufficient thrust and maneuverability for MATE Tasks
oak_d (reused / purchased)	Meets requirements: Stereo Depth Perception, Onboard AI Processing, RGB + Depth Fusion, Real-Time Performance
Rapoo cameras (new / purchased)	Rapoo cameras are used to capture images and videos for computer vision applications. They help robots and AI systems detect objects, faces, and movement.
Float Hardware (new / built)	Iterated float design with a better price to performance, reliability
Depth sensor (new / purchased)	The Bar30 depth sensor is utilized in Task 1.1, where it provides real-time depth measurements to the flight controller to maintain precise depth hold during operation.
Camera boxes (reused / built)	Meets requirements:Waterproof enclosures, Optical Clarity, Lightweight, Machinability
Thruster Guards (reused / built)	Meets requirements:IP20 rated, minimal drag, Corrosion Resistance, Machinability & Fitment
tether (reused / purchased)	Meets requirements:efficiency, safety, strength, abrasion resistance.
Electronics pod (reused / built)	Meets requirements: Custom enclosure optimized for waterproofing, internal organization, component placement.

[illegible]

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 expected to take ownership of safety by identifying hazards, proposing mitigations, and maintaining compliance across all activities.

As shown in Figure 28 before any work on the ROV began, all team members underwent mandatory safety training to ensure safe equipment handling and full awareness of lab safety procedures. The training introduced potential risks, emergency response procedures, proper tool usage, and the locations of safety equipment such as first aid kits and fire extinguishers.

To maintain a high level of preparedness, regular safety reviews and annual fire drills are conducted to ensure that all team members remain aware of emergency procedures and safety practices.

Specialized tasks including drilling, pneumatic testing, grinding, soldering electronics, and cable work are performed only in a designated hazardous-work area equipped with the required safety tools and protective equipment such as safety gloves and goggles. Access to this room is restricted to the members assigned to perform these tasks in order to maintain a controlled and safe working environment. In addition, workspaces are kept organized and emergency exits remain clear at all times to help prevent accidents and allow safe evacuation during emergencies.



Figure 28: personnel safety



- **Equipment Safety**

To ensure safe operation of the ROV during handling, maintenance, and product demonstration, multiple mechanical and electrical safety measures were implemented. Sharp edges and exposed components were eliminated by covering nylon cable tie heads with glue, enclosing screw ends using cap nuts, and protecting aluminium extrusion terminals with custom 3D-printed covers. In addition, all moving components were properly shielded to reduce the risk of accidental contact. The T200 thrusters were protected using aluminium mesh covers, while the bilge pump motor housing was enclosed using a 3D-printed mesh.

Electrical safety was also a major design consideration. Anderson Power SBS50 connectors were selected due to their ability to withstand high current loads, provide secure locking, and operate reliably in harsh environments. To protect the power system from overcurrent and short-circuit conditions, 25A and 15A fuses were integrated with appropriate safety margins to safeguard both the main tether and sensitive PCB components. In addition, a minimum cable size of 12 AWG was selected to safely handle current and reduce heat generation. Marine-grade fuse boxes and waterproofed electrical enclosures were also implemented to ensure safe and reliable operation in submerged environments.

Critical Analysis

To ensure safe, reliable, and efficient operation of the ROV, NAUTIX evaluates system performance across three main categories: mechanical, electrical, and software. This phase focuses on systematic testing and troubleshooting throughout all subsystems during the development process. The goal is to identify potential technical issues and apply effective solutions to ensure optimal system performance.

- **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 office and monitor all movements and functions this test help us at Early detection of mechanical issue 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 tests:

Pool tests are conducted three times per week for approximately four hours in an indoor pool to evaluate the ROV's neutral buoyancy and its ability to maintain stable positioning underwater. During these sessions, buoyancy is fine-tuned to ensure consistent and stable performance.

This testing phase simulates real mission conditions, including navigation, object manipulation, and data collection.

Power supply and Distribution :

we need to ensure reliable and stable performance 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 are tested to confirm their proper functionality before system integration. This includes checking wiring integrity, connection continuity, resistance values, and PCB operation to validate the correctness of the overall design.

After completing individual tests, all components are integrated into the full system, where performance is evaluated under real operating conditions. This includes monitoring power distribution, data transmission, and system response time to ensure reliable and stable operation.

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.

- **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 decided 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 including TCP and UDP were tested to ensure safe, 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.

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.

Budget

Nautix Robotics' CFO led a comprehensive financial strategy built around a \$4,100 USD budget, with a built-in 20% risk buffer to absorb unexpected R&D costs and component failures. This approach kept the engineering timeline on track and ultimately produced a financial surplus, confirming the model's effectiveness.

To counter foreign exchange risks from international procurement and competition expenses in USD and CAD, the team adopted a forward purchasing strategy – converting required funds early to lock in exchange rates and shield purchasing power from currency fluctuations, while keeping local funds reserved for domestic manufacturing needs.

On the operational side, a dual-layer digital tracking system combined the CashBook app with an automated Google Sheets database. A custom Google Forms workflow further streamlined finances by auto-generating PDF invoices, archiving them to Google Drive, and delivering them directly to team members – minimizing manual errors and maintaining a fully auditable financial record throughout the season.

- Income & Sponsorship Allocation**

The Pioneers division is primarily self-funded through direct team member contributions, alongside strategic hardware and software sponsorships to reduce cash burn:

Source	Type	Amount (USD)	Amount (CAD)
Team Members	Out-of-Pocket Cash	\$4,791.67	\$6,588.55
Vortex Robotics	In-Kind Hardware	\$3,198.00	\$4,397.25
Vortex Robotics	AI Tools Grants	\$385.00	\$529.38
Google	AI Educational Grant	\$0.00	\$0.00
Total Income	---	\$8,374.67	\$11,515.18

- Financial Category Summary Breakdown (Actual Cash from Team)**

Category	Actual Cash (USD)	Actual Cash (CAD)
1. Administration & Logistics	\$1,300.00	\$1,787.50
2. Electrical Components	\$1,485.40	\$2,042.43
3. Mechanical & Fabrication	\$383.00	\$526.63
4. Operation & Safety	\$131.00	\$180.13
5. R&D Losses (Contingency)	\$750.00	\$1,031.25
Total Project Cash Cost	\$4,049.40	\$5,567.94
Remaining Team Cash Balance (Surplus)	\$742.27	1020.61

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Appendix A : Safety Checklist

Pre Operation 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