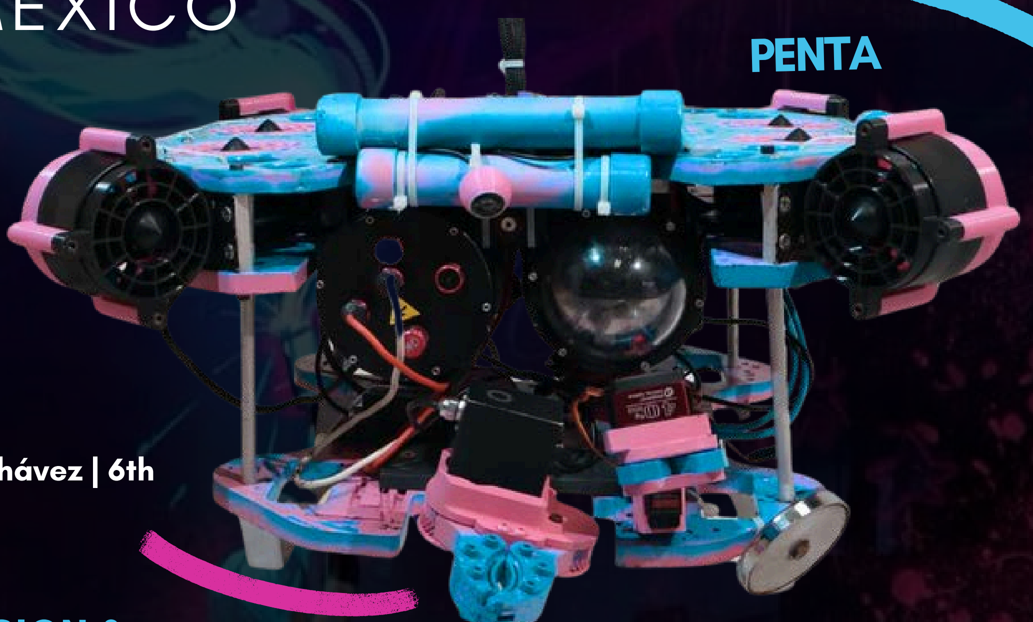
TECXOTIC

TECHNICAL REPORT 2024

XOCHITEPEC,
MORELOS, MÉXICO



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HECHO EN MEXICO

Tecnológico de Monterrey

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Fig. 1 TecXotic 2025 Product: Penta

Fig. 2 GCU

Glosary

Abstract:
- ROV: Remotely Operated Vehicle
- MATE: Marine Advanced Technology Education
- Scrum: An agile project management framework used to organize teamwork iterative work cycles called sprints

Safety:
- JSA: Job Safety Analisis
- Notion: Digital workspace platform
- PETG: Polyethylene Terephthalate Glycol

Team Work:
- Scrum Board: A visual tool used to track task progress in a Scrum framework.
- ClickUp: A cloud-based project management platform
- Sprint: A fixed period, usually 1-2 weeks, in which a team commits to completing a specific set of tasks or goals.
- Branch (Git): In version control systems like GitHub, a branch is an independent line of development
- Pull Request (PR): A process in GitHub where changes made on a separate branch are submitted for review and approval.
- VCS: Version Control System

Design and Mechanics
- Additive Manufacturing (AM): Fabrication method that builds objects layer by layer from digital models, allowing complex geometries with high precision and reduced cost.
- PolyAl: Material made from cellulose, aluminum, and plastic, valued for its mechanical strength, near-neutral buoyancy, and water resistance.
- Buoyancy (Fb): Upward force keeping objects afloat underwater.
- Enclosure (Acrylic Tubes): Transparent cylindrical housings for electronic systems.

Electronics:
- SMW: Simple Modular Well-made
- GCU: The Ground Control Unit
- TCE: The Thruster Control Enclosure
- MCE: The Main Control Enclosure
- ESC: Electronic Speed Controller PCB: Printed Circuit Board CCU: Case-Control Unit A

1. Abstract

The growing environmental challenges facing oceans, rivers, and lakes demand innovative engineering solutions—this is where Remotely Operated Vehicles (ROVs) can make a critical impact.

TecXotic, founded a decade ago and the first Latin American team to participate in the MATE ROV Competition, has consistently demonstrated creativity, professionalism, and technical skill. With experience gained through multiple generations of multidisciplinary engineers, TecXotic proudly represents Tecnológico de Monterrey and continues to push the boundaries of underwater robotics.

This year's ROV, Penta, is named in honor of a Mexican wrestling figure—symbolizing the resilience, discipline, and courage that define our team. Penta incorporates proven elements from previous designs, such as a durable frame, reliable materials, and our signature tension relief system. At the same time, it introduces major innovations that enhance its capabilities and mission relevance.

Among its standout features are: a mimicking tool system for intuitive remote operation, a modular control architecture built from scratch, and a flexible software system based on WebSocket communication-—a widely adopted protocol used in real-time applications such as messaging platforms and multiplayer games. Additionally, we adopted agile project management practices, such as Scrum, to improve team coordination and task efficiency.
TecXotic is proud to present Penta as a refined, adaptable, and forward-thinking solution that reflects our continued dedication to advancing marine technology and protecting aquatic environments.

Fig. 3 Tecxotic 2025

2. Safety

A. Safety Philosophy

At TecXotic, safety remains the highest priority. This commitment extends equally to team members, prospective clients, marine life, and the environment. Prioritizing safety instills confidence and comfort among collaborators, which supports accurate fabrication, task execution, and hazard mitigation. TecXotic is dedicated to fostering a clean, organized, and secure work setting for everyone involved.

B. Laboratory and Workshop Safety Protocols

In 2025, TecXotic enhanced its safety documentation through the use of Notion, introducing a revised version of its safety manual. This digital resource allows team members to quickly reference safety protocols anytime and facilitates ongoing updates. It contains essential information on safety standards, procedures, and risk mitigation strategies—such as Job Site Safety Analysis (JSA), Safety Reviews, and Safety Evaluations.

Safety review

Task	Date	Prior.	Document
Montaje de Circuit Boards	May 15, 2024	High	Expected Work Practices
Cableado de Circuit Boards	May 15, 2024	Medium	Expected Work Practices
Cableado Oculto	May 15, 2024	Medium	Expected Work Practices
Ordenamiento de Cables	May 15, 2024	Low	Expected Work Practices
Cubierta de Cables	May 15, 2024	Medium	Expected Work Practices
Encapsulamiento de Dispositivos	May 15, 2024	High	Expected Work Practices
Uso de Baterías	May 15, 2024	Medium	Expected Work Practices
Sello de Motores Brushless	May 15, 2024	High	Sealing Brushless Motors
Cobertura de soldaduras	May 15, 2024	Medium	Sealing Brushless Motors
Safety Requirement	May 15, 2024	Low	Sealing Brushless Motors
Prueba de MegaOhms	May 15, 2024	Low	Sealing Brushless Motors
Seguridad con el Megger	May 15, 2024	High	Sealing Brushless Motors
Fusible Anderson y Conectores	May 15, 2024	Medium	Initial Safety Inspection
Visualización de Control Box	May 15, 2024	High	Initial Safety Inspection
Aliviado de Tensión en el ROV	May 15, 2024	High	Initial Safety Inspection
Hélices Cubiertas en el	May 15, 2024	High	Initial Safety Inspection

Fig. 4 Notion Safety Review rubric

To promote consistent practice, structured safety assessment rubrics were introduced. These rubrics support real-time verification of safety compliance during lab and workshop activities.

C. ROV Safety Protocols

To ensure safe use and transportation of Penta, TecXotic developed dedicated JSAs covering facility usage, equipment management, and resource handling. These include detailed checklists for pre-deployment and post-deployment processes, designed to reduce risks of accidents or mishandling during ROV operation. These safety steps are vital to protecting the well-being and physical safety of all operators and teammates.
These protocols are digitized and integrated into our Notion system, and rubrics are used to facilitate safety checks during task execution.

Fig. 5 Safety Laboratory Protocols

D. Training

All team members are required to participate in general safety training, with specialized instruction provided based on specific roles. These training sessions help foster a safety-first mindset, decrease the likelihood of accidents, and encourage best practices both in the lab and in the field.
General topics covered include laboratory protocols, safe usage of power tools and machinery, and basic manufacturing techniques.

In 2025, TecXotic delivered 13 safety-focused workshops in collaboration with Corporate Social Responsibility and other institutional and external partners of Tecnológico de Monterrey.

Alongside formal training, a peer-to-peer support system is in place. Team members are encouraged to share knowledge and look after one another, ensuring continuous safety awareness and protection for everyone.

E. Safety Features

The ROV is equipped with multiple safety components. For example, 3D-printed PETG guards shield the thrusters, preventing contact with the propellers. Enclosure seals are applied following SDS guidelines specified in TecXotic's safety documentation, and the ROV frame is engineered for balance and stability.

Fig. 6 Thruster Guards

Proper fuse sizing has been applied to all electrical systems, including non-ROV components, to guarantee safe operation. In addition, a Main Emergency Stop Button—easily reachable by the operators—allows for immediate shutdown of all systems, helping prevent injuries and equipment damage.
Penta is outfitted with a comprehensive suite of safety features aligned with both MATE and TecXotic safety criteria. These features address structural design, operational workflows, software-level safeguards, and operator-focused measures.

3. Team Work

A. Company Organization

TecXotic is a multidisciplinary team affiliated with the School of Engineering and Sciences at Tecnológico de Monterrey. The team consists of 19 students from various majors and academic levels, unified by a shared goal of designing and building a competitive ROV. To ensure effective coordination and collaboration across such a diverse group, the team is structured into five departments: Finance and Social Media, Design and Manufacturing, Electronics, Software, and Corporate Responsibility. The collective efforts of these departments culminated in the development of this year's ROV, Penta.

Each technical department is led by a designated leader who is responsible for recruiting and mentoring new members, managing department-specific resources, and defining technical requirements in alignment with this season's mission objectives. The team fosters an inclusive environment where new members are encouraged to explore multiple departments and participate in ongoing projects throughout the year, promoting cross-functional learning.
In addition to the student-led departments, TecXotic is supported by dedicated mentors who provide technical guidance, emotional support, and strategic advice during critical moments of the project. A comprehensive organizational chart illustrating the team structure is included:

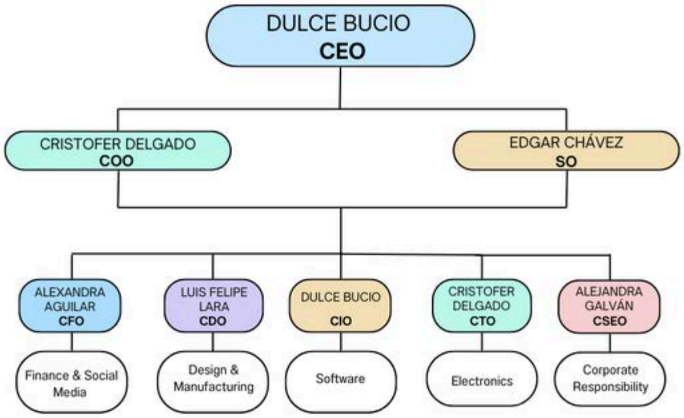


Fig. 7 TecXotic Company Structure

B. Project Management

This year, TecXotic adopted the Scrum methodology to better align with the dynamic nature of the MATE ROV competition. Given the evolving requirements and the complexity of coordinating a multidisciplinary team, Scrum provided a flexible yet structured framework to improve both project management and team collaboration.
The following table summarizes key Scrum principles and how they benefited our project:

Scrum Methodology	Benefit
Changing requeriments	Even though there is a defined competition manual through the season with minor changes to consider, working in the elaboration of the ROV always brings up unexpected problems
Iterative improvements	Help focus on small goals while still moving forward the project development
Quick syncs	Constant communication on advancements and impediments to be solved
Sprint planning	Maintains a controlled, centralized and prioritized task lists with their current states to make the project visible and clear

Table. 1 Scrum Benefits for TecXotic

As there are many different majors and not every all of them are related to agile methodologies, the implementation of this strategy started with a proper capacitation imparted by one of our SCRUM Master Certified mentors, and gradual implementation through the season.

A SCRUM Board was implemented and managed through ClickUp, chosen by its feature of implementing multiple boards, especially useful considering the many areas available and their different necessities and tasks.

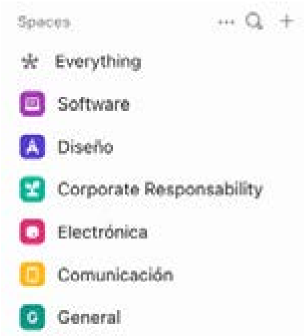


Figure 8. Different spaces in TecXotic's ClickUp

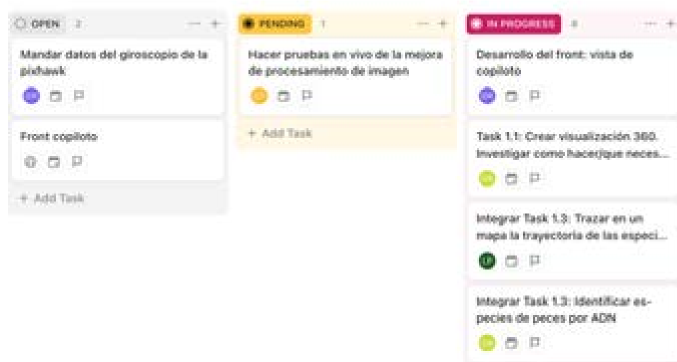


Figure 9. Scrum Board from Software Department

SCRUM was not strictly implemented and we kept the most valuable of their principles. The team gathered and reunited once a week to define goals, objectives and distribute responsibilities, while maintaining constant communication through our WhatsApp community and updating the SCRUM board.

Maintaining thorough documentation and keeping detailed records of progress is essential to ensure continuity, transparency, and efficiency across all departments. It allows the team to track what has been attempted, completed, or discarded, reducing redundant work and improving coordination.
For code management, we used GitHub as our version control system, implementing best practices throughout the development process.

Features were developed in separate branches, and changes were submitted through pull requests, which were reviewed and approved by the CIO. This process ensured that both the backend and frontend systems remained stable, functional, and well-maintained.

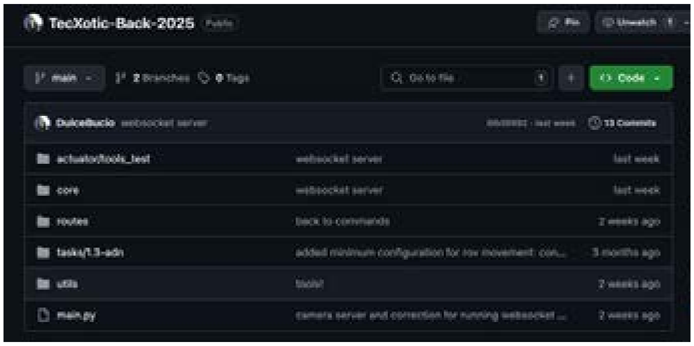


Figure 10. Code management through GitHub

For departments that do not have a standardized version control method—such as design, manufacturing, or system integration—we used Google Drive to store and organize critical files, including 3D models, System Integration Diagrams (SIDs), and prototype documentation. This cloud-based storage system ensured that all team members had real-time access to the latest materials, regardless of their department or location.

C. Project Scheduling

TecXotic's comprehensive project schedule begins in August, aligning with the academic calendar at Tecnológico de Monterrey. The team's workflow is divided into several key phases that guide the focus of our efforts throughout the year:

- Recruitment and Training: This stage is open to any student from our campus. During this period, experienced team members lead workshops and hands-on sessions to train newcomers in areas such as design, electronics, and software.
- Retrospective and Research: Prior to the release of the competition manual, the team focuses on analyzing our performance in past seasons. This allows us to identify areas for improvement. Simultaneously, we research new technologies and system alternatives to broaden our understanding and prepare for upcoming challenges.
- ROV Planning: Once the official competition manual is released, we begin planning the ROV in detail. This involves selecting tools, defining subsystems, identifying necessary materials, and starting early prototyping. Strategies during this phase include brainstorming sessions, iterative testing, and consultation with mentors.
- ROV Building: Construction of the ROV begins. Each team leader allocates tasks within their department and organizes their resources around two-week sprints to ensure timely progress.
- Testing and Integration: We conduct rigorous testing to verify mechanical integrity, electronics performance, and full system integration. This includes both dry and underwater testing to ensure mission readiness.

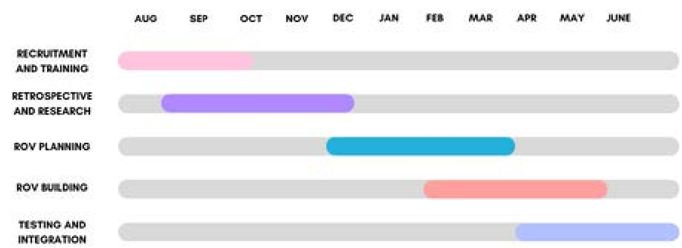


Figure 11. TecXotic 2025 Season Cronogram

4. Budget & cost planning

Given TecXotic's limited budget, cost-efficiency was a priority throughout the ROV development process. To minimize expenses, many components from previous designs were carefully reused, provided they met current mission requirements in terms of functionality and reliability.
Each department was allocated an individual budget. These budgets were managed independently but reported consistently to the Finances Department, which oversaw expense tracking and documentation. This approach ensured transparency and accountability in the team's financial planning.

When acquiring new components, the team prioritized cost-effective solutions that met defined technical requirements and contributed directly to tool development or performance improvements.

Care was taken to avoid unnecessary expenditures and to leverage existing resources wherever possible.

Appendant 3: Budget

5. Design Rationale

A. Design Overview

For the development of TecXotic's 2025 ROV, PENTA, three core principles shaped the design process: ensuring sustainability through the S.M.W. philosophy, retaining the most successful features from the previous model, Tzilacatzin, and adopting a renewed internal organizational structure. Rather than starting from scratch, the team strategically built upon the strengths of Tzilacatzin, especially its modular configuration and the reliability of its eight-thruster propulsion system.

Although the project preserved many proven elements, it also introduced promising innovations, such as a mimetic robotic arm designed to expand the ROV's capabilities. However, as of this stage, this system still lacks validated performance data and remains under development.

To ensure safety and operational effectiveness, the team conducted multiple Failure Mode and Effects Analyses (FMEA), through which several critical issues were identified and resolved. These included addressing flotation imbalances, enhancing the motors for tool systems, integrating the new robotic arm, and sealing the entire electrical and cabling system, thereby eliminating disconnection issues during missions. Additionally, all sharp edges were removed, contributing to improved safety and competition compliance.
Based on these evaluations, a set of specific design guidelines and recommendations was formalized to guide future development:

Appendant 4: FMEA

As a result of these evaluations, a formalized set of design guidelines and recommendations was created to inform current and future ROV development. These priorities reflect TecXotic's strategic balance between continuity and innovation, reinforcing the team's ongoing commitment to excellence, reliability, and safety.

1. **MAINTAIN** ⚓ Safety practices and protocols
2. **MAINTAIN** ⚓ Adjustable buoyancy
3. **INCREASE** ⌃ Frame's rigidity
4. **DECREASE** ⌄ Prototyping time
5. **DECREASE** ⌄ Assembly complexity
6. **IMPROVE** ⚙ Tool reliability and power
7. **IMPROVE** ⚙ Software reliability

Appendant 1. Criteria

B. Design Philosophy

A fundamental pillar of TecXotic's engineering strategy is the S.M.W. methodology (Simple, Modular, and Well-made) a framework originally developed by our mentor to guide educational and competitive engineering projects like this one. Since its adoption, this philosophy has become an essential tool for reducing prototyping and assembly times, improving manufacturability, and driving the iterative enhancement of our ROVs, particularly the current model, Penta.

Simple: Every design begins with a clear objective, to incorporate only what is essential. By minimizing the number of components and simplifying mechanisms, the team reduces the likelihood of mechanical failures, streamlines assembly, and ensures ease of troubleshooting. Simplicity also allows new members to understand systems more quickly, accelerating the learning curve.
Modular: Modular design enables systems to be disassembled, replaced, or upgraded without affecting the overall structure. This approach supports agile iteration, easier repairs during competition, and standardized spare parts manufacturing. It also improves logistics by reducing the volume and complexity of the equipment the team needs to transport.
Well-made: This principle ties the first two together by emphasizing execution quality across all processes: design, manufacturing, and integration. Every component must meet strict standards to ensure safety, durability, and functionality under demanding conditions. Quality assurance is a non-negotiable part of the S.M.W. approach.

The application of S.M.W. is not limited to technical work; it also defines how the team collaborates, evaluates risks, and implements improvements. Past challenges, such as unstable propulsion systems, chassis deformation, or power inconsistencies, have all served as learning points. These experiences have led to a robust and evolving set of internal guidelines that prevent recurring issues and promote creative problem-solving.

Ultimately, Penta is more than a vehicle, it is a reflection of a methodology that fosters engineering discipline, innovation, and team growth. The S.M.W. philosophy ensures that each new iteration is not just an upgrade, but a well-informed leap forward built on shared knowledge and a commitment to excellence. These design decisions, grounded in this philosophy, have had a measurable impact on the team's performance, improving efficiency, enhancing reliability, and elevating the team's competitiveness at every stage.

6. Mechanics

A. Mechanical Overview

Additive manufacturing remains a cornerstone in the ROV's construction, enabling the fabrication of intricate parts with precise tolerances at significantly lower costs. For this season, the mechanical modularity of last year's model was preserved—a strategic decision based on its proven performance, structural durability, and ease of integration with updated systems. This reuse aligns with TecXotic's focus on efficiency, sustainability, and waste reduction by avoiding unnecessary fabrication of new components. Additionally, maintaining a consistent mechanical platform simplifies both manufacturing and the implementation of new technologies. The robustness demonstrated in last year's competition further reinforced the decision. Throughout the process, strict adherence to safety protocols and design standards outlined in the RFP was upheld, emphasizing TecXotic's unwavering commitment to operational safety.

B. Frame

Penta's frame builds upon the strong foundation of its predecessor, integrating targeted improvements to enhance performance and structural integrity. Key upgrades include a redesigned gripping mechanism, reinforcement of areas previously susceptible to deformation, and a refined internal layout to optimize space usage. Central to the redesign is the continued use of PolyAl (a composite material made from cellulose, aluminum, and plastic) valued for its environmental sustainability and mechanical properties. With a density between 0.98 and 1.1 g/cm^3, PolyAl provides near-neutral buoyancy, while its waterproof, impact-resistant nature increases flotation and durability.

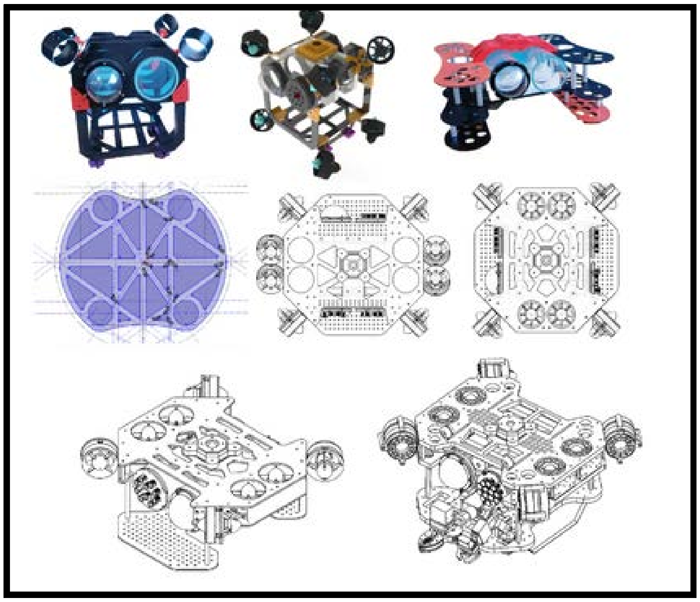


Figure 12. TecXotic Products Frame Evolution

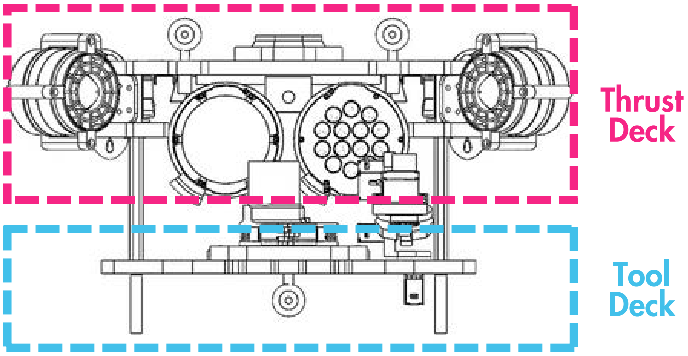


Figure 13. Penta's Frame Structure

Notably, each kilogram of PolyAl reuses approximately 140 Tetra Pak containers, reinforcing TecXotic's commitment to eco-conscious innovation.

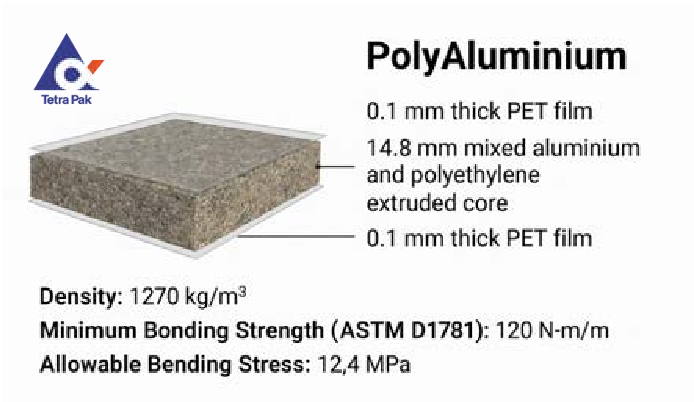


Figure 14. PolyAluminium Properties and Description

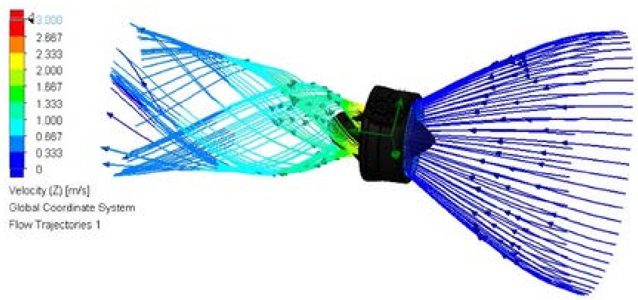
C. Propulsion & Hydrodynamics

Drag force is directly tied to the propulsion system, increasing exponentially with velocity and demanding greater thrust and energy. While T200 thrusters are efficient, high speeds raise power consumption. TecXotic's ROV, Penta, overcomes this with an eight-thruster configuration that ensures precise control without full throttle. Each T200 spins at 3,076 rpm, delivers ~1.2 kgf of thrust, and consumes 54.4 W at 12 V.

The ROV's hydrodynamic design minimizes drag in horizontal directions (Bow-Stern and Port-Starboard), as confirmed by simulations. Vertical motion requires more thrust to counter buoyancy. As shown in Figure 15, the thruster generates -12.077 N due to reverse pressure, yet maintains efficiency with stable pressure (95133.01 Pa) and minimal fluid displacement (0.000182 m^3).

This configuration enables efficient motion in all axes (surge, sway, heave, yaw) while optimizing energy use and extending thruster lifespan. Vertical thruster placement enhances heave stability and reduces drag impact in normal operation.

$$F_D = \frac{1}{2}\rho v^2 C_D A$$



Thruster water flow motion

Stern motion water flow

Port motion water flow

Down motion water flow

Figure 15. Hydrodynamics & mortion simulations

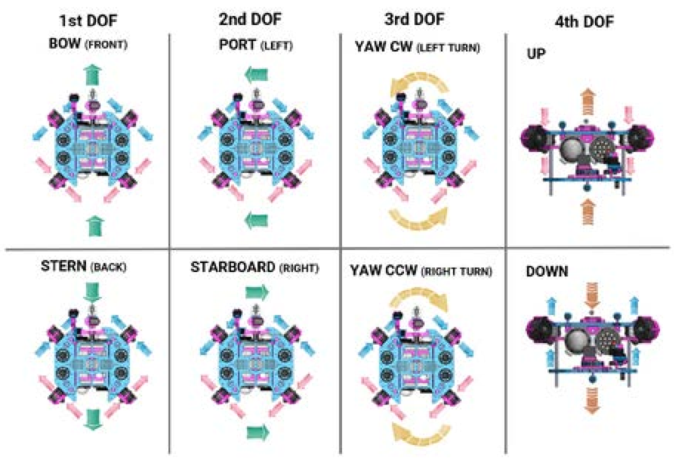


Figure 16. Penta's Propulsion Layout

D. Electronic Enclosure

The electronic system is housed in two 4" cast acrylic cylinders from Blue Robotics, selected for their affordability, strength, and visibility. Rated for 100 meters depth, they use O-rings and sealed penetrators for waterproofing. A vacuum test at -15 bar ensures integrity before deployment. Their cylindrical shape evenly distributes stress, reducing fracture risk. Clear domes are used for cameras, while aluminum end caps handle electrical connections.

Figure 17 . Thruster Control Enclosure

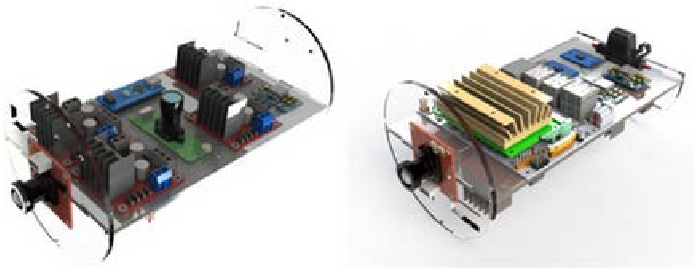


Figure 18 . Main Control Enclosure

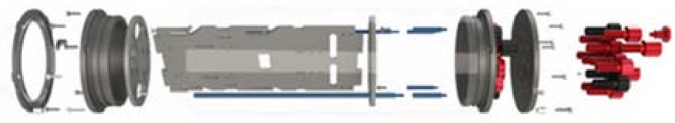


Figure 19. Exploded Enclosure View

E. Buoyancy

Buoyancy, governed by Archimedes' Principle, is the upward force acting on a submerged object, expressed as $F_b = \rho V g$ where ρ is fluid density, V is the displaced volume, and g is gravity.

Maintaining neutral to slightly positive buoyancy is critical for operational safety. Ensuring the ROV doesn't sink in the event of system failure, yet remains easily maneuverable. Penta's design achieves this balance using a custom buoyancy spreadsheet to model mass distribution and determine the need for added weights or floats. This year, we transitioned from foam to sealed tubes, as foam tends to absorb water over time, altering buoyancy. Aligning the center of mass with the center of buoyancy enhances angular stability, crucial for tool control and task precision. This configuration is validated using experimental data, volume measurements, and CAD modeling to fine-tune flotation and stability.

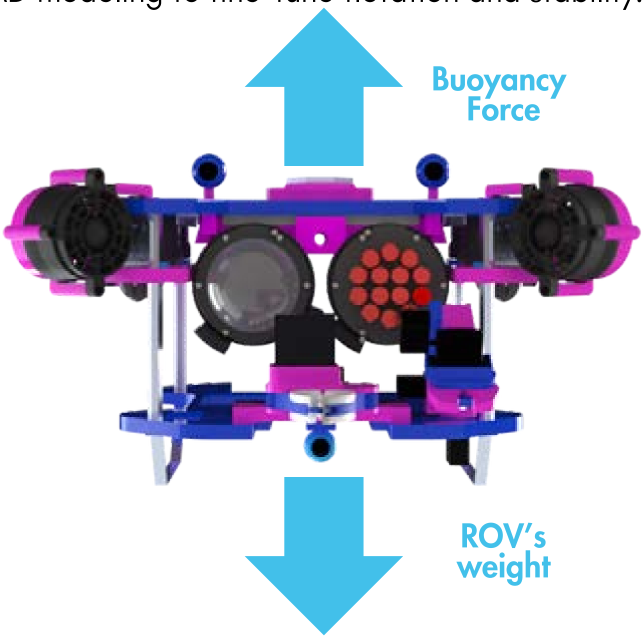


Figure 20. Buoyancy Physical Explanation

F. Tensor Relief

The tension relief system is mounted atop Penta and features a 3D-printed PETG ball secured with a clamp that intercepts tether stress. When the tether is pulled, the ball remains locked into an octagonal mount (adapted from a previous model) secured to the frame with graf nuts and screws. This mechanism transfers force directly to the structure, sparing the cable and connectors from strain while allowing flexible movement. PETG was selected for its marine-suited properties: high tensile strength, resistance to water and chemicals, and mechanical durability. Its flexibility helps distribute the load, reducing the likelihood of stress fractures and ensuring long-term integrity of the system under underwater conditions.

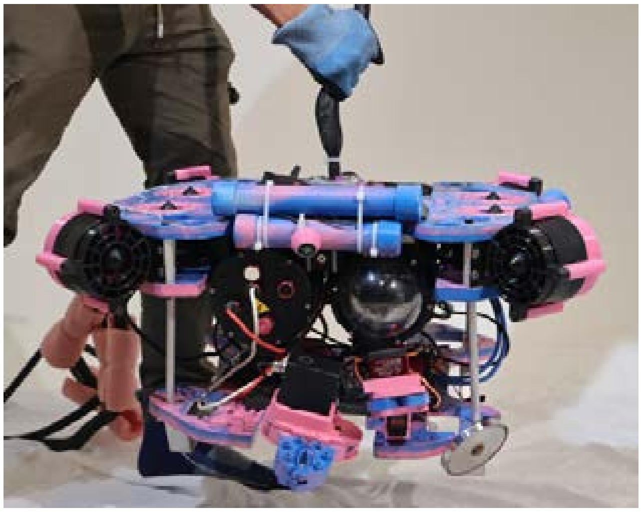


Figure 21. Tensor Relief Demonstration

G. Enclosure Supports

This year, the flexible bands were replaced by a TPU-printed holder specifically designed to fit the shape of the enclosure, offering significant functional improvements over previous methods. First, they simplify maintenance by allowing rapid removal without tools. Second, they distribute pressure evenly across a wider surface, minimizing stress concentration that could lead to material fatigue or damage. Finally it improves the stability and protection of the enclosures. This approach enhances both safety and accessibility in servicing critical electronic components.

Figure 22. Enclosure Supports

G. Thruster Guards

The thruster guards were designed in SolidWorks for both lateral and vertical thrusters and structurally integrated into the ROV's frame to reduce the number of 3D-printed parts and enhance rigidity by using PolyAl. These guards protect the propellers from debris and marine life while maintaining a streamlined shape. Although their implementation causes some dispersion in water flow compared to an unguarded configuration as seen in Figure 23, the resulting decrease in thrust and velocity is minimal. This design strikes a balance between safety and hydrodynamic efficiency. modeling to fine-tune flotation and stability.

To quantify the hydrodynamic effect, the drag force introduced by a guarded thruster can be estimated using the equation: $F_D = \frac{1}{2}\rho v^2 C_D A$
Assuming a water density ρ=1000 kg/m3, an average flow velocity at the propeller outlet v=1.5 m/s, and a thruster duct diameter of 90 mm =0.00636m2 of Area and taking a typical drag coefficient CD=0.61 for the enclosed geometry, the resulting drag force is FD≈4.36N approximately. This confirms that the addition of the guards introduces only a minor loss in performance, while significantly improving safety and structural integration.

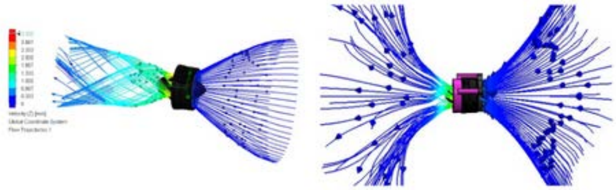


Figure 23. Flow simulation with and whitout thruster guards

7. Electrical & Electronics

A. Electrical Overview

Penta's electrical architecture builds upon advancements from previous iterations, featuring a more methodically distributed and accessible configuration while maintaining a strong commitment to the SMW philosophy. The overall structure remains consistent with prior models, comprising three principal subsystems: the Above the Waterline unit (GCU), which facilitates communication between the operator and the ROV; the Below the Waterline section, housed in two electronic enclosures where critical tasks such as voltage regulation and power distribution are conducted; and the Tether, designated exclusively for power delivery and data transmission.

The internal layout of these enclosures has been designed to expedite fault diagnosis and allow for efficient component replacement. In accordance with Penta's operational principles, pneumatic and hydraulic systems have been deliberately omitted. This decision eliminates the need for fluid conduits within the tether and avoids the associated instrumentation, such as pressure gauges, that would otherwise require monitoring from the GCU.
To ensure high maneuverability and multidirectional thrust, Penta retains the use of eight propulsion units. Specifically, it is equipped with eight T200 thrusters from BlueRobotics®, selected to provide balanced force distribution and optimal performance despite the vehicle's structural dimensions.

Consequently, Penta achieves peak operational efficiency, with a stable average current draw measured in amperes.

Appendant 6

B. Ground Control Unit

The Ground Control Unit (GCU) serves as the primary interface through which operators interact with Penta and its corresponding software environment. It features multiple display systems designed to visualize data from two primary sources: two digital cameras connected to the on-board processing unit (NVIDIA Jetson Nano), dedicated to software driven image analysis and processing; and four analog cameras focused on operational monitoring of the ROV. Additionally, the GCU includes the interface for data input and output to the central software platform.
Due to its frequent and direct human interaction during ROV operation, safety considerations were fundamental in the design and construction of the GCU. To that end, the system integrates several safety mechanisms, including an emergency stop switch that immediately disconnects the 48.0 V power supply, and a Littelfuse 30.0 A fuse positioned within 30.0 cm of the primary power input, in compliance with the calculated specifications outlined in the System Integration Document (SID).

Appendant 6: Penta's SID

Figure 24. Ground Control Unit

C. Waterline Transition

The tether functions as the sole physical link between the Ground Control Unit (GCU) and Penta, establishing the connection to the ROV through a proprietary tensor relief mechanism developed by the team. This configuration is designed to eliminate mechanical stress on the cables by transferring all tension forces to the structural frame of the ROV.

Measuring 20.0 meters in length, the tether comprises only four connection lines: two CAT6 Ethernet cables dedicated to the onboard processing system and analog video feeds and two AWG 14 cables for power transmission (positive and ground). To enhance durability and usability, the tether is enclosed within an expandable braided sleeve, which protects the internal lines, minimizes the risk of tangling, and improves maneuverability. Additionally, the reduced cable count, combined with strategically positioned buoyant floats, reduces hydrodynamic drag and optimizes tether handling during underwater operations.

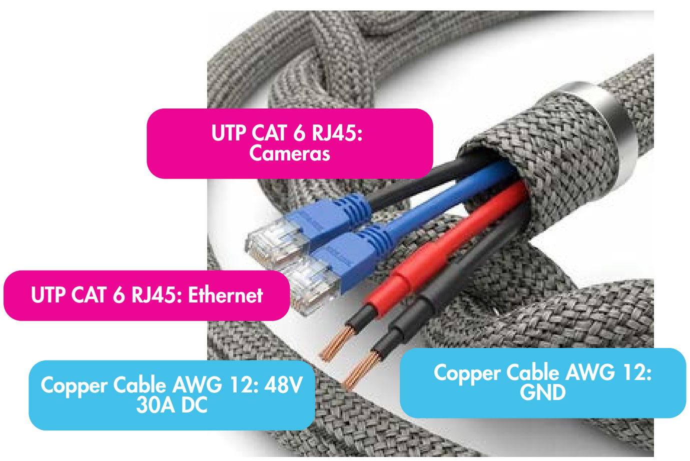


Figure 25. Penta's Tether Anatomy

D. Below Water Electronics

The onboard electrical architecture of Penta is distributed across two dedicated waterproof enclosures, each responsible for distinct operational functions. The Thruster Control Enclosure (TCE) manages power distribution and motor control, whereas the Main Control Enclosure (MCE) is tasked with computing operations, visual processing, and tool actuation. This compartmentalized layout effectively isolates power-related disturbances from those affecting computational tasks, imaging, or propulsion systems.

To ensure secure and efficient connectivity under high-current demands, both enclosures utilize Anderson Powerpole connectors. Connections from the tether, thruster assemblies, and inter-enclosure communication are routed through BlueRobotics® cable penetrators or, where applicable, BlueRobotics® WetLink penetrators, selected for their robustness and watertight sealing performance.

E. Thruster Control Enclosure

The main power input is delivered via the tether and enters directly into the Thruster Control Enclosure (TCE). Inside the TCE, the voltage is distributed across four 200.0 W regulators arranged in parallel. All units step the voltage down from 48.0 V to 16.0 V to supply the thrusters. Each regulator is assigned to a pair of thrusters to reduce current draw per unit and ensure balanced load distribution. Thruster operation is managed through BlueRobotics® ESCs, which receive PWM control signals from the Pixhawk 4.

F. Main Control Enclosure

The Main Control Enclosure (MCE) receives a 48.0 V power supply directly from the tether, which is then internally regulated to support the onboard systems. An isolated DC/DC converter is used as the first conversion stage, stepping the voltage down from 48.0 V to 12.0 V. This 12.0 V output powers seven Micro Servos tasked with actuating the mechanical tools. Additionally, it is also used to power four analog cameras, significantly enhancing the visual interface for the pilot and copilot, and enabling better control and situational awareness during ROV missions.

To support the core processing units, a secondary step-down converter reduces the voltage from 12.0 V to 5.0 V. This line powers both the NVIDIA Jetson Nano and the Arduino Uno. The Jetson Nano serves as the central processing unit, handling communication with the Ground Control Unit (GCU), managing digital camera inputs, supplying power and data to the Pixhawk 4, and interpreting controller inputs. These interpreted commands are then transmitted via serial communication to the Arduino Uno, which executes tool operations.

8. Software

A. Philosophy and Overview

Real-time communication is a critical component of any robotics system, especially for underwater vehicles where latency and reliability can significantly impact performance. Over the years, TecXotic has experimented with various control system architectures for the ROV. The primary challenges identified in previous seasons included high response latency, inconsistent tool reliability, and limitations in computer vision performance.
To address these issues, we adopted WebSockets as the core communication protocol for the control system. WebSockets offer a fast and persistent bidirectional connection between the topside control interface and the onboard system, enabling near-instantaneous transmission of commands and sensor data. This significantly reduces latency and improves system responsiveness.

The decision to use WebSockets is supported by its widespread adoption in real-time applications such as Slack, Facebook Messenger, and multiplayer games, where low-latency data exchange is essential.
This architectural shift represented a significant departure from our previous control system. However, we strategically retained key components and technologies that had proven effective in past seasons. Notably, we continued to use the NVIDIA Jetson Nano as our main onboard computer due to its robust image processing capabilities, which are critical for real-time computer vision tasks and mission-specific object detection.
Additionally, we maintained the use of serial communication via Arduino, integrated with a dedicated servo controller, to manage our tool systems reliably.

B. Design and Software Architecture

After selecting the communication protocol, onboard computer, and control subsystem, the software architecture was meticulously designed to be modular and scalable, enabling easy updates and system flexibility as the project evolved.

The architecture consists of four key components:

- Core: The core of the system is a WebSocket server hosted on the NVIDIA Jetson Nano. This server handles real-time, bidirectional communication with the surface station. It is organized using a modular class structure that defines specific methods and message routes. These messages are then relayed to the Pixhawk flight controller, which was selected for its reliability and efficiency in handling PWM-based thruster control. Pixhawk significantly reduced development time by simplifying the communication pipeline between the ROV and its propulsion system.
- Vision and Image Processing: Real-time, low-latency visual feedback is crucial for precise ROV operation. In parallel with the WebSocket server, a Flask server runs on the Jetson Nano to handle video streaming and image processing. By running both servers on separate threads, we ensured smooth and uninterrupted performance from both systems, even under load.
- Task Modules: Certain tasks—such as identifying invasive species via eDNA or modeling their projected paths through the Illinois River—can be partially automated using algorithms. Instead of manually executing these complex processes, we implemented dedicated endpoints within our backend system to handle them programmatically, reducing operational workload and improving efficiency.
- Client Interface: For seamless bidirectional communication between the ROV and the topside operation station, a reliable and user-friendly interface was developed. We chose React for its reactive state management, flexibility, and accessibility for new team members. This frontend framework has consistently enabled fast development cycles and intuitive user interactions.

C. Interface

For this season, we have designed a pilot interface that streamlines task execution and ensures successful completion. The pilot interface focuses on delivering an enhanced user experience by improving visibility through camera systems and applying image enhancement techniques such as filtering, color segmentation, and video transformation.

These enhancements help drivers by making key visual elements more distinguishable, especially in challenging environments, which improves situational awareness and supports faster, more accurate decision-making.

1. Gyroscope: A dynamic device that adjusts its position based on the movement of Penta.
2. Status Indicators: This section includes various displays showing relevant information about Penta status.
3. Camera settings: Provide options to start recording the video stream, to take photos, and to switch between different cameras.
4. Settings: Offers the option to make speed adjustments.
5. Controls: Allow to adjust the image brightness.

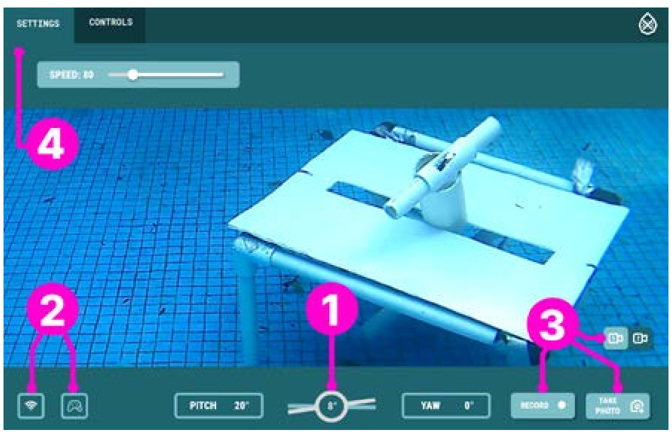


Figure 26. Pilot's interface and settings section

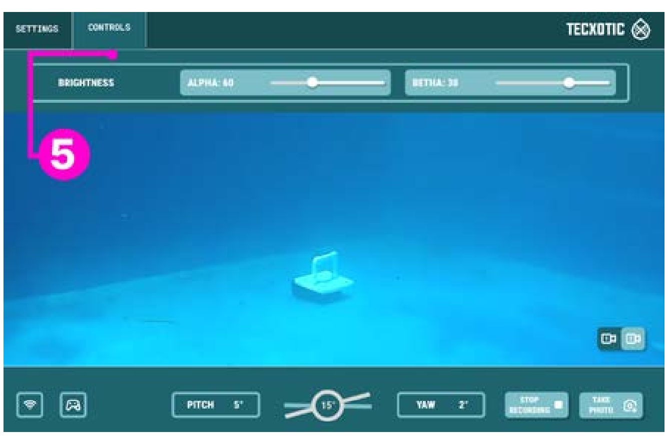


Figure 27. Pilot's interface and controls section

6. Task modules navbar: Features a functional interface for each specific task, allowing for efficient, organized, and intuitive execution of different tasks.

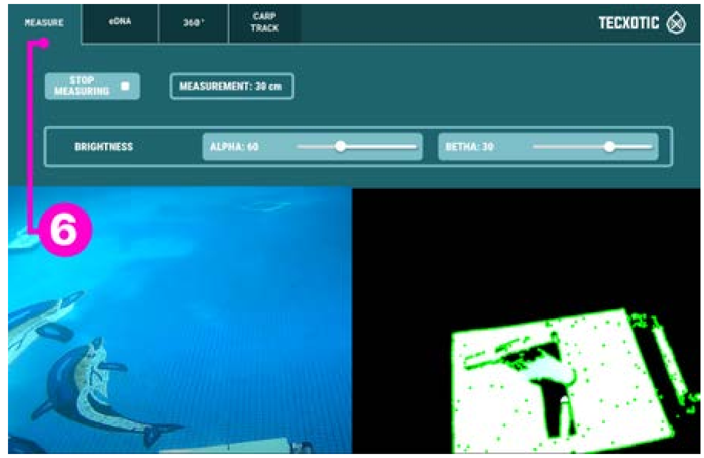


Figure 28. Copilot's interface and tasks features

As a key improvement this season, we have implemented techniques to enhance the visibility of the camera system. These enhancements make critical visual elements more distinguishable, improving situational awareness and enabling more accurate decision-making for drivers.

The first solution involves the use of cv2.convertScaleAbs(), which adjusts image brightness by scaling and shifting pixel values using defined alpha and beta parameters.

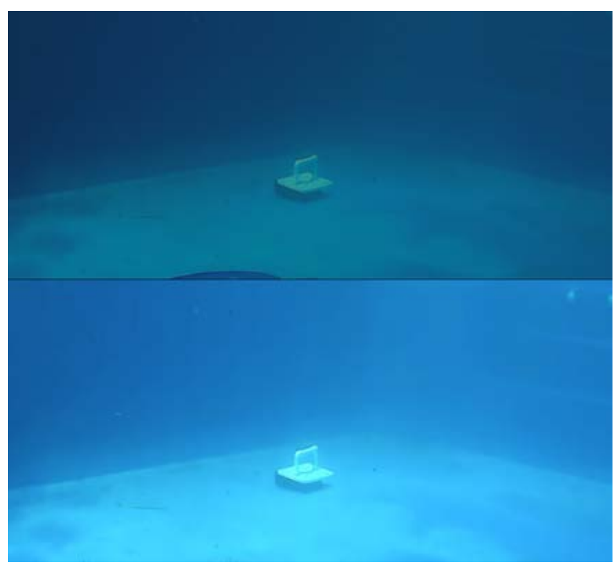


Figure 29. Images with different brightness adjustments

The second solution utilizes the Canny edge detector, an effective algorithm for edge detection, which enables the calculation of maximum distances between contours for approximate measurements

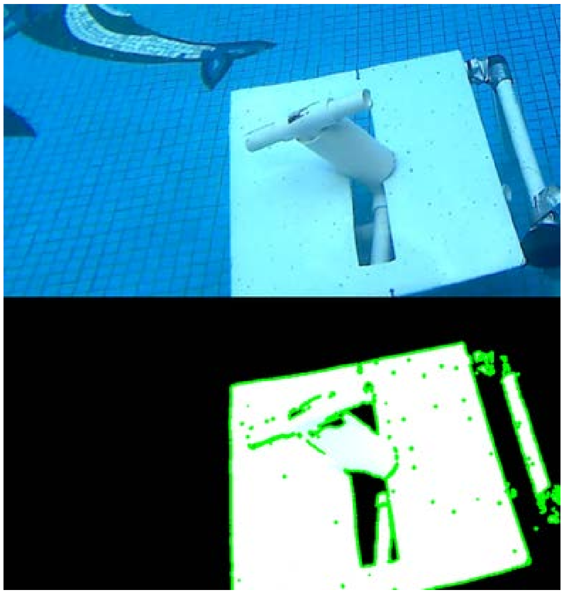


Figure 30. Edge detection demonstration

At the core of the architecture is the NVIDIA Jetson Nano, which functions as the central processing unit. It hosts both a WebSocket server and a Flask server, each handling different aspects of the ROV's communication and control. The WebSocket server receives control commands from the surface client and routes them to the Pixhawk flight controller. The Pixhawk then generates PWM signals that are sent to the Electronic Speed Controllers (ESCs), which in turn drive the Blue Robotics thrusters.

The Flask server is responsible for streaming live video from the onboard cameras to the client interface. It also processes high-level tool commands, which are transmitted via serial communication to the Arduino UNO. Tool actuation is managed through the PCA9685 I2C servo controller, which receives signals from the arduino to precisely control multiple servos.

This modular architecture ensures reliable bidirectional communication, low-latency control, and flexible integration of both vision and tooling systems.

D. Communication Flow Chart

All components of the control system can be visualized in the next diagram:

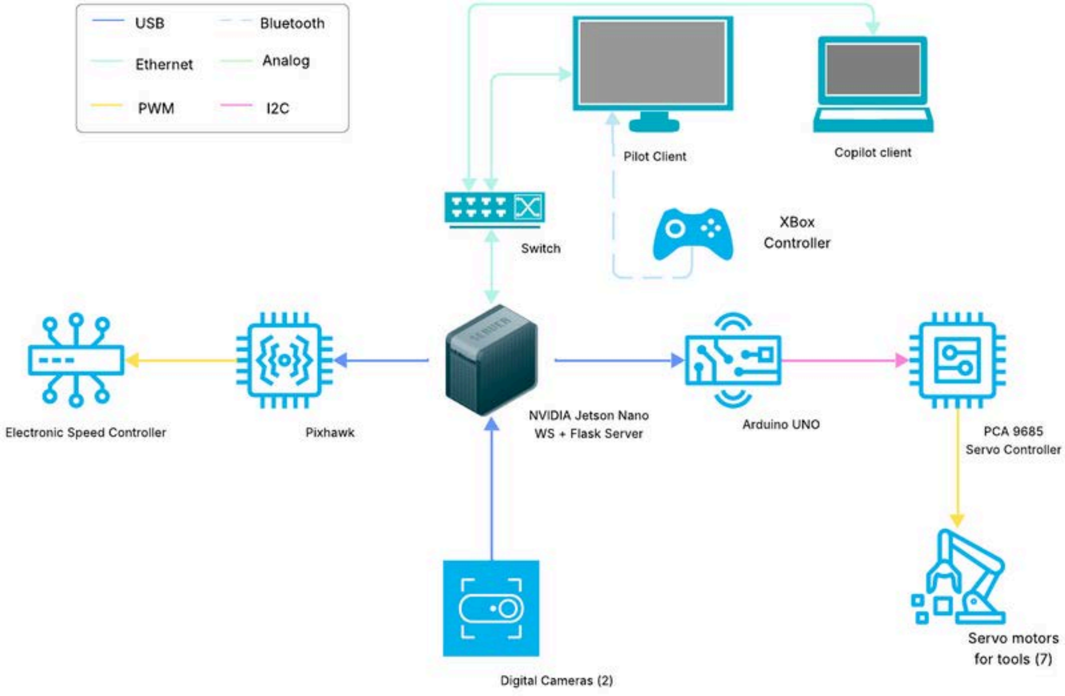


Figure 31. Software Architecture Diagram

9. Tools Overview

A. Cameras

To provide comprehensive visual feedback during operation, Penta is equipped with four custom waterproofed cameras, which are originally designed as rear-view car cameras. These cameras were waterproofed in-house using resin to ensure durability and reliable performance underwater.

The placement of the cameras is strategic to cover critical operational areas: one camera is located at the center of the ROV, inside the enclosure, providing a broad forward view via a USB camera; a second camera points toward Tool 1 (the front gripper) for detailed monitoring of manipulation tasks; a third camera focuses on Tool 2 (the robotic arm) to aid precise control; and the fourth camera is positioned below the tool deck to provide a downward view of the workspace. The lower camera will specifically assist with tasks carried out in the lower section of the ROV, ensuring that operations in that area are clearly visible.

This configuration ensures that the pilot and co-pilot have clear and continuous visibility of the ROV's surroundings and tool operations, enhancing task accuracy and safety.

Figure 32. Isometric View with cameras placement

For this season, Penta is equipped with two main tools designed to enhance its manipulation capabilities underwater.

B. 360° Claw

The first tool is an improved version of last year's multi-purpose front gripper mounted on the ROV's tool deck. Its components were 3D-printed using PA-CF (Polyamide with Carbon Fiber), which enhances durability and mechanical strength compared to PETG. This gripper uses a high-torque, all-metal servo motor with a 180° rotation range, powered by a 12 V DC source. The servo provides precise control for the gripper's movements, enabling effective manipulation of objects.

To optimize force transmission and reduce mechanical stresses, the traditional spur gear mechanism was upgraded to herringbone gears. This change eliminates axial forces, improving efficiency and longevity. Furthermore, TPU coverings were added to the gripper's claws to allow better adaptation and grip on irregular-shaped objects, enhancing operational flexibility. This tool will assist in Task 1.1, helping to remove and replace the cover as required for underwater operations.

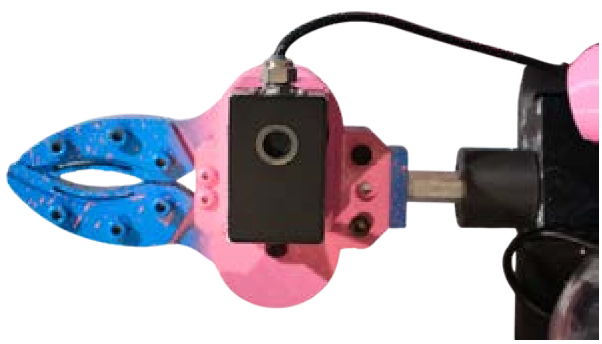


Figure 33. First tool

B. Robotic arm operated by mimicking system

The second tool is TecXotic's most ambitious project to date: a four-degree-of-freedom robotic arm mounted on the ROV. It is controlled remotely via a surface-based mimicking system. The operator manipulates an articulated external arm equipped with potentiometers, which controls the movements in real time on the underwater arm. The external arm is scaled relative to the ROV's arm, enhancing the operator's spatial awareness and precision. This setup offers intuitive, accurate control, making object manipulation more effective and user-friendly.

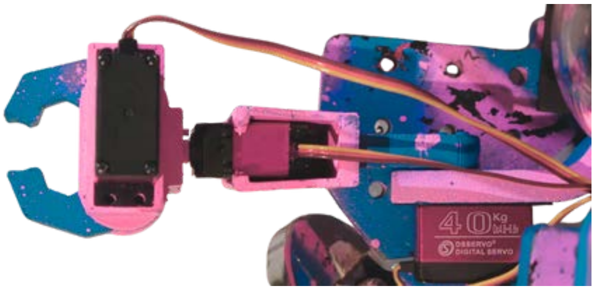


Figure 34. Second tool

The underwater arm uses high-torque 40 kg servos, which the team waterproofed themselves with bearing grease and oil to ensure reliable underwater operation. This robotic arm will assist in Task 1.2, allowing for the precise replacement of a thermistor and making the necessary connections, which require a higher level of accuracy. Additionally, the robotic arm is crucial for Task 2.1, where it can rotate the end effector to change the sacrificial anode with precision.

Figure 35. Waterproofing servos process

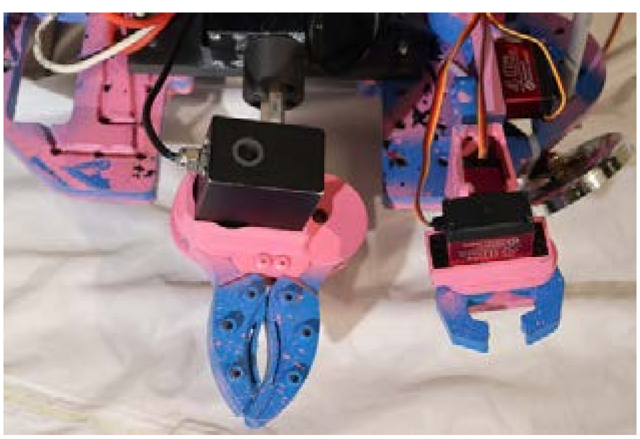


Figure 36. View of both Penta's tools

For task 1.3, we use a digital pH meter with an LED display, which is an electrochemical sensor originally designed for soil measurements but adapted to measure the acidity levels of water samples underwater. This sensor operates independently of the ROV and will be operated externally. Measurements will be taken outside the ROV, allowing precise monitoring of water quality as required by task 1.3. The measurements are planned to be conducted on site to cover all necessary points.

10. Non-ROV Device

A. Design and Buoyancy Engine

For the 2025 season, TecXotic has enhanced its buoyancy system by integrating two baumanometers, significantly refining control over flotation. The updated buoyancy engine operates through an inflatable membrane that expands or contracts, enabling precise regulation of volume and density. This allows the device to effectively manage vertical movement, adjusting buoyancy during both ascent and descent phases.

Figure 37. Non ROV Device

B. Electronics and Control

Housed within the main cylinder, the buoyancy system features an integrated setup that includes an air pump, a solenoid valve, and dual baumanometers—working in unison to manipulate an internal pressure bladder. Key sensors such as the Blue Robotics Bar30 Depth Sensor, along with a gyroscope and accelerometer, provide accurate depth and orientation data.
This system automatically controls the pump based on real-time sensor feedback. It also serves as the network interface for both pilot and copilot through a web-based dashboard, allowing the ground station to retrieve telemetry, monitor status, and initiate submersion procedures.

Thanks to the addition of the second baumanometer, the flotation system now delivers more consistent and responsive behavior. This upgrade has notably improved the performance of TecXotic's non-ROV flotation device, making it more effective for diverse underwater tasks and mission profiles.

Appendant 2. Non ROV SID

11. Testing and Troubleshooting

Building upon the initiatives established in the previous year's development cycle, this year, Penta continues to follow the philosophy of the Simple, Modular Well-made. Although only a few components from previous years have been reused, the modular nature of the design allows us to adapt and reconfigure the ROV from previous competitions to meet the specific needs of this year.

The initial design stage once again relies on digital simulations to minimize time, cost, and resource consumption during prototyping. Once validated against the SMW criteria, components are manufactured using appropriate technologies: additive manufacturing is used for custom tools and fine-detail parts to produce structural elements requiring greater strength and precision.

The troubleshooting phase follows an iterative method focused on identifying and resolving issues in mechanical, electrical, and software subsystems. Testing targets three critical areas. Durability, by exposing components to repeated cycles or mechanical stress to detect wear or failure. Reliability, through repeated full-system tests to confirm stable and consistent operation.Repeatability, by performing identical tasks multiple times and verifying consistent results.

Components that do not meet performance standards are replaced or adjusted, followed by new validation cycles. This process ensures the ROV is progressively optimized for stability and readiness in this year's mission tasks.

12. Conclussion

A. Results

Penta reflects the commitment, creativity, and discipline of a multidisciplinary team focused on solving complex challenges through efficient technological solutions. Each subsystem was designed, built, and validated under strict quality and safety standards, meeting both competition requirements and the team's internal objectives. The integration of new tools, an improved software architecture, and a robust control system have endowed the ROV with great versatility and precision to execute the assigned tasks.

B. Challenges

Throughout Penta's development, the team encountered various technical and logistical challenges. These included redesigning key components to meet this season's demands and implementing new management methodologies that required continuous organization and adaptability. The assembly and integration of systems involved multiple iterations, on-site troubleshooting, and effective coordination among all departments to maintain a steady workflow.

C. Future and Improvements

As part of its philosophy of continuous improvement, TecXotic plans to further document technical processes, standardize internal protocols, and develop new solutions to increase the ROV's autonomy and efficiency. Future efforts will also focus on enhancing the user interface, exploring emerging technologies in sensors and materials, and strengthening the onboarding of new members through accessible and well-structured training resources.

D. Lessons Learned and Skills Gained

The development of Penta enabled the team to acquire and consolidate skills in areas such as mechanical design, additive manufacturing, electronic control, computer vision, and software development. Additionally, key competencies such as teamwork, problem-solving, technical decision-making, and interdisciplinary communication were strengthened. These lessons not only empower the current team but also lay a strong foundation for future generations of TecXotic.

13. Acknowledgments

TecXotic expresses its sincere gratitude to all the individuals and institutions that made the development of Penta possible.

We thank our mentors—David García, Fernando Obispo, Iyali Curiel, Eladio Martínez, Ricardo Valera, and Gwendolyn Delgado—for their continued guidance, technical support, and encouragement throughout the season. Their expertise and mentorship were fundamental in overcoming challenges and fostering a learning-centered environment.

We are grateful to the School of Engineering and Sciences at Tecnológico de Monterrey for providing access to laboratories, equipment, and materials that enabled hands-on experimentation and prototyping.

Institutional and Staff Support – Campus Cuernavaca

- Abel Angelina, Media Lab Coordinator
- Alfredo Nava, B.A., Advanced Manufacturing Lab Coordinator
- Antonio Flores, Campus Security Coordinator
- Ignacio Merlín, B.A., Maker Space Coordinator (TecXotic HQ)
- Jorge Álvarez, Ph.D., Director, School of Engineering and Sciences
- José Moya, MBA, General Director
- Salvador Fuentes, Applied Engineering Center Coordinator
- Sergio Hernández, MSc, Computer Science Professor

National Support – Tecnológico de Monterrey

- Feniosky Peña-Mora, Ph.D., Dean, School of Engineering and Sciences
- Juan Pablo Murra, Ph.D., Rector of Professional and Graduate Studies

We also acknowledge the MATE ROV Competition organization for fostering innovation, teamwork, and growth among young engineers worldwide. Their platform continues to inspire our team and others to solve real-world marine challenges through robotics and collaboration.

Finally, we thank all TecXotic team members, past and present. Your passion, creativity, and dedication turned a complex vision into a functioning, competition-ready ROV. Every contribution—technical, logistical, or organizational—was vital to the success of Penta.

14. References

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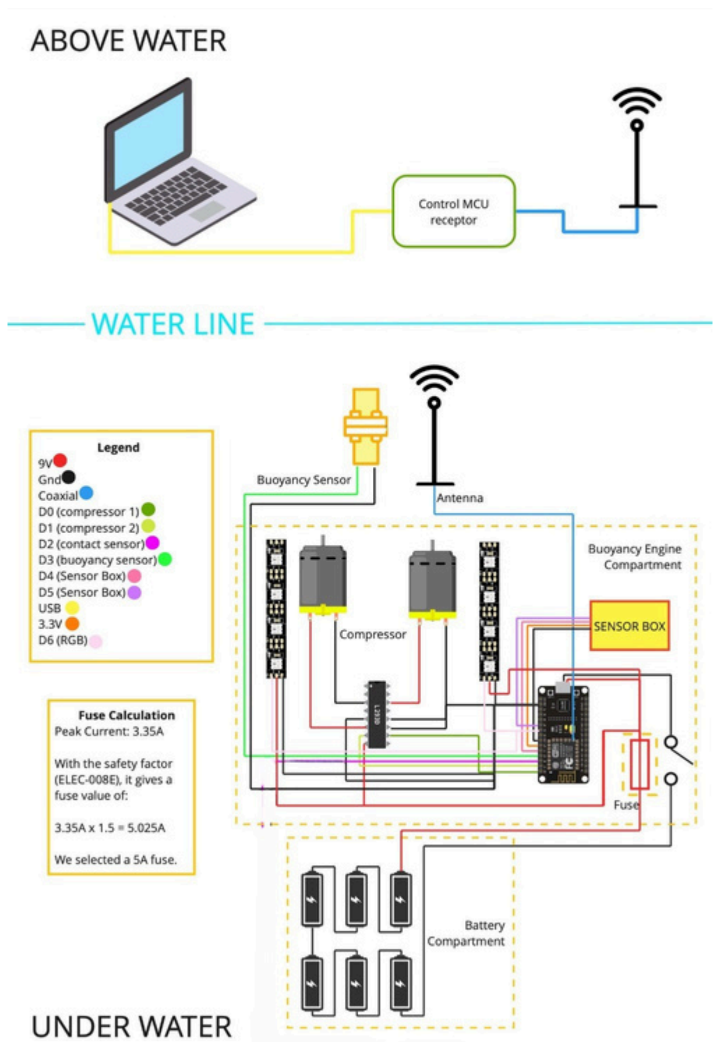
15. Appendants

CRITERIA	TZILACATZIN	PENTA	GOAL	RESULT	GA
Overall Width	0.68 m	0.62 m	⌄	⌄	A
Overall Length	0.63 m	0.55 m	⌄	⌄	A
Overall Height	0.33 m	0.30 m	⌄	⌄	A
Envelope Volume	0.13 m	0.13 m	⚓	⚓	A
Free Space Volume	850 cm3	850 cm3	⚓	⚓	A
Tether lenght	20 m	20 m	⚓	⚓	A
ROV Mass	17.74 kg	20.8 kg	⌄	⌃	NA
Tether Mass	3.2 kg	3.2 kg	⚓	⚓	NC
# Modular Floats	0	0	⚓	⚓	NC
# ROV Parts	171	171	⚙	⚙	A
# ROV Tools	1	2	⚓	⌃	NA
# Diff. nuts & bolts	6	6	⚓	⚓	NC
# Diff. Actuators	2	2	⚓	⚓	NC
Horizontal Thrust	58.8 N	58.8 N	⚙	⚓	NA
Vertical Thrust	58.8 N	58.8 N	⚙	⚓	NA
Horizontal Speed	0.75 m/s	0.69	⌃	⌃	A
Vertical Speed	0.62 m/s	0.58	⌃	⌃	A
Degrees of Freedom	1	10	⚙	⚙	A
Power Consumption	250.56 W	250.56W	⚓	⚓	A

Appendant 1. Criteria



Appendant 2. Non-ROV SID

GOODS & SERVICES

Part Name	Description	Expense	Repurposed	Sponsored
Thruster / Motors Expenses				
Thrusters	T200 Thruster	$ 258,00	$1.400,00	--
Basic ESC	A simple electronic speed controller for the T100 and T200 Thrusters.	$ 38,00	--	--
Thurster guards	3D printed guards	$ 29,00	--	--
Servos	50Kg IP69 Geared servo Motor (2)			$ 200,00

Part Name	Description	Expense	Repurpose	Sponsored
Cameras System Expenses				
	Angular camera (4)	$87	--	--

Part Name	Description	Expense	Repurpose	Sponsored
Frame Expenses				
Frame+Upper	Composite aluminum panel // PolyAl panel	--	--	$ 152,00
Tools components	3D printed tool pieces and frame parts	$ 59,00	--	--
Structure	Brass threaded inserts // 8 in. Cable Tie - Natural // Hot Glue Sticks // 1/4 - 20 lock nuts// 1/4 x 3/4	$ 118,00	--	--
Enclosure dome	Dome- optically clear acrylic (4" inner diameter)	$ 49,00	--	--

Part Name	Description	Expense	Repurpose	Sponsored
Electronic Expenses				
Sensor & Controls	Bar30 High-Resolution /Pressure Sensor // CUAV Pixhawk PX4 Flight Controller // Flat TV	--	$ 434,60	--
Water Enclousure	Acrylic Tube // Dome end CAP // Aluminum End Cap (4" Series) // Cable penetrator for 6 and 8 mm // Cable Penetrator Blank	--	$ 223,00	--
	Epoxy resin & catalyzer 1.5 kg // Loctite Epoxy // 10x Potted Cable Penetrator // O-Ring set	$ 115,00	--	--
Voltage converter	Dc-dc Buck Converter 15a 200w 8-60v Input (6 pieces) // Control voltage regulator DC 6-40 V	--	$ 57,00	--
Voltage converter	490-PQC75-48-S12-OH Isolated DC/DC Converter	$ 120.98		
Actuadors	10 watts led, sumersible pump, 4x 9v geared motor	$ 41,00	--	--
Tether,cable, wire	Turnigy Pure-Silicone Wire // THWN WIRE (2 x12 AWG)// UTP CAT6 WIRE // Ethernet and USB Cable	--	$ 258,00	--
Input device	Dualshock playstation 4	--	$ 83,70	--
FUSE	58V 40 A FUSE HOLDER // 30A 58V FUSE	$ 14,00	--	--
Connectors and joins	Thermofit 1/8" - 1/2"// Anderson SBS50 Heavy Duty Power Connector // Solder connector // (5 & 3) Pin PCT213 // Double sided adhesive	$ 148,55	--	--
Electronical Comp.	Nvidia Jetson nano // Logitech webcam // 7 Port Hub USB // Humidity control envelopes	--	$ 752,00	--

Part Name	Description	Expense	Repurpose	Sponsored
Tasks & Proof Expenses				
Product demostrations	1/2-inch PVC pipe // 1/2-inch end cap// 1/2-inch tees// 1/2-inch 90 and 45 elbows// 1/2-inch coupling// Paired wires // 18 gauge red black wire //Colored duct tape // Industrial Velcro // 2 gallon bucket // 1x soft bottle // LEDs // plastic test tube // Blue , Pink spray paint	--	$ 180,40	--
Product demostrations	3/4-inch PVC adapter // 1 inch PVC pipe// 1 and 2 inch PVC end-cap// 1/2-inch sideouts// 1 to 1/2-inch reducing tee// 1 to 1/2-inch reducer bushing// 4 inch PVC pipe//4 inch PVC knockout caps// rope // 3 inch carabiner //2 inch knockout cap// 2 inch PVC coupling // Industrial strength Velcro (white)// 2 gallon bucket // Photoresistor // fish fry // black spray paint	$ 89,20	--	--

	Expense	Repurposed	Sponsored
Goods & Services	$ 973,75	$ 3.483,30	$ 352,00
Invesments	$ 245,25		
Travel	$ 14.950,00		
Labor		$ 1.100,00	$ 10.000,00
	$ 16.169,00	$ 4.583,30	$ 10.352,00

Appendant 3. Budget

Project Income Summary	Type of Support	Estimated
Raffle tickets	Fundraising	$1.000,00
Tec de Monterrey	Sponsorship	$1.600,00
School of Engineering	Sponsorship/	$25,00
Blue Robotics	15% STEM Discount	$20,00
Würth	Tools in ongoing use	$180,00
Planeta Listo	Frame materials	$65,00
Crowdfunding	Donations	$55,00

INVESTMENT

Type	Part Name	Expense
Machinery & Tooling		
Machinery	Lathe cooling system	$ 60,00
Tools	Cutters & drills	$ 30,00
Tools	Crimpers	$ 25,00
Tools	Wrenchs	$ 130,25

TRAVEL

Type	Part Name	Expense
Travel Cost (12 people)		
Travel costs	Mentor travel costs	$ 1.200,00
Travel costs	Accomodation	$ 3.500,00
Travel costs	Ground	$ 1.500,00
Travel costs	Plane tickets	$ 3.800,00
Travel costs	Travel insurance	$ 950,00
Travel costs	Food	$ 4.000,00

LABOR

Type	Part Name	Expense
Labor Cost		
Uniforms for 17 people		$ 850,00
Personal protection equipment		$ 250,00
Design & manufacturing		$ 10.200,00

DFMEA-Design Failure Mode and Effects Analysis Tecxotic 2025

Product/part	Penta	Team:	TecXotic		# FMEA:	1	
Project:	Mate ROV	Person In Charge:	Carla Pardo	Manager:	Dulce Bucio	Start date: 12/05/2025	Check date: 21/05/25

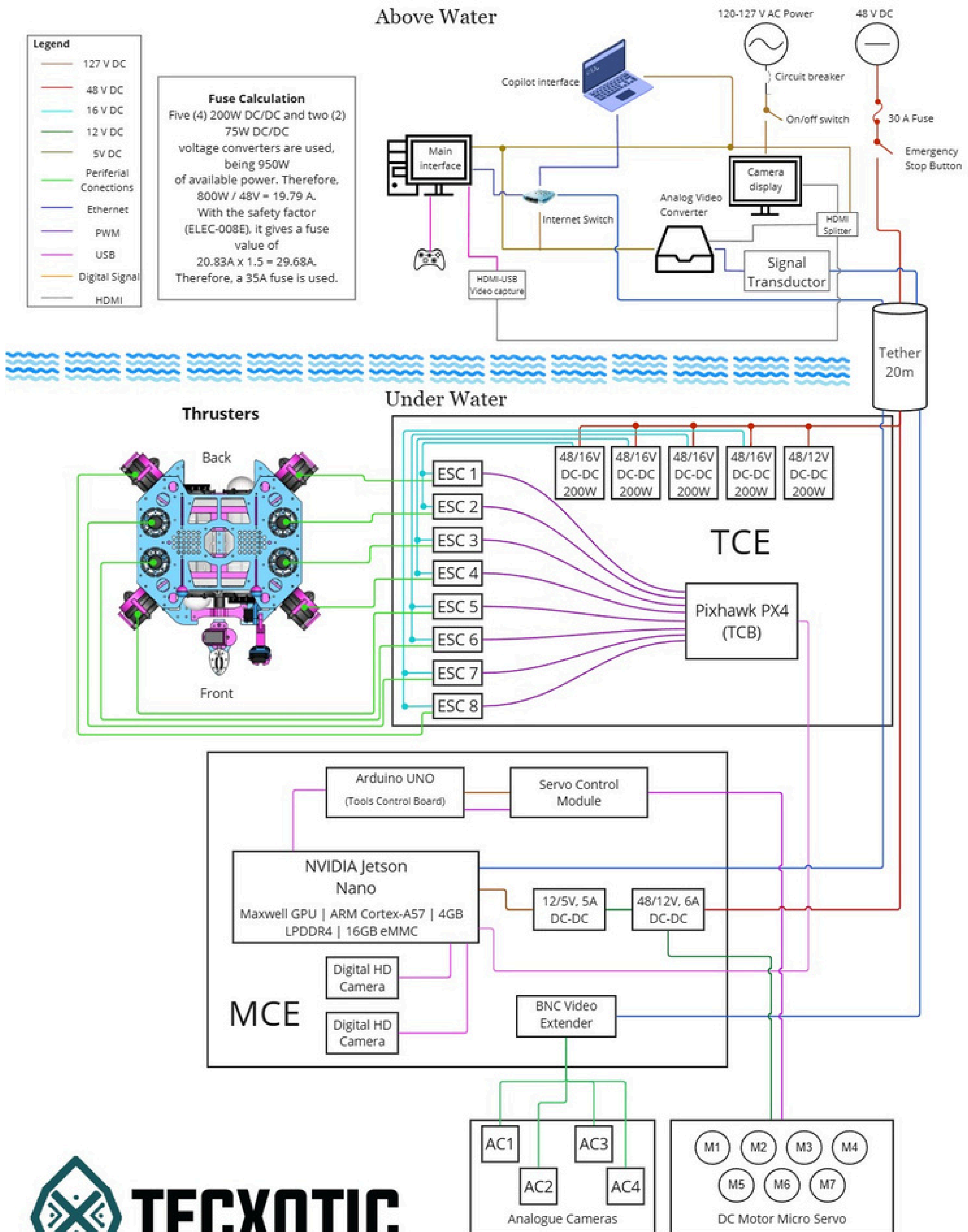
Failure Mode	Potential Causes of Failure	Potential Effects of Failure	Existing Conditions: Actual Controls	S	O	D	RPN	Criticality	Status and Recomended Area	Responsible Area for Corrective Action	Results: Corrective Action	S	O	D	RPN	Criticality			
Incorrect buoyancy	Miscalculation of volume or foam deterioration	Poor maneuverability or sinking	Design inspection tests in pool	8	7	4	224	56	Design	Design	Recalculate buoyancy with CAD simulation and test multiple prototypes	5	4	3	60	20		35.71428571	164
Tool motors failure	Water ingress or wiring failure	Tool becomes inoperative during mission	Water and manual wiring checks	9	6	5	270	54	Manufacture	Manufacture	Improve sealing with epoxy, test motors under pressure	6	4	3	72	24		44.44444444	198
Robotic arm malfunction	Overload or unbalanced mount	Inability to manipulate objects / lose mission points	Arm functionality test in dry and wet conditions	8	5	4	160	40	Design	Design and manufacture	Balance load, add torque limiters, test range of motion	5	3	2	30	15		37.5	130
Cable disconnection / poor sealing	Weak connectors or improper sealing process.	Power loss, short circuit, or signal interruption	Visual and manual pre-checks	9	6	4	216	54	Manufacture	Manufacture	Use of waterproof connectors, implement sealing verification protocol	5	3	3	45	15	9	27.77777778	171
Sharp Edges	Design oversight	Injuries during handling or cable damage	Manual inspection	5	6	3	90	30	Manufacture	Rounding all edges	Correct positioning of the tensioners	2	2	2	8	4		13.33333333	82
			TOTAL	39	30	20	960	234			TOTAL	23	16	13	215	78		#REF!	#REF!
																		#REF!	#REF!

Average criticality reduction	31.2	Average RPN reduction	149
Percentage criticality reduction	33.33%	Percentage reduction RPN	22.40%

Appendant 4. FMEA

POWER BUDGET					
SUBCOMPONENT	QTY	VOLTS (V)	CURRENT (A)	TOTAL CURRENT (A)	TOTAL POWER (W)
DC-DC CONVERTER 48 TO 16V 200W EFFICIENCY 94%					
T200-THRUSTER-R2-RP WITH ESC	2	16.00	1.70	3.40	54.40
DC-DC CONVERTER 48 TO 16V 200W EFFICIENCY 94%					
T200-THRUSTER-R2-RP WITH ESC	2	16.00	1.70	3.40	54.40
DC-DC CONVERTER 48 TO 16V 200W EFFICIENCY 94%					
T200-THRUSTER-R2-RP WITH ESC	2	16.00	1.70	3.40	54.40
DC-DC CONVERTER 48 TO 16V 200W EFFICIENCY 94%					
T200-THRUSTER-R2-RP WITH ESC	2	16.00	1.70	3.40	54.40
MOTOR MICRO SERVO	7	12.00	1.00	7.00	84.00
ANALOG CAMARA	4	12.00	0.15	0.60	7.20
DC-DC CONVERTER 12 TO 5V 200W EFFICIENCY 94% 15A MAX.					
JETSON NANO	1	5.00	0.11	0.11	0.55
PIXHAWK 4	1	5.00	0.15	0.15	0.75
WEB CAMARA LOGITECH C505	2	5.00	0.03	0.06	0.30
DC-DC CONVERTER 48 TO 12V 75W EFFICIENCY 97%					
DC-DC CONVERTER 12 TO 5V 75W EFFICIENCY 94%					
SERVO CONTROL MODULE	1	5.00	0.02	0.02	0.10
ARDUINO UNO	1	5.00	0.02	0.02	0.10
WHOLE ROV SYSTEM*				21.56	310.60
WITH SECURITY FACTOR OF 1.50				32.34	
*THIS ONLY INCLUDES DC DEVICES					
TOTAL CALCULATED CURRENT CONSUMPTION IS 32.34 A; THEREFORE, A 35 A FUSE IS USED.					

Appendant 5. Power Budget



Appendant 6. Penta's SID