

Enigma Rangers



Alexandria, Egypt



SETTO

Technical Documentation 2026

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Abstract

Enigma is a company based in Alexandria, Egypt, composed of 14 engineers from **Sidi Gaber Language School**, operating under the mentorship of **Innova STEM Education**. This unique interdisciplinary collaboration is united by a shared passion for developing technology that addresses real-world challenges. **SETTO** is **Enigma's** most advanced remotely operated vehicle (ROV), built through a philosophy of detailed planning, strong collaboration, iterative design, and rigorous testing. Its production was overseen by four engineers, each responsible for a distinct sub-system, including, but not limited to, software, control & electrical, and mechanical systems.

SETTO is designed to operate in harsh and dynamic underwater environments, integrating an AI-based vision system, a six-degree-of-freedom thruster configuration, and a dual-actuation manipulation system to enable interaction with subsea infrastructure and biological samples, with a design focus on building innovative underwater ROVs that tackle critical environmental challenges while surpassing benchmarks in maneuverability and mission adaptability. The ROV directly addresses the technical requirements outlined in the 2026 Marine Advanced Technology Education (**MATE**) Request for Proposal (**RFP**). This technical document not only details **SETTO's** cutting-edge design, development process, and capabilities, but also highlights its potential to assist the global community by identifying underwater objects, navigating safely around marine life, recognizing healthy marine habitats and ecosystems, and collecting data to monitor ocean health, offering a powerful tool for environmental stewardship and scientific discovery.



Figure 1: **SETTO**



Figure 2: **Enigma's Team**

Contents

1 Project Management	1		
1.1 Company Overview	1		
1.2 Team Members and Roles	1		
1.3 Project Schedule	2		
1.4 Resource and Operation Management	2		
2 DESIGN RATIONALE	3		
2.1 Design Evolution	3		
2.1.1 MATERIAL	3		
2.1.2 VEHICLE DESIGN AND STRUCTURE	3		
2.1.3 Frame Design	4		
2.2 Manipulators and Mechanisms . . .	5		
2.2.1 First Mechanism:	5		
2.2.2 Second Mechanism:	5		
2.3 Propulsion & Maneuverability . . .	5		
2.4 Buoyancy and Stabilization	6		
2.5 CFD Analysis	7		
2.5.1 Sealing	7		
3 Electrical Design	7		
3.1 System Architecture	8		
3.2 Power Distribution PCB	8		
3.3 Motor Drivers	8		
3.4 IMU PCB	9		
3.5 Actuators PCB	9		
3.5.1 Electrical Safety	9		
3.5.2 Tether	10		
3.5.3 Tether Management	10		
4 Software System	10		
4.1 Active stability	10		
4.2 Communication Protocols	10		
4.3 Graphical User Interface	11		
4.3.1 Vision System	12		
5 Safety	12		
		5.1 Safety Rationale	12
		5.2 Vehicle Safety Features	12
		5.3 Safety Procedures	13
		5.3.1 Construction Safety Checklist	13
		5.3.2 Operation Safety Checklist .	13
		6 NON-ROV Device	13
		6.1 Buoyancy Engine	13
		6.1.1 Communication system . . .	13
		6.2 SENSOR SUITE and CONTROL ELECTRONICS	14
		6.3 Power System and Fuse	14
		6.4 MECHANICAL,ENCLOSURE DESIGN	14
		7 Missions	14
		7.1 Coral garden ridge modelling	14
		7.2 Species Frequency	14
		7.3 Float Graph	15
		7.4 Crab Detection	15
		8 Innovation	16
		8.1 Bilge Pump Thrusters	16
		8.2 Enigma's motor driver	16
		9 Testing	16
		10 conclusion	17
		10.1 Future Plans	17
		10.2 Lessons Learned	17
		11 Accounting	18
		11.1 Cost Overview	18
		11.2 Build vs. Buy, New vs. Reused . .	18
		11.3 Cost vs Performance Trade-off . . .	19
		11.4 Funding and Support	19
		A Pneumatic SID	20
		B Project Cost Breakdown	21
		C Electrical Power Budget	21

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- **Horse Owners Club and Olympic Club** for providing pool access for pilot training.
- **AFIZ and Makers Electronics** for offering discounts.
- **AI Cognitro** for providing components.



Figure 3: Organizations and sponsors acknowledged by Team Enigma

1 Project Management

1.1 Company Overview

Enigma was founded in 2019 by a group of passionate students at **Sidi Gaber Language School**. What began as a small exploratory project quickly evolved into a structured organization committed to innovation, sustainability, and technical excellence. Since its founding, the team has grown to include approximately 14 active members.

1.2 Team Members and Roles

The responsibilities of our team were divided as shown in Figure 1.

- **CEO (Chief Executive Officer):** Responsible for making major decisions and managing overall operation.
- **CTO (Chief Technology Officer):** leads technical innovation and defines design, engineering and software stack of the ROV.
- **CFO (Chief Financial Officer):** manages financial planning and ensures financial sustainability for the project.
- **Leader (Team Leader/CTO):** Distribute the tasks and monitor the progress of his sub-team making sure its on track
- **Member (Engineering/Operations Team):** focuses on specific technical tasks.

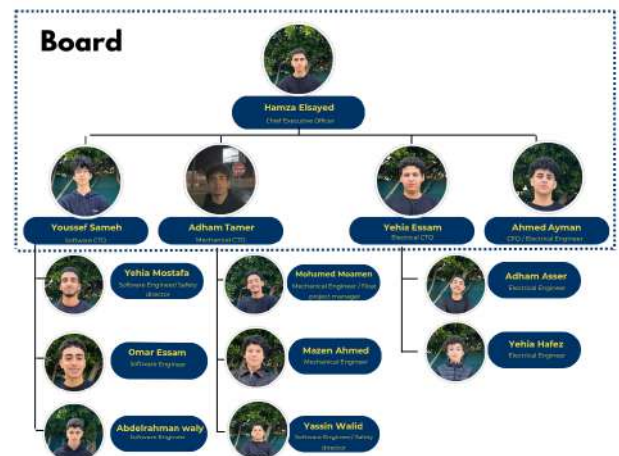


Figure 4: Company Organization chart

The team was organized into specialized sub-teams to ensure clear responsibility and efficient coordination. Their roles are summarized in Fig. 5.

Sub-Team Roles and Functional Responsibilities			
Mechanical	Electrical	Software	Operations / Management
- Frame Design - CAD Modeling - Mechanism Development	- PCB Design - Power Distribution - System Wiring	- Control Systems - GUI Development - Vision Processing	- Project Planning - Team Coordination

Figure 5: Sub-Team Roles and Functional Responsibilities

The selection of a CTO for each sub-team enabled the implementation of an **Integrated Sub-system Coordination Framework (ISCF)**, ensuring effective management and coordination between teams.

1.3 Project Schedule

Aligned with our organizational structure, our project schedule is divided into four distinct phases:

- Recruitment and Training:** From October to December 2025, new members were recruited and trained under the supervision of senior team members. This phase also addressed a key challenge from the previous season by ensuring balanced sub-team distribution to improve workflow efficiency.
- ROV and System Designing:** Each department advances ROV development based on its specialization, supported by structured coordination meetings. Weekly full-team meetings are conducted on Fridays to synchronize progress across all departments, while additional sub-team meetings are held throughout the week to refine subsystem designs and address technical challenges.
- Manufacturing and Prototyping:** The Mechanical team manufactures the frame and manipulators, enabling Hardware integration of PCBs and wiring. In parallel, the Software team prepares mission-specific code for testing.

- Testing and Refining:** Pool tests are conducted twice a week to ensure consistent performance. Refinements are applied to improve system reliability, while documentation is finalized to align with competition requirements.



Figure 6: Schedule

1.4 Resource and Operation Management

The integration of specialized digital tools enables coordination across departments. The team utilizes **GitHub** for version control and code management, while **Overleaf** and **Discord** are used for documentation and communication. Tasks are assigned, tracked, and reviewed iteratively, ensuring continuous progress and alignment across all sub-teams. This toolchain ensures consistency across tasks and supports effective collaboration throughout the project lifecycle.

Tool	Description
Discord	Team communication
Github	Code and PCB files
Google Drive	Documents for tasks and progress and management
overleaf	Documentation of Engineering design process

Figure 7: Project management tools

To address coordination challenges during development, the team followed structured problem-solving approaches. Issues were identified, analyzed collaboratively, and resolved through iterative design reviews and subsystem coordination. This workflow minimized integration conflicts and improved overall system reliability, as summarized in Fig. 8.

Challenge	Solution	Impact
Integration conflicts	Weekly design reviews	Reduced rework
Version mismatch	GitHub version control	Stable codebase
Communication gaps	Discord channels per subsystem	Faster response

Figure 8: challenge

Material	Weight	Cost	Strength	Manufacturability	Decision
Artelon (Nylon)	Low	Medium	High	Medium	Selected
PVC	Low	Low	Medium	Easy	Rejected
Aluminum	Medium	High	Very High	Difficult	Rejected
Acrylic	Medium	High	Very High	Difficult	Rejected

Figure 10: Material selection

2 DESIGN RATIONALE

2.1 Design Evolution

The process of this year’s design started from evaluating the pros and cons of our last year ROV **Christopher**, identifying strengths and limitations to improve **maneuverability, durability, and ease of operation**.



Figure 9: Design Evolution

Based on this evaluation, key improvements were implemented across different subsystems. The following subsections present a detailed analysis of each aspect, including material selection, frame design, propulsion configuration, maneuverability, buoyancy, and sealing strategies, all of which contributed to the final optimized ROV design.

2.1.1 MATERIAL

Artelon was selected for its excellent balance of strength, low weight, corrosion resistance, and affordability, making it ideal for continuous underwater use. Compared to hollow square profiles, the **SETTO** design reduced material costs and total mass while maintaining structural stability and allowing for easy fabrication. The material comparison used in the selection process is shown in Figure 10.

The analysis shows that Artelon (nylon) provides an optimal balance between weight, strength, and cost. While PVC is easier to manufacture, it lacks the required structural strength for the intended mission tasks. Aluminum offers high strength but significantly increases both cost and weight. Therefore, Artelon was selected as the most suitable material for the ROV frame.

2.1.2 VEHICLE DESIGN AND STRUCTURE

The 2026 ROV was redesigned to improve maneuverability, modularity, and ease of assembly compared to previous models. The design process began by defining mission requirements, including stability, multi-directional motion, maintainability, and reliable subsystem integration. Based on these requirements, multiple frame concepts were evaluated, including plate-based and extrusion-based structures. The finalized design of the ROV is shown in Fig. 11.



Figure 11: Rendered finalized model of **SETTO**

Plate-based frames offered lower weight but limited flexibility for mounting and future modifications. In contrast, extrusion-based frames provided superior modularity and ease of assembly at the cost of slightly higher weight. Based on this

trade-off, an improved extrusion-based design was selected.

This approach reduced manufacturing complexity and cost while enabling reuse of proven components from previous designs. All design decisions were guided by mission requirements, cost efficiency, and manufacturability.

The redesigned ROV has a **diameter of 15 cm**, a length of **48.5 cm**, and a dry mass of **12 kg**. Compared to the 2025 design (55 cm), this reduction improves hydrodynamic performance and maneuverability by lowering drag and moment of inertia. The frame consists of two main structures: an outer frame for mounting external components, and an inner frame that houses the main cylinder and electronics. This separation improves protection, simplifies maintenance, and enhances subsystem integration.

The detailed dimensions are shown in Fig. 12.

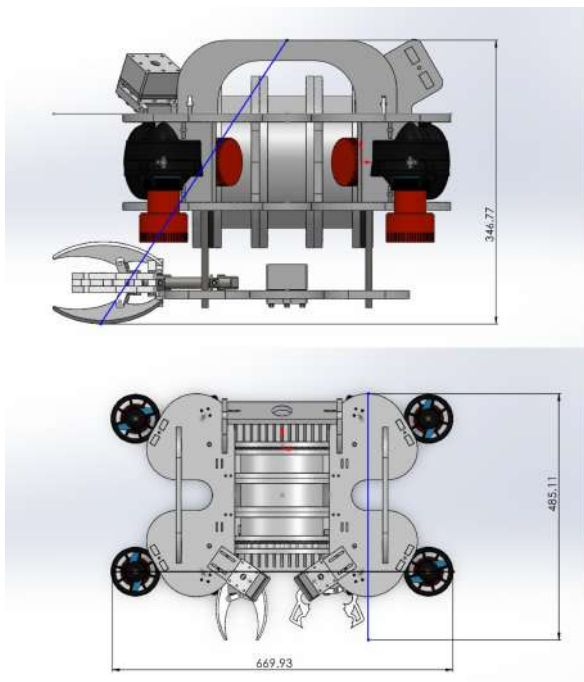


Figure 12: SETTO's detailed drawing and dimensions

An early conceptual sketch is shown in Fig. 13.

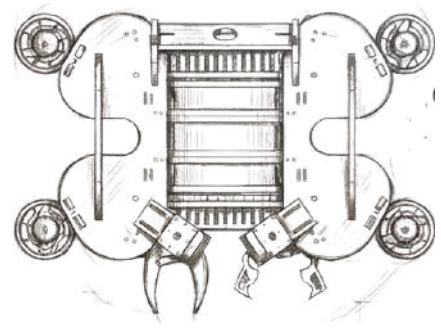


Figure 13: SETTO's initial concept sketch

2.1.3 Frame Design

The frame serves as the primary structure connecting all ROV components and was designed to achieve an optimal price-to-performance ratio within budget constraints. Different material options were evaluated based on strength, weight, manufacturability, and flexibility, leading to the selection of **Artelon**, which provides a suitable balance for a medium-sized ROV.

To improve hydrodynamic performance and reduce weight, wing-like appendages were designed for thruster mounting, incorporating multiple cutouts. The frame layout also ensures sufficient space for mechanism integration and ease of assembly.

The design was developed using **SolidWorks** and refined through iterative modeling and validation. The final structure was fabricated with verified dimensions, and sealing elements (glands) were integrated to protect internal components from water ingress.



Figure 14: SETTO's frame

2.2 Manipulators and Mechanisms

SETTO features pneumatically actuated multi-functional mechanisms, utilizing both pneumatic and electrical power for various competition tasks. Pneumatic actuation was selected over purely electrical solutions due to its higher reliability and reduced electrical risks in underwater environments.

2.2.1 First Mechanism:

This mechanism has two degrees of freedom (DOF) and is actuated by two pneumatic pistons, enabling both rotational and linear motion. The first piston provides up to 45° of rotation for orientation adjustment, while the second actuates the end effector for object manipulation. This configuration improves control and versatility, while pneumatic actuation ensures reliable underwater performance. Its compact and simple design allows easy integration, reduces interference with other subsystems, and minimizes maintenance requirements. The first manipulator is shown in Fig. 15.



Figure 15: Gripper 1 render

2.2.2 Second Mechanism:

A four-bar linkage-based manipulator is used for reliable underwater gripping and clamping. It was selected for its simplicity, rigidity, and ability to provide controlled, repeatable motion while maintaining consistent end-effector orientation, compared to more complex linkage or servo-based designs. The mechanism is pneumatically actuated using a 30 mm bore, 20 mm stroke piston, providing sufficient force in a compact design. Pneumatics were chosen for their reliability, fast response, and reduced electrical risk underwater. The end effector can grasp objects up to 109 mm in diameter, with a geometry that ensures even force distribution and minimizes slippage. Two manipulators are mounted on the ROV, enabling simultaneous

tasks, object stabilization, and multi-object handling, improving overall efficiency and operational flexibility.

The second manipulator is shown in Fig. 16.



Figure 16: Gripper 2 render

2.3 Propulsion & Maneuverability

The ROV is powered by eight identical motors, each coupled to a propeller. These motors were originally 12 V bilge pump motors.

Eight thrusters were selected to provide full maneuverability and precise control of the ROV in multiple directions. Four horizontal thrusters enable forward, backward, and rotational motion, while four vertical thrusters control depth and vertical stability. Although increasing the number of thrusters raises power consumption, this configuration significantly improves maneuverability and vehicle stability during mission tasks. Bilge pump motors were selected because they provide sufficient thrust at a much lower cost compared to commercial ROV thrusters, allowing the team to balance performance with budget constraint. To estimate the thrust generated by each thruster, a simplified fluid dynamics model is used based on the momentum of the expelled water jet. The thrust can be calculated using the following equation:

$$T = \rho \frac{Q^2}{A} \quad (1)$$

Where:

T : Thrust force (N)

ρ : Density of water ($\approx 1000 \text{ kg/m}^3$)

Q : Volumetric flow rate (m^3/s)

A : Outlet cross-sectional area (m^2)

The motors were carefully separated from their external plastic casings using saws, while strictly adhering to safety precautions. Each motor operates

at 12 V and 3.3 A, with an electrical input power of approximately 40 W, resulting in a total propulsion power of approximately 288 W.

The propellers are two-blade units enclosed in 3D-printed shrouds, which were specially designed with hydrodynamic considerations. The shrouds help guide the water flow in a specific direction, increasing thrust efficiency and reducing turbulence. This improves the ROVs stability, particularly at low speeds.

The two-blade design reduces drag, and when combined with the shrouds, enhances performance at low velocities. This ensures smooth and stable movement while still supporting higher speeds when necessary.

The propulsion system trade-off analysis is shown in Fig. 17.

Option	Thrust	Power Consumption	Cost	Decision
T100 Thruster	High	High	Very High	Rejected
Hipex Pump 2000 GPH	High	High	Low	Rejected
Hipex Pump 1100 GPH	Medium	Medium	Low	Selected

Figure 17: Trade-off analysis for propulsion system selection

The analysis shows that while the T100 thruster provides high performance, it is not cost-effective for the teams budget. The 2000 GPH bilge pump offers higher thrust but consumes more power, reducing efficiency and battery life. The 1100 GPH bilge pump provides an optimal balance between thrust, power consumption, and cost, making it the most suitable choice for the ROV.

The configuration comparison is shown in Fig. 18.

Configuration	Maneuverability	Complexity	Decision
4 Thrusters	Medium	Low	Rejected
6 Thrusters	High	Medium	Rejected
8 Thrusters (Customized Bilge Pumps)	Very High	High	Selected

Figure 18: Comparison between different configurations

The 8-thruster configuration was selected because it provides superior stability and maneuverability in all directions, which is critical for completing

complex mission tasks. Although this configuration increases system complexity, the benefits in control and performance outweigh the drawbacks. Customized bilge pumps were used to further optimize performance and integration within the vehicle design.

Utilizing eight customized bilge pumps with a large arm moment, Enigma was able to provide the vehicle with improved 6-DoF motion. Furthermore, the team added a PID controller and other software features to enhance stability, smoothness, and maneuverability.

The final thruster configuration is shown in Fig. 19.

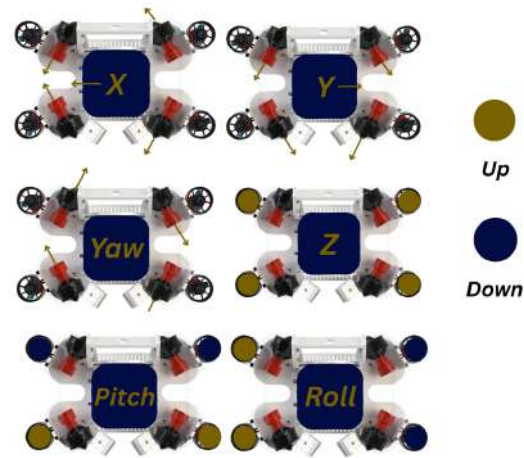


Figure 19: SETTO configuration

2.4 Buoyancy and Stabilization

Neutral buoyancy was achieved using a combination of air within the enclosure and high-rigidity foam to provide lift. The buoyant force is defined by Archimedes Principle:

$$F_b = \rho_{water} g V_{displaced} \tag{2}$$

The system was designed such that the buoyant force closely matches the ROV weight of **12 kg**, achieving near-neutral buoyancy during operation. Foam elements are mounted on the top and sides of the ROV with adjustable positioning. Stability was enhanced by maintaining geometric symmetry and distributing mass evenly, while placing the center of buoyancy above the center of mass to ensure passive stability.

2.5 CFD Analysis

A Computational Fluid Dynamics (CFD) simulation was conducted using **SolidWorks Flow Simulation** to evaluate the hydrodynamic performance of the ROV during forward motion. The simulation provides insight into the velocity distribution and flow behavior around the vehicle.

As shown in Fig. 20, the velocity field ranges up to approximately **1.16 m/s**, as indicated by the simulation scale. Higher velocity regions are observed around the outer edges of the ROV, while lower velocity zones appear near structural components and behind the vehicle.

The results show a relatively smooth flow around the frame, with limited flow separation at the front and sides. A wake region is formed behind the ROV, which is expected due to flow detachment, but its extent remains controlled due to the compact design and reduced frontal area.

The streamlined structure and symmetric layout contribute to minimizing turbulence and reducing hydrodynamic drag. This improves stability during operation and reduces the load on the propulsion system, allowing more efficient movement underwater.

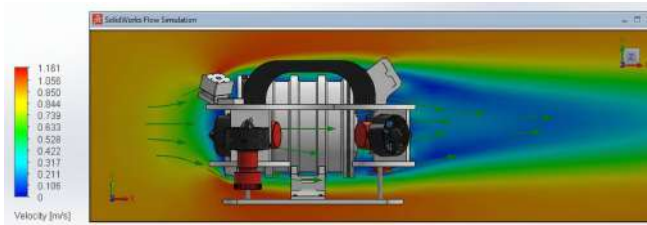


Figure 20: **SETTO**'s flow simulation in SolidWorks

2.5.1 Sealing

1. **Cylinder sealing:** SETTO main cylinder sealing uses HDPE plates with stainless steel glands mounted on the back side of the ROV to securely seal the cables. Gaskets are fitted on both sides and fastened with screws to ensure a watertight seal for the HDPE plates. The housing was designed to withstand pressure up to 3 bar, equivalent to 30 m depth.



Figure 21: Cylinder exploded view

2. **Manipulator camera case:** This camera case, shown in Fig. 22, is mounted to overlook the rotating manipulator. It is composed of a rectangular Artiron container with an area of $44 \times 40 \text{ mm}^2$ and a height of 35 mm. A rectangular flange with an area of $65 \times 60 \text{ mm}^2$ is welded to it. The case is covered by a rectangular 5 mm thick acrylic lens to provide a clear view, and it is sealed by a custom-made rectangular gasket that is bolted to the flange by the acrylic lens. The camera itself is fixed by a PLA 3D-printed part, and its cables are sealed by a stainless steel gland added to the back of the case.



Figure 22: Manipulator camera case overlooking the rotating mechanism

3 Electrical Design

The electrical system of SETTO was engineered to be modular, compact, and robust, balancing power distribution, space constraints, and control requirements within a watertight enclosure. Key decisions were driven by previous testing experience and the need to maximize reliability while minimizing cost and integration complexity.

3.1 System Architecture

The electrical system was designed to provide stable power distribution, reliable motor control, and protection against electrical faults. The system comprises dedicated motor driver PCBs, a power distribution board, and a protection circuit.

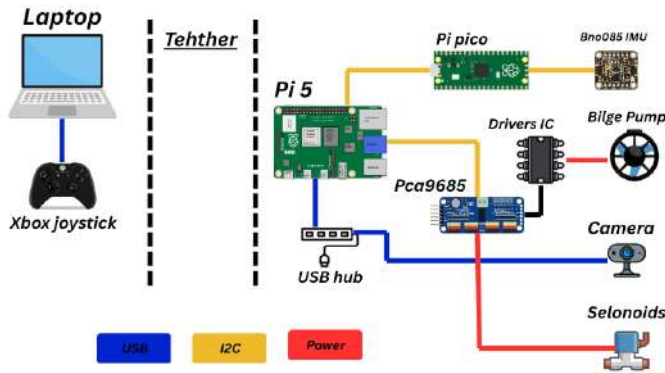


Figure 23: SETTO System Logic Level Schematic

3.2 Power Distribution PCB

A dedicated power distribution PCB was designed to regulate and distribute power from the main 12V supply. This board incorporates two buck converters:

1. The **HW-613** buck converter, which steps down 12V from the power supply to 3.3V, providing power to the **PCA9685** and **Raspberry Pi Pico 2**.
2. The **XY-3606** step-down buck converter, which steps down 12V to fixed 5V with 5A , safely powering the **Raspberry Pi 5** via a USB connection.

3.3 Motor Drivers

This customized motor driver design ensures independent and precise control of all thrusters. It provides precise, independent control for each thruster while maintaining electrical stability, increasing reliability and overall performance of the ROV at a reasonable production cost. For power connections, **XT60** connectors were used due to their

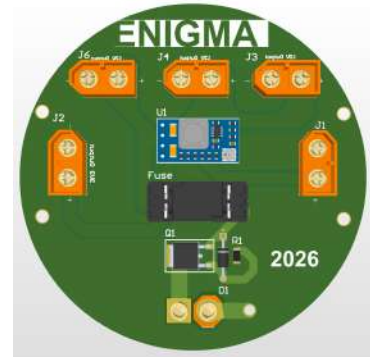


Figure 24: Power distribution pcb

high current capability and reliable contact, making them well suited for ROV power systems. The motor driver PCB is shown in Fig. 25. The deci-

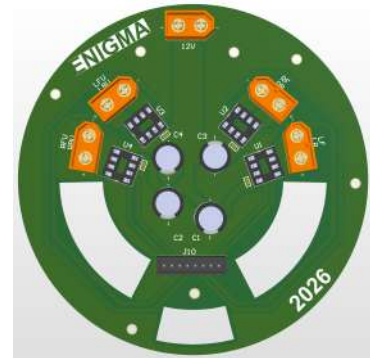


Figure 25: Motor driver PCB

sion to design and manufacture a customized motor driver PCB was made after evaluating and comparing it with the Cytron motor driver used in the previous years ROV.

Table 1: Motor Driver Comparison (2025 vs 2026)

Parameter	2025 (Cytron Driver)	2026 (Custom PCB)
Control	2 motors	Independent control for all thruster
Cost	High (commercial module)	Lower (in-team design)
Customization	Fixed configuration	Fully customizable design
Integration	External modules	Integrated into system PCB
Efficiency	Moderate	Improved due to reduced voltage drop
Reliability	Standard	Improved electrical stability and protection

3.4 IMU PCB

A dedicated IMU PCB was designed to interface the **BNO085 IMU sensor** with the **Raspberry Pi Pico 2**. The PCB provides stable power and reliable communication using the I²C protocol, ensuring accurate orientation and motion data. Care was taken in the layout to reduce noise and improve signal integrity, which is critical for stable sensor readings.

The IMU PCB also simplifies wiring and integration within the ROV by organizing connections in a compact and accessible form. This improves system reliability and allows easier maintenance during operation.

The IMU PCB is shown in Fig. 26.



Figure 26: IMU PCB

3.5 Actuators PCB

A dedicated actuators PCB was designed to control the pneumatic mechanisms of the ROV. The board receives control signals from the **PCA9685**, which is managed by the **Raspberry Pi 5**, and distributes them to the actuators.

The PCB ensures organized signal routing and stable connections between the controller and the pneumatic system. It also simplifies wiring and integration within the ROV, reducing complexity and improving reliability during operation.

The actuators PCB is shown in Fig. 27.

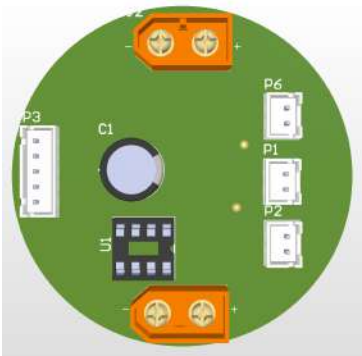


Figure 27: Actuators PCB

3.5.1 Electrical Safety

The design ensures efficient voltage regulation and minimizes heat losses compared to linear regulators.

For safety, the following measures were implemented:

- 1. A 25 A fuse was installed on the power distribution PCB to automatically interrupt the circuit if the current exceeds the maximum amperage limit.

2. To prevent high voltage drops in the power electronics, a MOSFET-based protection circuit was used. This circuit includes an **AOD403 SMD MOSFET transistor**, a 12 V, 0.5 W Zener diode, and a 100 k Ω resistor. It protects the ROV from reverse polarity by allowing current to flow in only one direction. This design produces less heat, improves overall system efficiency, reduces thermal stress on components, and ensures more voltage reaches the load.

3.5.2 Tether

The tether is a critical component of the ROV system, serving as the physical link that enables control, monitoring, and data transfer during operation. **Enigma** uses a tether cable designed to provide reliable power delivery and high-speed communication between the underwater ROV and the control station.

The tether was constructed using semiconductor materials, with **silicon-insulated wire** specifically chosen for its high flexibility, durability, good thermal stability, and resistance to insulation degradation under load. These properties make silicon-insulated cables well suited for underwater ROV applications, where the tether is constantly subjected to motion, tension, and environmental exposure.

Power is transmitted to the ROV through a pair of low-resistance wires, selected after a thorough analysis of power stability under heavy current loads. In addition to the power cables, the tether contains an Ethernet cable that facilitates communication between the **Raspberry Pi 5** located inside the ROV and the control station.

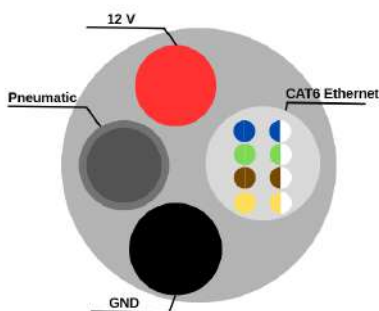


Figure 28: tether cross section view

3.5.3 Tether Management

A tether management protocol was implemented to prevent damage and maintain reliable communication. Before deployment, the tether is coiled neatly and inspected for breaks or wear. During operation, the tether is kept free of knots and excessive tension, with strain relief provided at connection points inside the ROV and at the surface control station. After each mission, the tether is carefully wound, dried if necessary, and stored to prevent kinking or insulation degradation. These procedures ensure long-term reliability and safe operation of the ROV.

4 Software System

4.1 Active stability

We developed attitude control with 3 PID controllers to correct for pitch, roll, and yaw using the BNO085 IMU sensor. This ensures stability, even with uneven payloads, and allows the ROV to lock its heading when needed. The pilot can select auto or manual mode for orientation control. This helps in missions that need rotation stability.

$$\begin{bmatrix} \text{forward} \\ \text{lateral} \\ \text{vertical} \\ \text{yaw} \\ \text{pitch} \\ \text{roll} \end{bmatrix} = \mathbf{K} \times \begin{bmatrix} T1 \\ T2 \\ T3 \\ T4 \\ T5 \\ T6 \\ T7 \\ T8 \end{bmatrix}$$

4.2 Communication Protocols

Communication protocols are a critical aspect of electronic system design, as they allow different components to recognize each other and exchange data. These protocols enable the creation of an integrated system where sensors, controllers, and drivers work together in a coordinated and efficient manner.

In our ROV, we implemented two I2C communication subsystems:

1. Integration of the **PCA9685** with the **Raspberry Pi 5** using the I²C protocol, enabling additional PWM channels for motor drivers and servo motors.
2. Integration between the **Raspberry Pi Pico 2** and the **IMU sensor (BNO0085)** via I2C.

A well-designed grounding system ensures that all components share the same electrical reference point. Without it, signals can become unstable and communication may fail. For this reason, establishing a common ground was a major focus in our ROVs electronics design.

The communication and software architecture of the system is shown in Fig. 29.

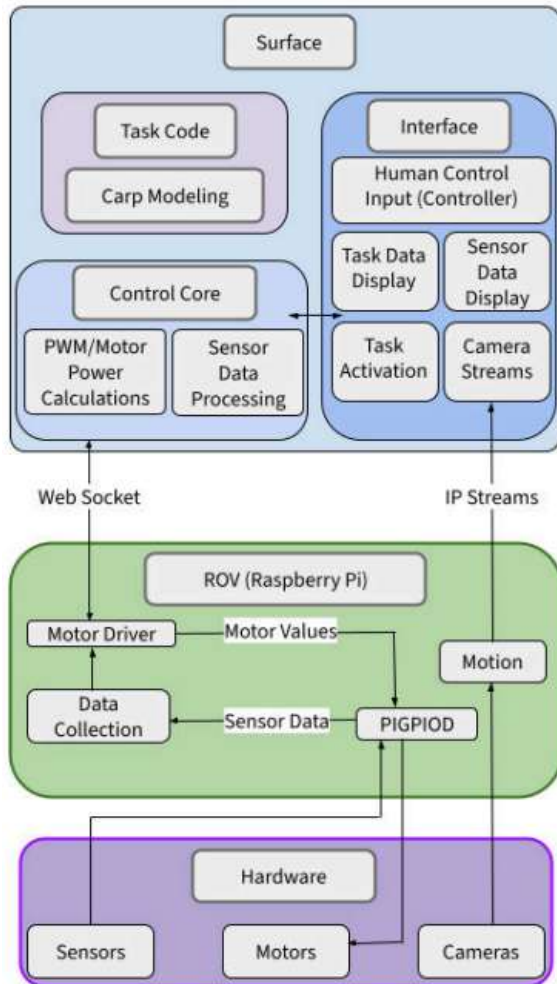


Figure 29: Architecture diagram of SETTO software systems

4.3 Graphical User Interface

The aim of the GUI is to maximize **SETTO**'s potential by providing the pilot and co-pilot with full control, real-time sensor data, and camera monitoring. Designing an intuitive and user-friendly GUI is one of the most important aspects of any ROV. With this in mind, **SETTO** features two GUIs designed to optimize functionality, enhance organization, and improve usability for both the pilot and co-pilot. All GUIs were developed using Qt Designer 5 and Python.

In total, there are two main GUIs: the pilot's GUI and the co-pilot's GUI. The pilot's GUI primarily displays the four cameras, allowing the pilot to control the ROV freely. The co-pilot's GUI presents sensor data and manages software tasks, including image processing missions and autonomous operations.

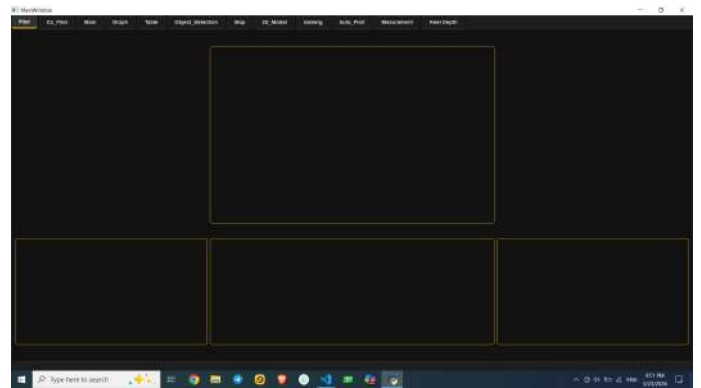


Figure 30: Pilot GUI

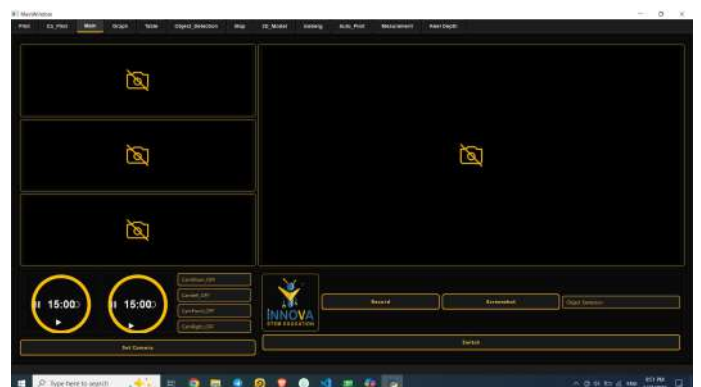


Figure 31: Co-pilot GUI

4.3.1 Vision System

The ROV is equipped with a **ZED 2 stereo camera** used for depth sensing and stereo measurement. The camera provides 3D mapping, object detection, and distance estimation, which help the ROV navigate and avoid obstacles during operation.



Figure 32: zed camera

In addition, the ROV is equipped with three cameras. Two cameras are mounted on the manipulators, with one dedicated to each mechanism to assist in precise operation and object handling. The third camera is mounted at the bottom of the ROV to provide a clear view of the working area during navigation and task execution.



Figure 33: SETTO'S FOV

5 Safety

5.1 Safety Rationale

SETTO was developed with a safety-first mindset, prioritizing the protection of team members, equipment, and testing environments. Throughout the design and build process, safety protocols were integrated into electrical, mechanical, and operational decisions. **SETTO** team took proactive steps to prevent hazards such as electrical shorts, overheating, water ingress, sharp edges, and unintentional thruster activation.



Figure 34: Safety measures taken while working

5.2 Vehicle Safety Features

The vehicle includes several safety features:

- All electrical connections are insulated to prevent short circuits.
- Sharp edges were covered to avoid injuries during handling.
- Motors and moving parts were secured to prevent accidental contact.
- The vehicle was tested at low power before full operation.
- All bilge pumps are equipped with protective shrouds to prevent accidental contact during handling and poolside work.
- Main power is disconnected during maintenance using accessible inline connectors and circuit isolation, reducing the risk of accidental startup. Landing Covers: minimizing the risk of damage or sharp contact when placing the robot on surfaces.
- Cable Management: The tether and internal wiring use zip ties and shielding to prevent short circuits, entanglement, and signal interference.

These precautions helped reduce risks during tasks and ensured safe operation of the vehicle.

5.3 Safety Procedures

A safety checklist was followed during construction and operation to ensure everything was done safely.

Construction Safety:

- ☐ Maintain clean workspace and proper material storage
- ☐ Use PPE (goggles, gloves)
- ☐ Inspect tools, machinery, and wiring before use
- ☐ Ensure proper grounding and energy isolation

Pre-power Checks:

- ☐ Area clear, switches and breakers OFF
- ☐ Tether secured with strain relief
- ☐ Electronics housing sealed
- ☐ Wiring, thrusters, and voltage (12 V) verified
- ☐ Pumps and video feed operational

In-Water Operation:

- ☐ Monitor for bubbles and leaks
- ☐ Activate bilge pumps
- ☐ **Loss of communication:** Power down immediately
- ☐ Resume only after system recovery
- ☐ Inspect cables, tether, and components
- ☐ Clean bilge pumps after operation

5.3.1 Construction Safety Checklist

Before each test or mission, the team follows a **checklist** that includes tether inspection, battery checks, leak sensor verification, and software diagnostics. **Dry Power-On Testing:** All subsystems are tested out of water prior to deployment to ensure stable software communication and electrical connections. **Surface Operator Lock-In:** The joystick and command software remain disabled until verbal confirmation is given that the area is clear and all systems are verified.

5.3.2 Operation Safety Checklist

- Inspect the vehicle before placing it in water.
- Ensure all seals are closed properly.
- Keep hands away from moving parts during operation.
- Turn off power immediately if a problem occurs.

6 NON-ROV Device

6.1 Buoyancy Engine

Our Float employs a worm-gear-driven syringe as its buoyancy engine. A 12 V DC motor (equipped with an integrated quadrature encoder) is coupled through a worm gear reduction to the lead screw that drives the syringe plunger. By precisely commanding the motor via its driver, the syringe either sucks water into the float's internal bladder raising its mass to initiate descent or expels water back into the ambient, reducing its density to ascend. The positive-displacement pump is inherently isobaric, ensuring smooth, repeatable volume changes throughout the profiling cycle.



Figure 35: Float Frame

6.1.1 Communication system

Data and command links between the Float and the shoreside receiver are handled by a LoRa SX1278 transceiver over the 915 MHz ISM band. Every pressure and attitude measurement is packetized by the ESP32 microcontroller and sent via LoRa to a ground station with automatic ACK and retransmit. If a command (e.g. abort profile or surface now) is issued after deployment, it is uplinked over the same LoRa link; the Float

then decodes and executes it in under 200 ms. A real-time-clock module stamps each transmission with year, month, day, hour, minute, and second, allowing post-mission synchronization with other oceanographic assets.

6.2 SENSOR SUITE and CONTROL ELECTRONICS

- **Microcontroller:** ESP32 running FreeRTOS, handles motion control, data logging, and radio.
- **Pressure Sensor:** BMP280 for depth measurement via pressure displacement.
- **Real-Time Clock:** Crystal 14.31818MHz 20PPM 20pF 40 HC-49S module to timestamp each packet.
- **Motor Driver:** Our customized motor driver with the ta6585 chip

6.3 Power System and Fuse

The Float is powered by ten Beston Rechargeable AA Battery 2500mAh 1.2V. Typical cell capacity is 2500 mah. At full load (motor startup surge up to 4 A, plus electronics 150 mA), the pack delivers safely for the duration of a profile. **Battery design:** Cells are held in a 3D printed case. Balanced against each cell is an anti-reverse diode to prevent back-feeding. All electronics (12 Vrated motor and driver) run directly from the pack; the ESP32, sensors. A 5 A fast-acting fuse is placed in-line with the main positive feed. This rating exceeds the maximum continuous draw (2 A) but protects against short-circuit currents above 5 A, ensuring safe discharge and preventing thermal runaway.

6.4 MECHANICAL, ENCLOSURE DESIGN

The entire mechanism is housed in two O-ringsealed modules of UV-resistant acrylic: Lower Module: Contains the worm-gear drive, syringe assembly, and water inlet/outlet ports. Upper Module: Houses the electronics, LoRa antenna, and battery pack. Stainless-steel fasteners with silicone

O-rings maintain pressure seals up to 5 bar. Cable glands and potted bulkheads prevent water ingress around sensors. The center of buoyancy is located approximately 30 mm above the center of gravity, yielding a stable vertical profile even under mild sea currents.

7 Missions

7.1 Coral garden ridge modelling

To construct the 3D model of the coral garden ridge (Task 1.2), **SETTO** captures five images of the coral garden from five planes using the front and bottom cameras while the pilot is in control. To obtain the required dimensions, the co-pilot calibrates the pixels per centimeter using known reference dimensions and marks the measurements directly on the images. To generate the coral garden as a CAD model, we used a pre-existing tool that takes the dimension-marked images and produces an STL file, which can then be opened in a CAD program.

7.2 Species Frequency

The threat map in **ENIGMA** is an essential tool for the iceberg task (Task 2.2). The first iceberg is positioned in the water, and the threat level is determined based on the distance between the platform and the iceberg. The GUI is divided into two main sections: a data table and the iceberg information.

The table contains the following columns for platform data:

1. Platform Name
2. Latitude
3. Longitude
4. Depth

Below the table, the iceberg data is displayed with the following fields:

1. Latitude
2. Longitude
3. Heading

4. Keel Depth

The left side of the window contains both the platform and iceberg data, while the right side displays a map with all platform locations. After entering the iceberg data in the bottom-left corner and clicking the **Calculate** button, the iceberg appears on the map. The threat level is calculated using predefined formulas.

An additional button, **Calculate Subset**, is available for each platform. This button computes the subset threat level for that platform. Threat levels are indicated by color:

- **Red:** Danger
- **Yellow:** Caution
- **Green:** Safe

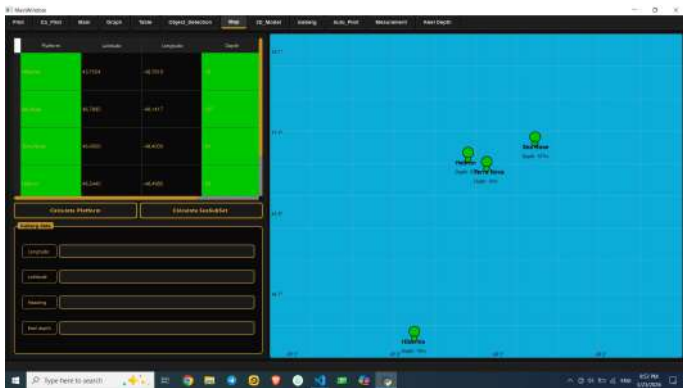


Figure 36: Frequency

7.3 Float Graph

The code utilizes a PyQt5 GUI integrated with Matplotlib to display a graph within a window. It defines a class called **Canvas**, which inherits from **FigureCanvasQTAgg**. The purpose of this class is to generate a figure and create a subplot for plotting. To achieve this, the class provides properties to set the figure size (width and height) and resolution (DPI). This class allows the plot to be created and embedded into any widget associated with the GUI.

Another class, **graphW**, is a subclass of **QThread** and is responsible for updating the graph in a separate thread, preventing the application from freezing due to main-thread workload. The **graphW** class maintains two lists: **x1** and **y1**. The **x1** list

contains all x-axis values (such as time or index), while **y1** contains the corresponding y-axis values (such as depth). It also includes an index for the next point to be appended. The class takes a GUI widget (referred to as **graph**) and creates a canvas in that **graphW** instance for later use.

The **run()** method of **graphW** is called automatically when the thread starts. Every second, it appends a new x value and a corresponding y value (using the **random.randint(1,100)** method). This call can be replaced with data from a CSV file or any other source. When more than 20 points are plotted, the oldest points are removed so that only the most recent 20 points are displayed.

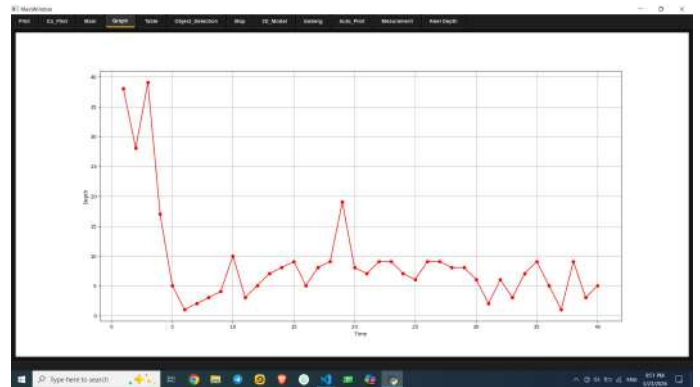


Figure 37: Float graph

7.4 Crab Detection

The crab detection task aims to train a model to both count and annotate green crabs with bounding boxes. We used Roboflow to develop our model, collecting images of crabs from both the water surface and underwater to create a comprehensive dataset. These images were annotated to train the model effectively.

Bounding boxes were drawn around green crabs in purple, while red boxes were used for other types of crabs. Additionally, a manual input option was implemented to allow users to enter the number of crabs in case the detection fails.

We can confirm that our model achieves highly accurate detection. This accuracy is due to training with datasets captured from multiple angles, under varying lighting conditions, and including crabs in proximity to one another. This ensures that the model can reliably detect green crabs without confusion from surrounding crabs.

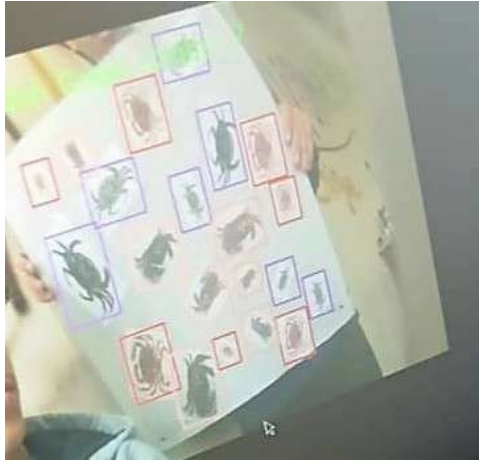


Figure 38: Crab detection

8 Innovation

8.1 Bilge Pump Thrusters

During the brainstorming period, a difficult decision regarding the thrusters had to be made. While the Blue Robotics thrusters, **T100** and **T200**, were economically impractical, the SEAFLO 1100 GPH bilge pump emerged as a more feasible option. However, the significantly lower cost of the bilge pumps thrust compared to the **T100** thruster presented a drawback. To address this dilemma, an innovative solution was implemented: the **T100 nozzle** and **propeller** were combined with a custom-made coupler and a 3D-printed fixation part to integrate with the **1100 GPH bilge pump**, achieving high thrust at a reasonable cost. **This modification not only reduced the overall cost of the propulsion system but also allowed the ROV to achieve thrust levels comparable to commercial thrusters, improving maneuverability and mission efficiency.**

8.2 Enigma's motor driver

Two customized **motor driver PCBs** were developed, with each PCB capable of controlling four **bilge pumps**. Each motor is managed by a dedicated **TA6586 motor driver IC**. Capacitors were included to maintain stable operation and reduce electrical noise, with values selected according to the **TA6586** datasheet recommendations.

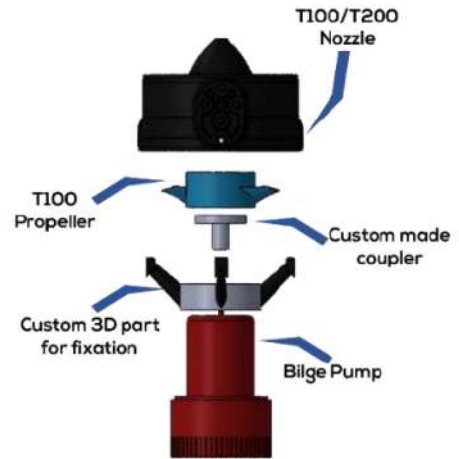


Figure 39: Customized bilge pumps

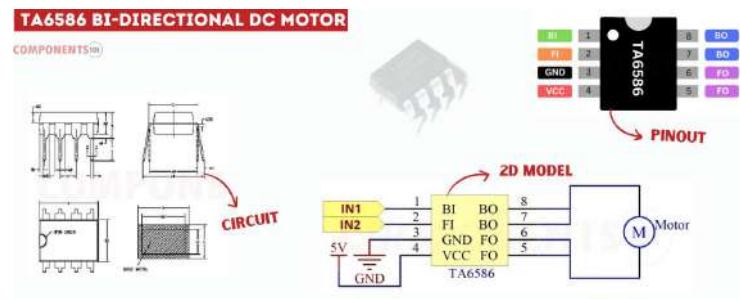


Figure 40: ta6586 IC

9 Testing

A structured testing methodology was implemented to validate the ROVs mechanical, electrical, and software systems under realistic operating conditions. Testing was conducted iteratively throughout development to verify design decisions, identify faults, and improve overall system reliability.

Mechanical Testing: Pool tests were performed to evaluate buoyancy, stability, and maneuverability. These tests enabled refinement of mass distribution, control response, and overall vehicle performance. Additional validation included pressure testing of the enclosure up to **6 bar**, exceeding competition requirements, ensuring watertight integrity under extreme conditions.

Electrical Testing: All electrical components were tested individually and under full system load to verify voltage stability, current draw, and signal integrity. Integrated system testing revealed issues such as voltage drops and noise, which were resolved through improvements in wiring, shielding, and PCB design.

Software and Diagnostics: A real-time logging and diagnostic system was implemented to monitor subsystem communication and detect faults. Automated reconnection and tiered error reporting improved debugging efficiency and system robustness.

Mission Validation: Mission-specific tests were conducted to simulate real competition tasks, leading to improvements in navigation, camera positioning, and manipulator performance.

Troubleshooting Strategy: A structured troubleshooting approach was applied by categorizing issues into mechanical, electrical, and software domains, enabling efficient root-cause identification and targeted solutions.

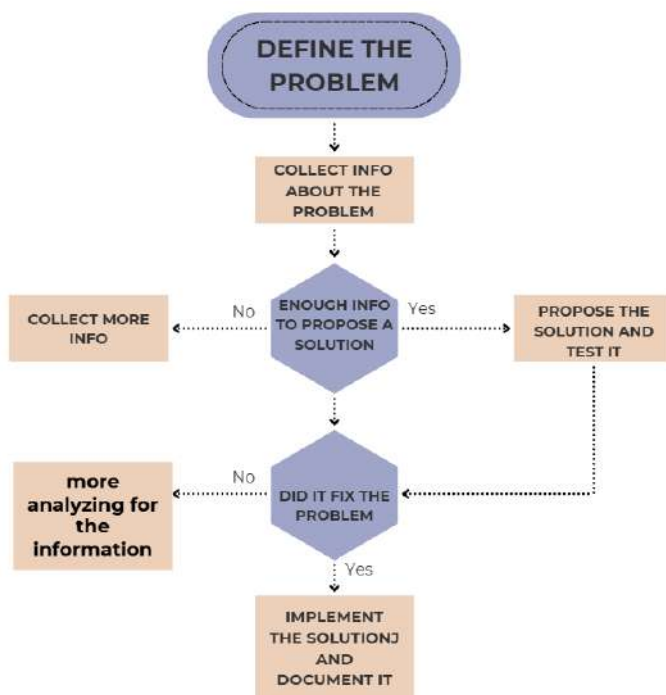


Figure 41: Troubleshooting Strategy

10 conclusion

10.1 Future Plans

In the coming years, Enigma Team aims to significantly enhance the performance and capabilities of its ROV system. One of our primary goals is to replace the currently used bilge pump motors with **Blue Robotics T200 Thruster**. These thrusters are more efficient and provide higher thrust output, which will result in smoother and more precise maneuverability during operation. Additionally, we plan to upgrade our onboard processing unit from the Raspberry Pi 5 to the **NVIDIA Jetson Nano**. The Jetson Nano offers superior GPU capabilities, allowing for advanced image processing, real-time object detection, and better support for autonomous functions, making it a more powerful choice for future development.

10.2 Lessons Learned

Throughout this years ROV development, we significantly improved our teamwork and problem-solving skills. As both students and engineers, we learned how to effectively organize our ideas and manage our time to balance academic responsibilities with project demands. Facing various technical and logistical challenges encouraged us to think outside the box and develop creative solutions. We also gained valuable experience in budget management, learning how to achieve the best possible quality while keeping costs as low as possible. Additionally, we strengthened our leadership abilities by coordinating tasks, supporting team members, and making decisions that guided the project toward success.

11 Accounting

Component selection and system design decisions were guided by budget constraints while ensuring that all mission requirements were met. A detailed cost breakdown is provided in **Appendix B**.

11.1 Cost Overview

The total cost of the ROV was calculated to be **3482.34 USD**, remaining within the allocated budget. The electrical system and control components represent a significant portion of the total cost due to their impact on system performance and reliability. Cost distribution was carefully managed by combining purchased, custom-built, and reused components to achieve an efficient and balanced design.

11.2 Build vs. Buy, New vs. Reused

In the development of **SETTO**, we carefully balanced between purchasing components and building custom solutions to meet our specific mission requirements. Several motor options were considered, and the team selected the **1100 GPH bilge pumps** due to their suitable voltage and current ratings, sufficient torque, and cost-effectiveness. The cameras were purchased because they provided high quality and efficiency at a reasonable price, fulfilling imaging and navigation requirements without the need for in-house development. Many of the electrical components were custom-built to better suit the ROVs design and reduce costs. For example, our electrical system included **two custom PCBs** and a breakout board. The first PCB managed power distribution, regulating voltage and current according to system requirements and including fuses for safety. The second PCB contained our motor drivers, built in-house instead of purchasing expensive off-the-shelf controllers, ensuring precise motor speed and direction control with minimal voltage drop. Additionally, a breakout board for the **PCA9685** was created, providing extra PWM channels that the Raspberry Pi could not natively support, enhancing motor control.

Table 2: Custom-Built Components

Component	Purpose	Reason for Build
Motor Drivers PCB	Propulsion Control	Provides precise independent control of all thrusters while reducing cost compared to commercial motor controllers
Power Distribution PCB	Power Management	Ensures stable voltage regulation and protection while allowing customization for system requirements
IMU PCB	Motion Sensing	Improves signal stability and reduces noise for accurate orientation and control
Actuators PCB	Pneumatic Control	Organizes control signals from PCA9685 and simplifies integration of pneumatic mechanisms
PCA9685 Break-out Board	PWM Expansion	Provides additional PWM channels required for controlling multiple actuators and thrusters

Some components were purchased, including two 1080p webcams, the cylinder, and the ROV frame. In addition, a stereo **ZED 2i** camera was funded by **AI Cognitro**, supporting advanced vision capabilities required for the mission. Some components were reused from the 2025 ROV, including bilge pumps and sensors such as the **BNO085**. These components were carefully inspected and verified to meet this years requirements, allowing the team to reduce cost, save assembly time, and maintain proven reliability.

Table 3: Build vs Buy and Reuse Decisions

Compon	Category	Justification
Bilge Pumps	Reused	Cost-effective and compatible with system requirements
ZED 2i Camera	Funded	Provides advanced vision capabilities for mission tasks
Motor Drivers PCB	Custom Built	Reduces cost and allows precise control
Power Distribution PCB	Custom Built	Ensures proper voltage regulation and safety
Webcams	Purchased	Provides reliable imaging at low cost
Frame and Cylinder	Purchased	Requires precision manufacturing and structural integrity
IMU Sensor (BNO085)	Reused	Proven reliability and compatibility

The reuse of components from previous ROV designs further reduced costs and minimized development time while maintaining system reliability.

11.3 Cost vs Performance Trade-off

The design of SETTO reflects a balance between cost and performance. While higher-end commercial components could provide improved performance, the selected components offer sufficient capability to meet mission requirements within the available budget. This approach allowed the team to maximize system performance while maintaining financial efficiency and sustainability.

11.4 Funding and Support

Some components of the system were supported through external funding. In particular, the **ZED 2i stereo camera** was funded by **AI Cognitro**, enabling the integration of advanced vision capabilities without increasing the overall system cost. This support contributed to enhancing the ROVs performance while maintaining budget constraints. The complete cost breakdown, including detailed component costs and budget comparisons, is provided in Appendix B.

By strategically combining purchased, custom-built, and reused components, SETTO achieves a balanced design in terms of performance, cost efficiency, and mission readiness. Cost optimization was a key factor in the design process. Bilge pump motors were selected instead of commercial ROV thrusters, significantly reducing propulsion system costs while maintaining acceptable performance. In addition, several subsystems such as motor drivers and power distribution were designed and manufactured in-house. This reduced dependency on expensive commercial solutions and allowed better customization of the system.

A Pneumatic SID

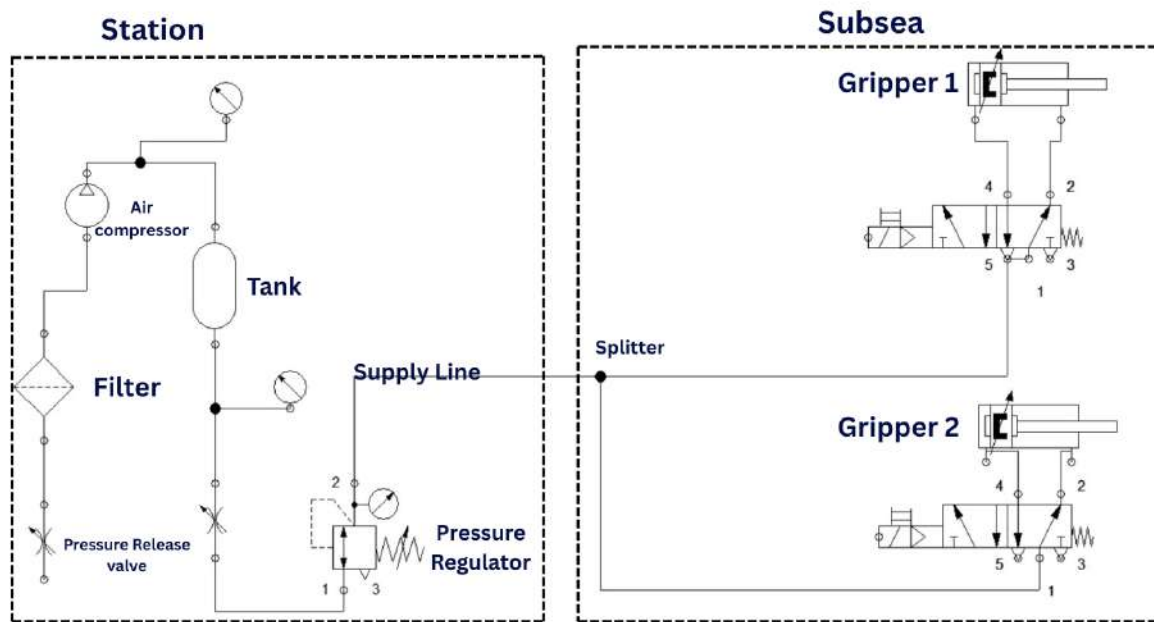


Figure 42: SETTO Pneumatic System Integration Diagram (SID)

B Project Cost Breakdown

	Component	Description	Estimated Budget (USD)	Status	Budgeted Value (USD)	Difference (USD)
Product Cost	Bilge pumps	1100 PGH Bilge Pumps	145.21	Reused		
		6*T100 probellers, 8*Nozzles	45.29	Reused		
	Material	Artiron(sheet+Cylinder),Acrylic sheet	47.77	New	50	-2.23
	Fabrication	CNC Routing, Laser Cutting, 3D printing	50	New	60	-10
	Pneumatic system	Pistons,valves,Fitting,Tubes,DCV's	55	New	60	-5
	Fasteners	Screws(stainlesssteel),counter nuts,	25	New	30	-5
	Sealing	tainless steel glands, Silicon	30	New	26.5	-3.5
	Electrical system	PCB's, Electronic Components, 2*DC to DC convertors	296.15	New	250	46.15
	Vision system	4 USB cameras, usb hub, Zed 2i camera	710	Funded		
	Tether	sheath, silicon wire cable, Ethernet cable, pneumatic cable	30	New	40	-10
	Control Unit	Control Box, Monitor, Buttons, Joystick, AWG-6 wires	200	Reused		
	Vicle Safety Equipment	Shrouds, Fuses	10	New	15	-5
		Total (USD)	1644.42		531.5	40.73
R&D costs	Mechanical	Strain leaf, Float	43.5	New	50	-6.5
	Electrical system	Test Board PCB	8.2	New	20	-11.8
		Total (USD)	51.7		70	-18.3
Running costs	playground	PVC pipes, PVC Connectors, Spray Color, Corrugated Sheets	30	New	20	10
	Complition Registration	Mate, Mate Egypt, Fluid Power Quiz	470	New	450	20
	Marketing	posts boosts	10	New	20	-10
	Printables	Brochures, Poster, Banners, Technical Report	10	New	15	-5
	T-shirt	Company Staff T-Shirts	64.81	New	70	-5.18
	Training & Testing	Pool	Funded			
		Total (USD)	547.81		575	9.92
Equipments	Compressor	25 Litre Compressor unit +FLR unit	43	New	50	-7
	Power Supply	2*12V-25A	21	Reused	15	6
	Mechanical Tools	Driller, Screw Drivers, Sand Paper, Piller, Silicon	10	New	15	-5
	Electrical Tools	Soldering Iron Station, Flux, Solder, Avo Meter	30	New	35	-5
		Total (USD)	104		115	-11
		Total (USD)	3,482.34		1,291.50	20.62

Figure 43: Detailed Project Cost Breakdown

C Electrical Power Budget

Components	Qty	Current (A)	Power (W)	Current (A)	Power (W)	Current (A)	Power (W)	Current (A)	Power (W)
BNO085	5	0.0159	0.0159	0.795	0.795	1	0.795		0.795
Raspberry pi 5	5	2	5	10	25	1	10		25
Raspberry pi pico	5	0.02	0.07	0.1	0.35	1	0.1		0.35
USB hub	5	0.9	0.9	4.5	4.5	1	4.5		4.5
TA6596	12	0.5	7	6	84	8	48		672
1080P webcam	5	0.5	0.5	2.5	2.5	3	7.5		7.5
Zed 2i Stereo camera	5	0.38	0.38	1.9	1.9	1	1.9		1.9
Solenoids	12	0	0.3	0	3.6	2	0		7.2
Buck convertor(12-5)	12	2	5	24	60	1	24		60
Bilge Pumps	12	3	7.5	36	54	8	288		432
Total							277.7		1211.245
Total current drawn from Mate power supply (A)/Fuse value (A)							23.1/ 25		

Figure 44: SETTO Electrical Power Budget

Technical Documentation

Electrical SID

