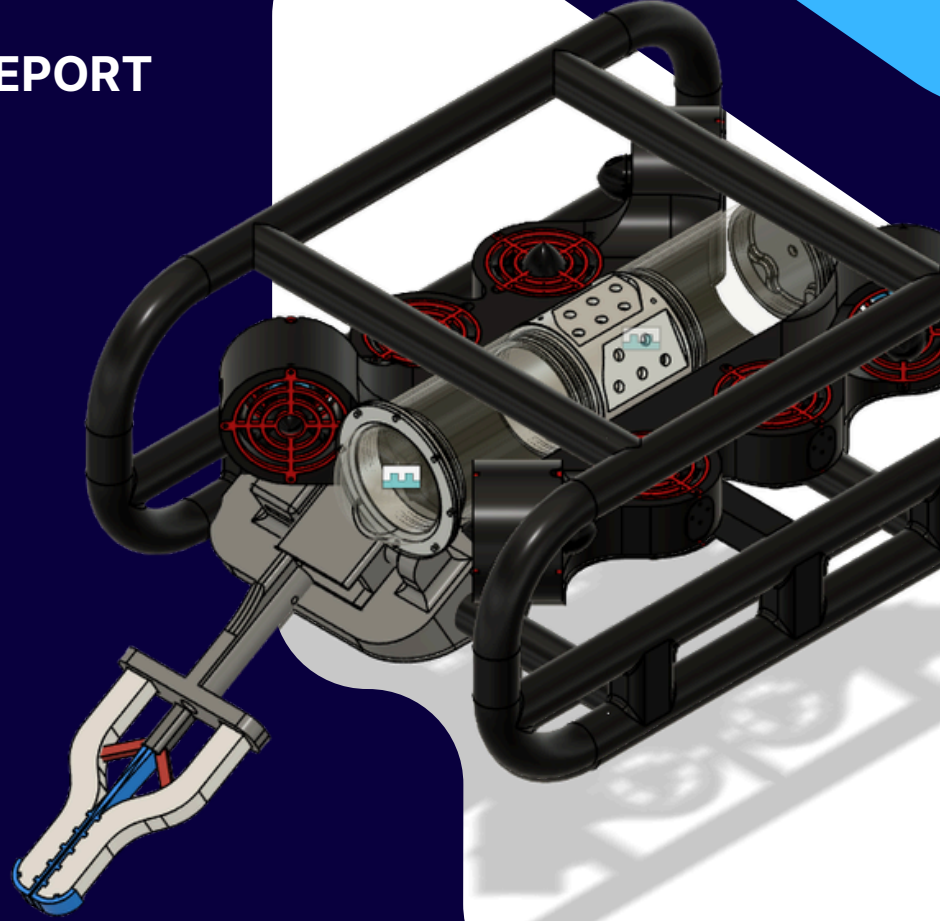




ALESTA

Adana Science High School
Seyhan Youth Centre

2026 TECHNICAL REPORT



Vehicle Name:
HURRICANE

10th Grade

Mehmet Ulaç Girgin

CEO

10th Grade

Buğlem Nisan Ekinci

CFO

10th Grade

Kağan Kaya

CTO

10th Grade

Mustafa Kahramanoğulları

COO

9th Grade

Beyzanur Dizman

Mechanic, PR

9th Grade

Derin Nergiz

Mechanic

9th Grade

Emre Alperen

Software

9th Grade

Yiğit Köylü

Electronic

9th Grade

Ulaş Doruk Seyfettinoğlu

Software



Table of Contents

1. Abstract	3
2. Project Management	4
3. Design Rationale	5
3.1. Engineering Design Rationale	5
3.2. Vehicle Structure	7
3.3. Vehicle Systems	7
3.3.1. Mechanical Systems	8
3.3.2. Pneumatics System	8
3.3.3. ROV Electrical System	9
3.3.4. ROV Control System	10
3.3.5. Topside Electrical System	11
3.3.6 Tether	11
3.3.7. Software System	12
3.3.7.1. System Architecture	12
3.3.7.2. Onboard Software & Firmware	13
3.3.7.3. Topside Software & Ground Control Station	13
3.3.7.4. Image Processing	14
3.3.8. Payload and Tools	15
3.3.8.1. Vision and Observation System	15
3.3.8.2. Hybrid-Actuated Manipulator Arm	16
3.3.8.3. Vertical Profilling Float	16
4. Build vs Buy	17
4.1. Components We Chose to Build	17
4.2. Components We Chose to Buy	17
5. Testing and Troubleshooting	19
5.1. Testing Metholodogy	20
5.2. Subsytem Testing Data	20
5.3 Troubleshooting Case Studies	20
6. Safety	21
7. Budget	23
8. Cost Accounting	24
9. References	25

1. ABSTRACT

Our team is a high school-based engineering group dedicated to designing and developing innovative underwater robotic systems for real-world applications such as underwater searchings . With 7 year of experience in robotics competitions, our team has consistently focused on improving both technical performance and teamwork.



Figure-1

Each member of the team is assigned specific roles based on their strengths, allowing us to work efficiently and collaboratively. Through this structured approach, we ensure that all aspects of the project from mechanical design to system integration are carefully managed.

Our primary goal is not only to successfully complete mission tasks but also to develop engineering skills, problem solving abilities, and effective communication within the team. By continuously learning from previous experiences, we aim to improve our designs and achieve higher performance each year.

Our team consists of 9 members, all of whom attend Adana Science High School. To make things more organized and easier, we work in four main departments: software, mechanics, electronics, and PR.

The software department creates the necessary algorithms for the vehicle, writes the software, and is responsible for artificial intelligence and image processing.

The mechanics department creates the mechanical design of the vehicle, performs assembly, ensures waterproofing and sealing, and is also responsible for the vehicle's stabilization.

The electronics department creates the electronic design of the vehicle, troubleshoots problems when they arise, and pilots the vehicle.

The PR department promotes the team on social media, does advertising, and provides financial support to the team.

2. PROJECT MANAGEMENT

Adana Science High School is one of Türkiye's leading state high schools, known for its emphasis on science, mathematics, and technology. With its experienced teachers and success-oriented environment, the school aims to cultivate analytical, innovative, and successful students in both academic and technological fields.

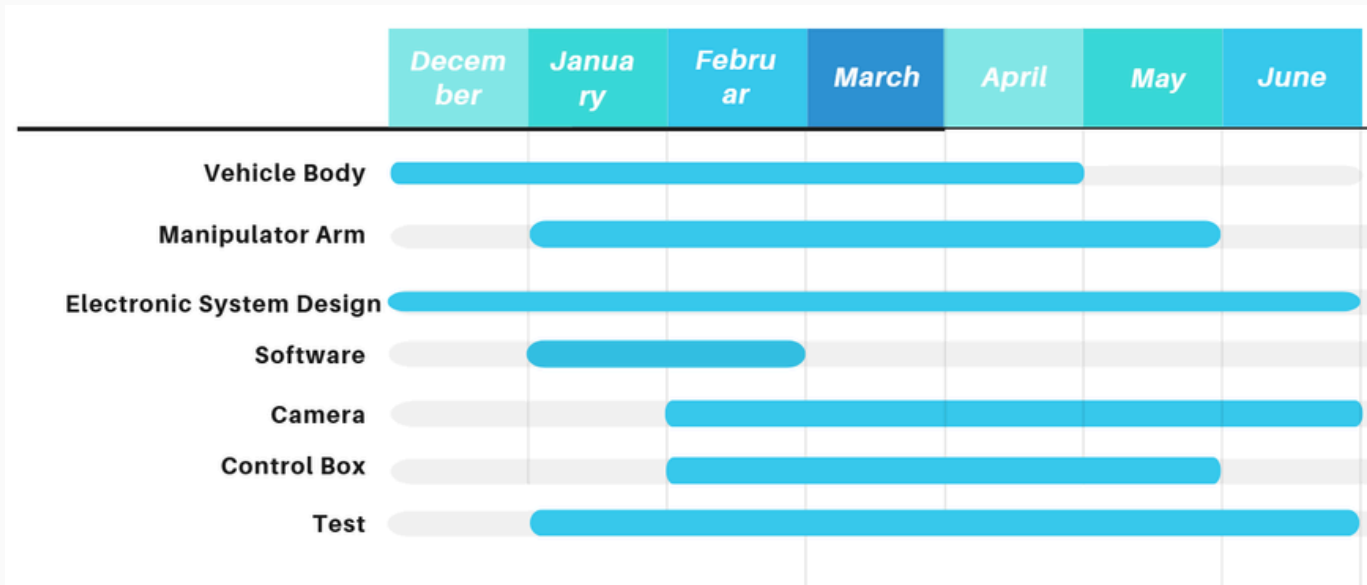


Figure-2

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3. DESIGN RATIONALE

3.1. Engineering Design Rationale

Manufacturing Method	Material	Application Area	Purpose / Key Advantage
Lathe (Turning)	7075 Aluminum	Plug components, simple geometries	Efficient production of simple, axisymmetric parts
6-Axis CNC Machining	7075 Aluminum	Main chassis	High precision and ability to manufacture complex geometries
Plexiglass Thermoforming	Acrylic (PMMA)	Camera dome, electronic enclosure tube	Transparency for visual inspection and camera operation
3D Printing	PETG-GF, TPU, PETG-CF, ABS	Outer shell, robotic arm parts, mounts, tray	Lightweight, customizable, and rapid manufacturing

Figure-3

The ROV, named Hurricane, was designed and manufactured to perform all mission tasks in the most efficient and reliable manner, with a strong emphasis on mechanical robustness, hydrodynamic efficiency, and operational stability. The manufacturing methods used in the production of the vehicle are presented in Figure 3. These methods include CNC machining of 7075 anodized aluminum components, the use of plexiglass pressure housings, and 3D-printed parts produced with water-resistant PETG material.

Hydrodynamic flow analysis of the vehicle was conducted using ANSYS software, and the results are illustrated in Figure 4. This analysis demonstrates the streamlined structure of the ROV and highlights the reduction of drag forces acting on the vehicle during operation, contributing to improved efficiency and stability underwater.

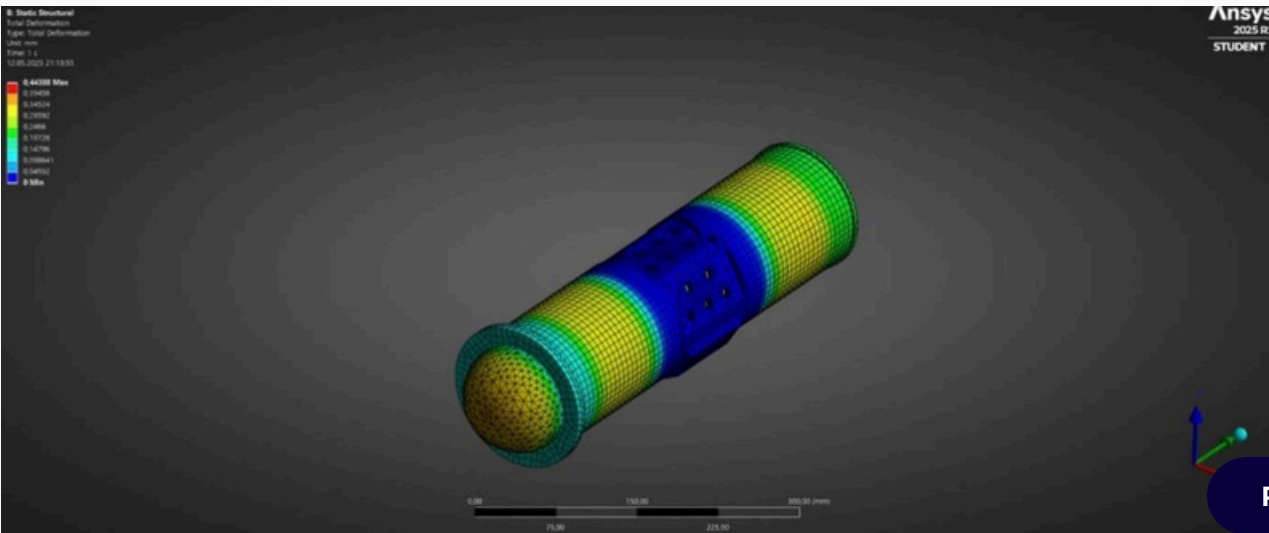


Figure-4

During the design process, multiple structural configurations were evaluated to determine the most optimal solution. A robust yet lightweight structure was selected to ensure durability without compromising maneuverability. In this context, the use of a plexiglass tube played a critical role, providing a strong pressure-resistant enclosure while maintaining low weight. This balance allows the vehicle to remain both durable and easily controllable underwater.

The internal placement of components was carefully engineered to achieve optimal weight distribution. By strategically positioning key elements such as batteries and electronic systems, the center of gravity was stabilized, minimizing unwanted tilting and improving overall control performance. This design approach significantly enhances the vehicle's stability during operation.

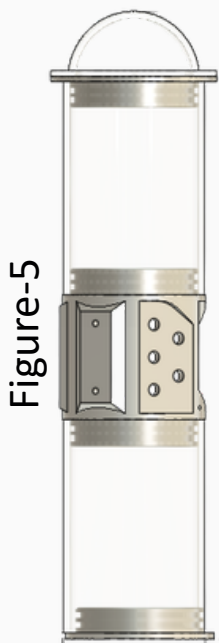


Figure-5

For the vision system, a dome structure was specifically designed for the camera module. This dome enables maximum utilization of the camera's field of view, allowing wider visual coverage and increasing efficiency during mission tasks such as object detection and navigation.

The propulsion system underwent a comprehensive optimization process. Initially designed with a 6-thruster configuration, the system was subsequently redesigned to feature an 8-thruster configuration. While the 6-thruster system offered more efficient energy consumption, it also entailed disadvantages such as restricted mobility and an inability to execute missions with maximum efficiency. Following a thorough evaluation, the 8-thruster configuration was selected, as it offered a superior solution for achieving greater stability and maximum maneuverability.

The 6-thruster system reduces power consumption while still delivering sufficient maneuverability for all required mission tasks. Furthermore, the reduced number of thrusters simplifies the electrical and control systems, thereby improving reliability and ease of maintenance. This optimization results in efficient movement, precise control, and extended operational duration without compromising performance.

Additionally, the ROV was designed with a compact form factor to enhance maneuverability and operational flexibility. The smaller size allows easier navigation in confined underwater environments, reduces hydrodynamic drag, and improves precision during complex tasks. It also contributes to lower material usage and overall weight reduction, increasing overall system efficiency.

A rendered image of the ROV design is presented in Figure 5, showcasing the overall mechanical structure and integration of system components.

3.2. Vehicle Structure

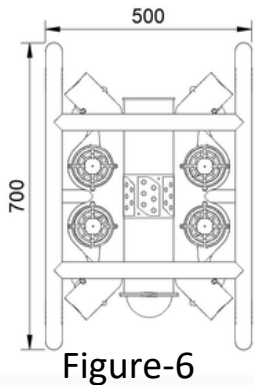


Figure-6

During the design and calculation of our vehicle's dimensions, particular attention was paid to ensuring a compact and modular structure; furthermore, the optimal dimensions were determined by carefully avoiding the inclusion of any components or sections that would occupy unnecessary space within the vehicle. As illustrated in Figure 6 and Figure 7, the final dimensions of our vehicle are projected to be 700 x 450 x 250 centimeters. In planning these dimensions, the vehicle was designed to maintain its stability, to possess maximum maneuverability, and to be minimally affected by water pressure.

The structure is engineered to fit within a 700 mm diameter sphere, meeting the required size limitations. This compact design enables the vehicle to operate effectively in confined underwater environments while maintaining structural integrity.

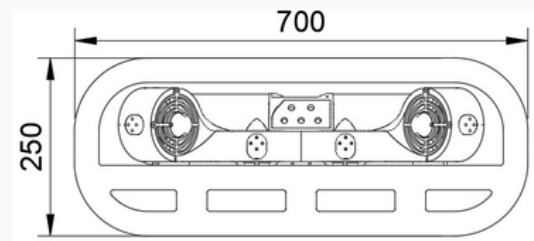


Figure-7

3.3. Vehicle Systems

3.3.1. Mechanical System

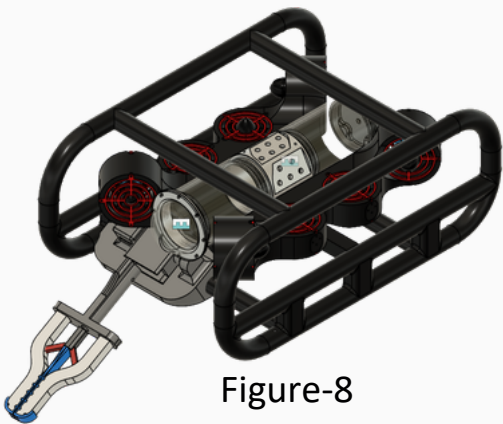


Figure-8

The external shell used in the vehicle is designed to protect the system against external factors during underwater operations and serves as the primary protective structure against impact, pressure, and mechanical stresses. This lattice (frame) structured design not only increases strength but also provides protection without negatively affecting the vehicle's hydrodynamic performance. Rendered image of the Hurricane is presented in Figure 8.

The external shell is positioned to integrate with the vehicle body and the robotic arm system. This ensures the internal components are securely fixed while minimizing vibrations and displacements that may occur during operation. Connection points located at the lower part of the structure allow the robotic arm system to be safely attached to the shell.

Within the shell, a Sigma profile is used as the supporting frame. Thanks to its modular design, the Sigma profile allows system components to be mounted in an organized and robust manner while distributing loads evenly to enhance structural strength. Its ease of assembly and maintenance also contributes significantly to its selection for this application.

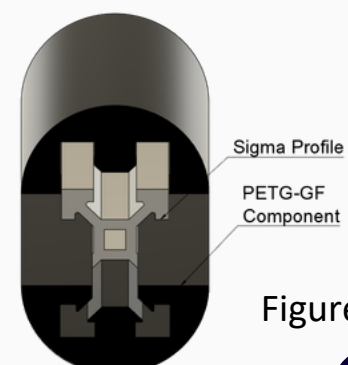


Figure-9

PETG-GF (glass fiber reinforced PETG) material has been chosen for the external shell. Compared to standard PETG, this material provides higher mechanical strength, rigidity, and impact resistance. The addition of glass fibers increases the shell's resistance to deformation under high loads and ensures that its structural integrity is maintained during prolonged use. Additionally, PETG-GF offers chemical resistance suitable for underwater conditions along with ease of manufacturing. Rendered image of the sigma profile and PETG-GF is presented in Figure 9.

To evaluate the mechanical performance of the structure, a static stress analysis was conducted on the external shell. The analysis examined the stress distribution under potential loads and identified critical regions. The results indicate that the external shell design has sufficient load-bearing capacity and provides structural strength against impact effects. Furthermore, the combination of the Sigma profile used in the main supporting frame and the PETG-GF material on the outer surface enhances overall system rigidity and reduces the risk of deformation.

In conclusion, the designed external shell meets the criteria of high strength, modularity, protection, and stability, making it a critical structural component that directly contributes to the overall performance of the vehicle.

3.3.2. Pneumatics System

Our company designed a custom, topside-supplied pneumatic actuation system for the ROV's manipulator. In this entire pneumatic loop, the primary air source — a compact compressor safely located at the Ground Control Station — is the sole electrically powered component. To meet strict MATE ROV fluid power safety requirements, the air first passes through a manual Emergency Shut-off Valve, allowing the deck crew to instantly isolate the air supply in case of a system failure.

The air is then routed through a Pressure Regulator equipped with an analog pressure gauge, which steps the raw compressor pressure down to a highly optimized and safe working limit of 35 PSI. This configuration also allows safety inspectors to visually verify system compliance during inspection. As a redundant safety measure, a Pressure Relief Valve (PRV) set to 50 PSI is installed in-line to automatically vent excess air if the regulator fails, preventing the pneumatic lines from over-pressurizing.

Instead of using electronic solenoid valves — which introduce software dependency and the risk of electrical failure — we integrated a purely mechanical, lever-operated 5/2 directional control valve into our topside station. When the pilot physically shifts the lever, the valve mechanically redirects the regulated airflow down one of the two 4.5 mm polyurethane pneumatic tubes bundled securely inside the tether.

These tubes, rated for a maximum pressure of 145 PSI (1000 kPa), provide a massive safety factor against our 35 PSI working pressure and run directly to a Double-Acting Pneumatic Cylinder mounted on the ROV's manipulator arm. One tube supplies air to extend the cylinder and close the gripper, while the second tube retracts it to reopen the gripper.

Unlike servo motors that draw massive stall currents to hold heavy props, this pneumatic cylinder maintains its maximum grip force using static air pressure while drawing absolutely 0 Amps from the ROV's electrical system. By operating at an efficient 35 PSI, we reduced mechanical stress on the cylinder while still providing sufficient grip force for all mission tasks.

Keeping the compressor and mechanical control valves on the surface allowed us to fully isolate the manipulator's actuation system from the ROV's software. This approach achieved near-complete mechanical reliability, eliminated all high-voltage pneumatic electronics from the underwater environment, reduced the ROV's overall weight, and freed up critical space within the electronics enclosure.

3.3.3. ROV Electrical System

To ensure a secure, high-current, and universal connection architecture, our ROV utilizes Anderson power connectors for the main power input. This universal standard allows our team to seamlessly switch between a tethered topside power supply and onboard batteries without reconfiguring the hardware, significantly reducing setup time during pool tests and competition runs. Immediately following the main power input, the raw 12V power is routed through a Matek Systems Power Monitor.

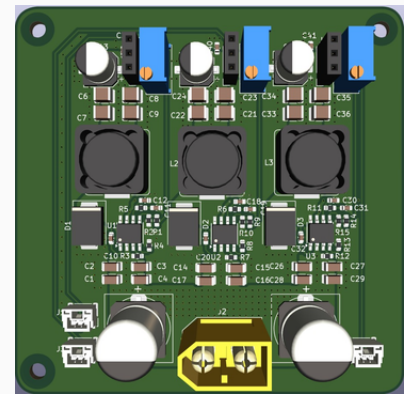


Figure-10

This robust module comfortably handles up to 150A of continuous current draw and interfaces directly with the main flight controller via a CAN Bus network. This component acts as our primary diagnostic gate, precisely measuring incoming voltage and total system current draw before the power is distributed to the rest of the vehicle.

From this monitoring gate, power flows into our primary distribution network. Our electronics department designed and manufactured a custom primary Power Distribution Board (PDB1), which supplies power to components. Power enters PDB1 via an XT60 connector and is distributed across 12 individual XT30 output ports. To ensure maximum electrical safety and prevent wire melting under heavy loads, the PCB traces and each XT30 connector are engineered to safely handle up to 30A. These 12 outputs are strategically allocated: eight ports are dedicated to the bidirectional Electronic Speed Controllers (ESCs) for the propulsion system, two power the underwater lighting systems, and the final two are routed to supply power to our step-down boards.

Because sensitive electronics, microcomputers, and servomotors require clean, regulated power at various voltage levels, the raw power from PDB1 is routed to our secondary custom board known as PDB2. To distribute the thermal load and ensure system redundancy, we integrated two identical PDB2 units into our electronics enclosure. Each PDB2 is equipped with three high-efficiency TPS5460BDDAR synchronous step-down (buck) converters, each capable of delivering 5A of continuous current. The switching frequency was deliberately tuned to 440 kHz.

This specific frequency strikes the optimal balance between minimizing the physical footprint of the required inductors and capacitors and maximizing overall thermal efficiency. Furthermore, the output voltage of each buck converter is not fixed; it is fully adjustable via onboard trimpots. This modular design allows us to fine-tune the power supply for different components. The six total regulated outputs across the two PDB2 units are strictly allocated to isolate noisy motors from sensitive logic boards. PDB2 Unit 1 utilizes two outputs to power the heavy-duty servos on the manipulator arm, while its third output powers the first servo of the camera's pan/tilt mechanism. PDB2 Unit 2 allocates one output for the second camera servo, while the remaining two outputs provide highly stable logic power to the Raspberry Pi and the Fiber Optic media converter.

3.3.4. ROV Control System

To execute all operational tasks reliably, our company utilizes a custom-designed autopilot board based on the STM32F437 microcontroller. This custom flight controller simultaneously processes pilot commands from the Ground Control Station (GCS) and data from onboard sensors to stabilize the vehicle and output precise PWM signals to the Electronic Speed Controllers (ESCs). The board features 16 independent PWM outputs to independently drive the eight thrusters, mission-specific servos, and underwater lighting systems. A Type-C port provides power and establishes a high-speed data link with the companion computer. A Micro SD port is integrated to log system data during missions for post-test hardware diagnostics. Furthermore, I2C, UART, SPI, and CAN Bus ports are included to handle current sensor communication and provide a flexible infrastructure for future modular upgrades.

The flight controller features two embedded BMI088 6-axis IMUs to measure real-time orientation on the roll and pitch axes. These sensors possess a high tolerance for mechanical vibration. Utilizing them in a dual configuration filters out high-frequency motor noise, increases data accuracy, and provides critical hardware redundancy. They communicate with the processor via a high-speed SPI interface. For yaw axis stabilization and precise heading accuracy, a Matek Systems RM3100 magnetometer is integrated into the architecture. By mounting this high-quality sensor externally, it is completely isolated from the electromagnetic interference and artificial magnetic fields generated by the ROV's internal high-current lines and motors. It communicates with the flight controller via the CAN Bus network. Additionally, for Z-axis (vertical) stabilization, a Lenta Marine M300 pressure sensor measures hydrostatic pressure for accurate depth-holding, interfacing with the system exclusively via I2C.

The propulsion system is driven by Degz Blu30A Electronic Speed Controllers. These ESCs convert the incoming DC power into 3-phase alternating current to operate the brushless motors, precisely controlling their speed and rotational direction. The system utilizes PWM signaling: 1100 μ s for full-reverse, 1500 μ s for neutral (stop), and 1900 μ s for full-forward thrust. Based on our power architecture and the operational current draw of our thrusters, the 30A continuous current capacity provided by the Blu30A ESCs is entirely sufficient to operate at peak performance without compromising system safety.

To manage high-level processing, a Raspberry Pi is integrated as the companion computer. It acts as the primary communication bridge between the ROV and the surface, compressing high-resolution digital video from the cameras in real-time and routing incoming telemetry commands to the autopilot board via a USB connection. For data transmission to the surface, our system relies on a fiber optic infrastructure rather than traditional copper ethernet cables. Standard copper cables suffer from signal attenuation over long distances and are highly susceptible to electromagnetic interference (EMI) from the thruster power lines, which can cause severe data loss and video freezing. Because fiber optic systems transmit data via light signals, they are 100% immune to electrical noise. This hardware choice guarantees zero-latency communication and maximum bandwidth, ensuring uninterrupted multi-camera streams and stable telemetry to the GCS regardless of tether length.

3.3.5. Topside Electrical System

The topside control station is designed for operational simplicity and safety compliance. The setup consists of a custom topside control box and a laptop. To ensure precise maneuverability, the pilot operates the ROV using a standard game controller connected to the laptop.

For data management, the control box houses the surface fiber media converter. This unit enables bi-directional optical communication through the tether.

It translates incoming optical signals into a standard Ethernet connection to deliver low-latency video and sensor data to the laptop, while simultaneously converting and transmitting the pilot's controller inputs back down to the ROV's control system.

For safety, the topside box features an Emergency Stop (E-Stop) system to adhere to MATE safety protocols. Rather than routing the main ROV power directly through a mechanical switch, the E-Stop button triggers an 80-amp relay. Given our system's maximum continuous draw of 25A, this 80A rating provides a massive safety factor, completely eliminating the risk of contact welding.

Furthermore, a 30-amp main system fuse is integrated directly into the topside box. Thanks to the surface placement of this main fuse, power is cut off in the event of any short circuit, whether inside the vehicle body or along the 16-meter connecting cable. This relay and topside-fuse architecture safely isolates the high-current path, maximizing both operator safety and component reliability.

3.3.6. Tether

The tether serves as the critical umbilical cord of the ROV, facilitating high-power delivery, zero-latency data transmission, and pneumatic supply within a single expandable braided mesh sleeve. Its internal composition consists of four highly flexible 4 pieces of 8 AWG copper cable in parallel (two for positive VCC, two for GND), a single armored fiber optic data line, and two 4.5 mm polyurethane pneumatic tubes.

The length of the tether has been determined to be 20 meters. Transmitting power over a 20-meter distance naturally introduces voltage drop due to the internal resistance of the copper conductors. To mathematically justify our dual parallel wiring configuration, we conducted a calculation for maximum load of 25A. The round-trip loop resistance R_{tether} for a single 8 AWG conductor pair across a 20-meter length is approximately 0.0824 ohm. By deploying two parallel 8 AWG lines for both the VCC and GND channels, the total system resistance is halved to exactly 0.0412. Using Ohm's Law $V=I \cdot R$, the exact voltage drop at peak operational load is calculated as $V_{\text{drop}}=25\text{A} \cdot 0.0824 \text{ Ohm}=2.06 \text{ Volts}$ for a standard single 8 AWG pair. Conversely, our dual parallel configuration yields a highly optimized drop of just $V_{\text{drop}}=25\text{A} \cdot 0.0412 \text{ Ohm}=1.03\text{V}$. To ensure steady-state operation of the internal flight controller and thruster ESCs, we evaluated overall transmission efficiency across standard 12V and boosted 14.8V topside power supply outputs. At a 12V topside supply, a single 8 AWG pair provides 9.94V at the ROV (82.8% efficiency), while our dual setup delivers 10.97V (91.4% efficiency). By combining a 14.8V topside power input with our parallel 8 AWG distribution, we guarantee a 93.0% power transmission efficiency at peak 25A draw. This architecture delivers a highly stable 13.77V directly to the internal electronics, entirely mitigating the risk of logic board brownouts or unexpected ESC resets under full load. While deploying a single 4 AWG copper cable for the power channels would yield a slightly lower electrical resistance than our parallel configuration, it would introduce a severe mechanical bottleneck. A 4 AWG wire exhibits extreme structural rigidity, creating immense hydrodynamic drag that would heavily distort the ROV's physical balance and response time. By strategically selecting two parallel 8 AWG cables, we preserved the heavy-current capability required for our propulsion network while maintaining the physical flexibility necessary for agile maneuvering. Finally, to counter the physical weight of the heavy copper lines and prevent the umbilical cord from exerting an awkward mechanical tilt on the vehicle frame, highly durable floats are permanently attached to the exterior sleeve at precise half-meter increments. This ensures the tether remains completely neutrally buoyant in the water column, preventing it from sinking or snagging on pool floor obstacles.

3.3.7. Software System

3.3.7.1. System Architecture

The software layer of the system architecture is developed using the Python programming language. Python stands out in this field compared to other programming languages due to its easy-to-learn structure, extensive library support, and easy integration into systems. These features of Python provide a significant advantage in the software design process, enabling the creation of a system with high-level efficiency.

MAVLink is a lightweight message processing protocol that enables the secure transmission of telemetry and commands between air, land, and sea vehicles and ground control stations. The Pymavlink library, a Python version of the MAVLink message processing protocol, is used to enable communication between the vehicle and the topside control station. This library ensures the transmission of mission plans, movement commands, and autonomous decision data with minimal delay.

3.3.7.2. Onboard Software & Firmware

ArduSub is open-source autopilot software developed to meet the requirements of underwater vehicles (ROV/AUV), incorporating sensor fusion algorithms and PID (Proportional-Integral-Derivative) control loops. In our vehicle architecture, ArduSub processes high-frequency data from the IMU and depth sensors, ensuring the ROV's stability against underwater currents and pressure changes. Furthermore, thanks to its integrated Stabilize and Depth Hold driving modes, ArduSub detects deviations in the vertical and horizontal axes in milliseconds, instantly optimizing motor thrust distribution. By default, ArduSub software is compatible with industry-standard autopilot boards and vehicle systems.

However, our uniquely designed Alesta V1 autopilot board differs from standard autopilot boards in terms of its microcontroller pinout and sensors. Due to this situation, directly integrating a standard ArduSub firmware into the Alesta V1 hardware is not possible, as it could lead to incorrect pinout mappings and consequently, inability to read sensor data or sending incorrect signals. To overcome this, modifications were made to the open-source code provided by ArduSub according to the architecture of our own autopilot board. During the development process, a hardware file specific to the Alesta V1 board was created in the hardware abstraction layer of the ArduPilot architecture. After the hardware mappings and changes were made, the source code was compiled in a way that was compatible with the architecture of our own autopilot board, creating a custom ArduSub firmware. Thanks to this custom ArduSub firmware, our Alesta V1 board can work fully compatibly with the powerful software offered by ArduSub.

3.3.7.3. Topside Software & Ground Control Station

QGroundControl is an open-source control station software used for controlling, configuring, and monitoring drones, unmanned aerial vehicles, and especially ROV/AUV systems. With its powerful C++ infrastructure and QML (Qt Modeling Language) interface architecture, it offers stable telemetry and parameter management. However, due to the high focus and instantaneous decision-making requirements of competition missions, QGroundControl software proved insufficient to meet our needs. The standard interface's inability to directly integrate object detection outputs added extra screen load for the pilot and reduced operational efficiency. To solve this problem and create a control interface entirely tailored to our needs, we are developing AlestaControl, our own custom Ground Control Station, based on the open-source code of QGroundControl.

AlestaControl leverages the flexibility offered by open-source code to create a unique structure capable of fulfilling competition missions. The software directly transmits the low-latency image from the vehicle's camera to the interface. Furthermore, the transmitted image is recognized as a camera image by the system, facilitating image processing. This also eliminates the need for an additional screen, reducing the pilot's workload.

AlestaControl is also designed with a modular structure that offers ease of use to speed up testing and calibration processes. In this context, thanks to the motor test section integrated into the system and customized according to the motor configuration, the condition of the thrusters can be checked, and pre-prepared shortcuts allow for easy testing of the ROV's movement capabilities such as "surge," "heave," and "yaw," enabling the detection and resolution of any potential problems in a very short time. Figure-11 shows a screenshot of the AlestaControl interface screen.

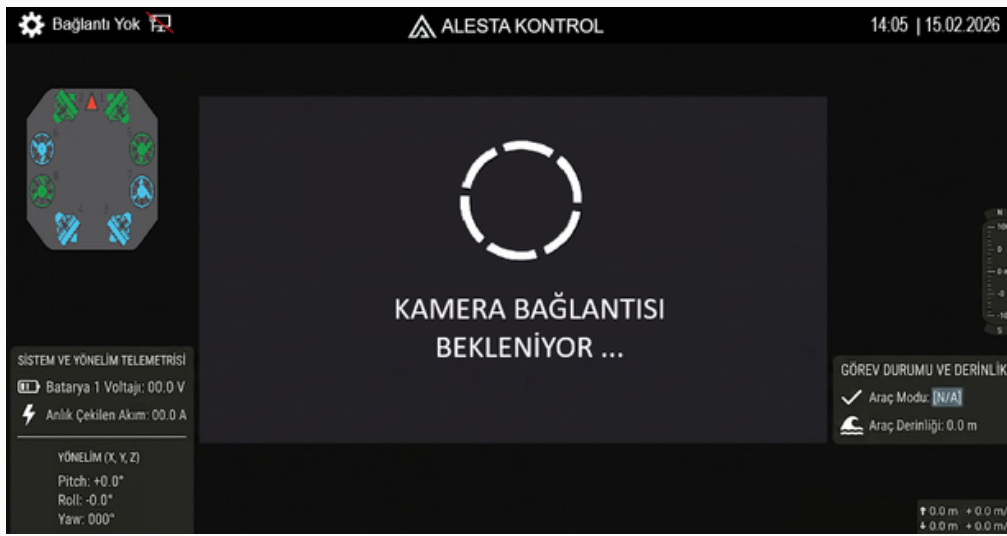


Figure-11

3.3.7.4. Image Processing

In image processing, the OpenCV library, an open-source library with globally accepted standards and strong applications in computer vision projects, is used. OpenCV offers significant advantages for underwater systems thanks to its extensive function support, high processing speed, and easy cross-platform integration. Raw images captured underwater by cameras are directly affected by negative factors such as light refraction, blurring, and color loss. Since this can reduce the success of artificial intelligence and measurement algorithms, the powerful preprocessing and filtering techniques of the OpenCV library are utilized. Contrast equalization (CLAHE), noise reduction (Gaussian/Median Blur), and color space transformations applied to the images make the outlines of underwater objects much clearer. These preprocessing steps significantly improve image quality, maximizing the accuracy of our object detection and modeling algorithms.

The AI-based YOLO (You Only Look Once) algorithm is used to perform object detection tasks in real-time and with high stability. YOLO is one of the most successful algorithms in its field, capable of object detection and tracking in a single step using a deep learning infrastructure, and stands out with its low latency and high accuracy rates.

To ensure the flawless operation of this algorithm, a very comprehensive dataset study was conducted from the very beginning of the regional competition preparations. This dataset, consisting of thousands of underwater photographs, continues to grow exponentially with the addition of new data from the start of the process, ensuring the model's ability to recognize objects accurately even under varying lighting and angle conditions. In our project, we chose the YOLOv10 architecture, one of the most up-to-date members of the YOLO family. The main reason for choosing YOLOv10 is that it increases object detection speed (FPS) and accuracy while consuming significantly less processing power compared to previous versions. This allows for real-time and stable object detection without overloading our surface computer. Figure 12 shows a working output of the YOLO object detection artificial intelligence developed by our team.

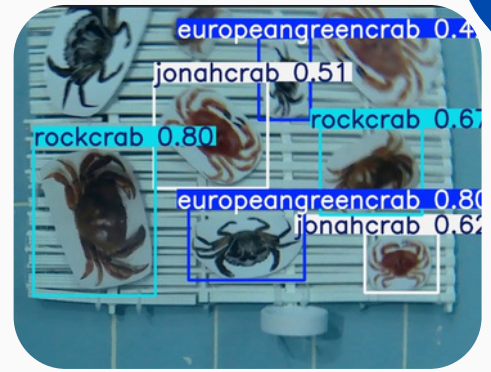


Figure-12

In the process of analyzing the target object, one of the tasks in the competition, we utilize automated 3D modeling applications, which provide a significant advantage to our system. Computer vision-based 3D reconstruction algorithms process camera images of the object taken from different angles to create depth maps and automatically generate a three-dimensional digital model of the object. Thanks to this system, when our pilot approaches the object, our software displays the object's volumetric and geometric structure completely on the screen.

Image-based dimensionality measurement can be used as a supporting method for the same task, integrated with this 3D modeling system. In the dimensionality measurement process, the object's contours are identified using the OpenCV library, and pixels are converted to real-world measurements (cm/mm) using a reference object or camera calibration values. These two systems work in a complementary way; the dimensionality measurement algorithm accurately calculates the object's instantaneous aspect ratios, while the 3D modeling application extracts the object's depth and overall geometry, ensuring the task is completed accurately and completely.

3.3.8. Payload and Tools

3.3.8.1. Vision and Observation System

To provide the pilot with maximum situational awareness during complex mission tasks, our primary camera is securely housed within a transparent waterproof dome at the front of the ROV. This dome design minimizes hydrodynamic drag while offering an unobstructed, wide-angle view of the underwater environment. To eliminate the need to expend thruster energy just to adjust the field of view, the camera is mounted on a custom two-axis pan and tilt mechanism driven by two dedicated servo motors. The first servo controls the horizontal pan axis, allowing the camera to sweep left and right, while the second servo controls the vertical tilt axis for up and down articulation. This dynamic vision system enables the pilot to thoroughly inspect mission props, navigate tight spaces, and monitor the manipulator arm with pinpoint accuracy while the ROV maintains a stable hover.

3.3.8.2. Hybrid-Actuated Manipulator Arm

To successfully complete the physical intervention tasks required in the Ranger class, we developed a highly specialized, hybrid-actuated manipulator arm. By combining electrical articulation with pneumatic gripping, we achieved an optimal balance of dexterity and power. The arm features two electrical degrees of freedom paired with our custom pneumatic end-effector. A high-torque servo motor controls the vertical pitch articulation, allowing the manipulator to reach objects at various angles and heights relative to the ROV's frame. Additionally, a secondary 360-degree continuous rotation servo is integrated into the wrist mechanism to provide unlimited roll capabilities. This provides a critical mechanical advantage for specific mission requirements such as twisting latches, turning valves, or perfectly orienting asymmetrical payloads before placement. The actual grasping mechanism is powered by our custom topside-supplied pneumatic system. Driven by a double-acting pneumatic cylinder operating at a highly efficient 35 PSI, the gripper opens and closes to secure objects. This hybrid design is a major engineering trade-off that works entirely in our favor: the electrical servos provide the intricate twisting and lifting dexterity required for the mission, while the pneumatic cylinder provides a stall-free holding force to securely grasp heavy payloads without violating our power budget.

3.3.8.3. Vertical Profiling Float

Storm is a 2.7 kg autonomous, tetherless profiling float engineered for energy-efficient vertical exploration through the water column. As a specialized non-ROV payload, it operates via an internal mass-displacement buoyancy engine rather than traditional thrusters, allowing it to transition seamlessly between positive, neutral, and negative buoyancy states. The primary pressure vessel consists of a 400 mm long, 110 mm inner diameter plexiglass tube. This hull is completely sealed by custom-lathed 7075 aluminum end-caps and a redundant dual-layer O-ring system to ensure maximum watertight integrity at depth.

Vertical motion is achieved through a core actuator consisting of a NEMA 17 stepper motor driving a power screw and a medical-grade syringe. By drawing ambient water in through a bottom penetrator, the float increases its density to initiate a dive; expelling the water restores positive buoyancy for a controlled ascent. To ensure passive vertical stability during these profiles, a 340 mm internal tray acts as a modular spine to secure the electronics and motor. The vehicle utilizes an aggressively low Center of Gravity (CoG) to create a strong righting moment, which is achieved by placing metal ball-bearing ballast and the heavy aluminum interface cap at the bottom of the hull.

The onboard electrical suite is specifically designed for safety, precise actuation, and wireless data telemetry. The system is powered by a 9S NiMH battery pack, safeguarded by a 3A inline fuse and a custom 3.3V switching regulator for logic circuits. To maintain the hull's absolute seal, a magnetic reed switch triggers an internal relay, enabling contactless power activation from the outside.

For precise autonomous depth control, an ESP32 microcontroller processes real-time hydrostatic data from a Lenta Marine M300 pressure sensor. It executes a closed feedback loop, commanding a TMC2209 stepper driver to precisely micro-step the syringe mechanism. Additionally, the ESP32 utilizes its onboard Wi-Fi capabilities to establish a wireless link with the surface control station, broadcasting live depth and diagnostic telemetry during pool deployments.

4. BUILD VS BUY

Our engineering team utilized a strict decision matrix to determine whether to custom-manufacture (Build) or purchase commercial off-the-shelf components (Buy). Our primary goal was to maximize educational value and mission specificity while never compromising on core system reliability and safety.

4.1. Components We Chose to Build

Custom Autopilot Board (STM32F437)

Pros: Allowed us to design the exact physical footprint required for our electronics enclosure. Eliminated unnecessary I/O ports found on commercial boards, saving space. Provided an immense learning opportunity in microcontroller architecture and firmware porting.

Cons: Highly time-consuming. Introduced the risk of complex PCB routing errors and required extensive troubleshooting to port the control software perfectly.

High-Current Power Distribution Boards (PDBs)

Pros: Tailored specifically for the Ranger class 12V power limit. Allowed us to implement custom EMI mitigation strategies (like guard rings) and place isolated fuses exactly where our subsystem branches needed them. Vastly cheaper than commercial high-current PDBs.

Cons: Routing high-current traces requires advanced PCB layout skills and carries the risk of thermal failure or trace melting if miscalculated.

Hybrid Manipulator Arm (Servo + Pneumatic)

Pros: Commercial underwater arms are prohibitively expensive and draw massive stall currents. Our custom build perfectly balances dexterity (electrical servos) with a 0-Amp static holding force (pneumatic cylinder). Geometrically optimized for specific 2026 mission tasks.

Cons: Required iterative 3D printing and machining to achieve the necessary structural integrity. Fine-tuning the pneumatic sealing and mechanical linkages was labor-intensive.

4.2. Components We Chose to Buy

T200 Thrusters (Blue Robotics)

Pros: Industry-standard reliability and guaranteed watertight integrity. Manufacturing custom brushless DC motors and sealing them for depth is beyond our current machining capabilities. Buying these provided known thrust curves and saved hundreds of hours of development time.

Cons: High financial cost. As a commercial product, we had to design our frame mounts around their fixed physical dimensions rather than customizing the thruster to our frame.

Pneumatic Safety Components (Compressor, Regulator, PRV)

Pros: Safety. When dealing with compressed air, relying on ISO-certified, mathematically tested industrial components is a strict safety requirement. Buying these guarantees fail-safe operation and prevents catastrophic pressure line explosions.

Cons: Industrial pneumatic fittings can be bulky, requiring us to carefully manage space on our topside Ground Control Station.

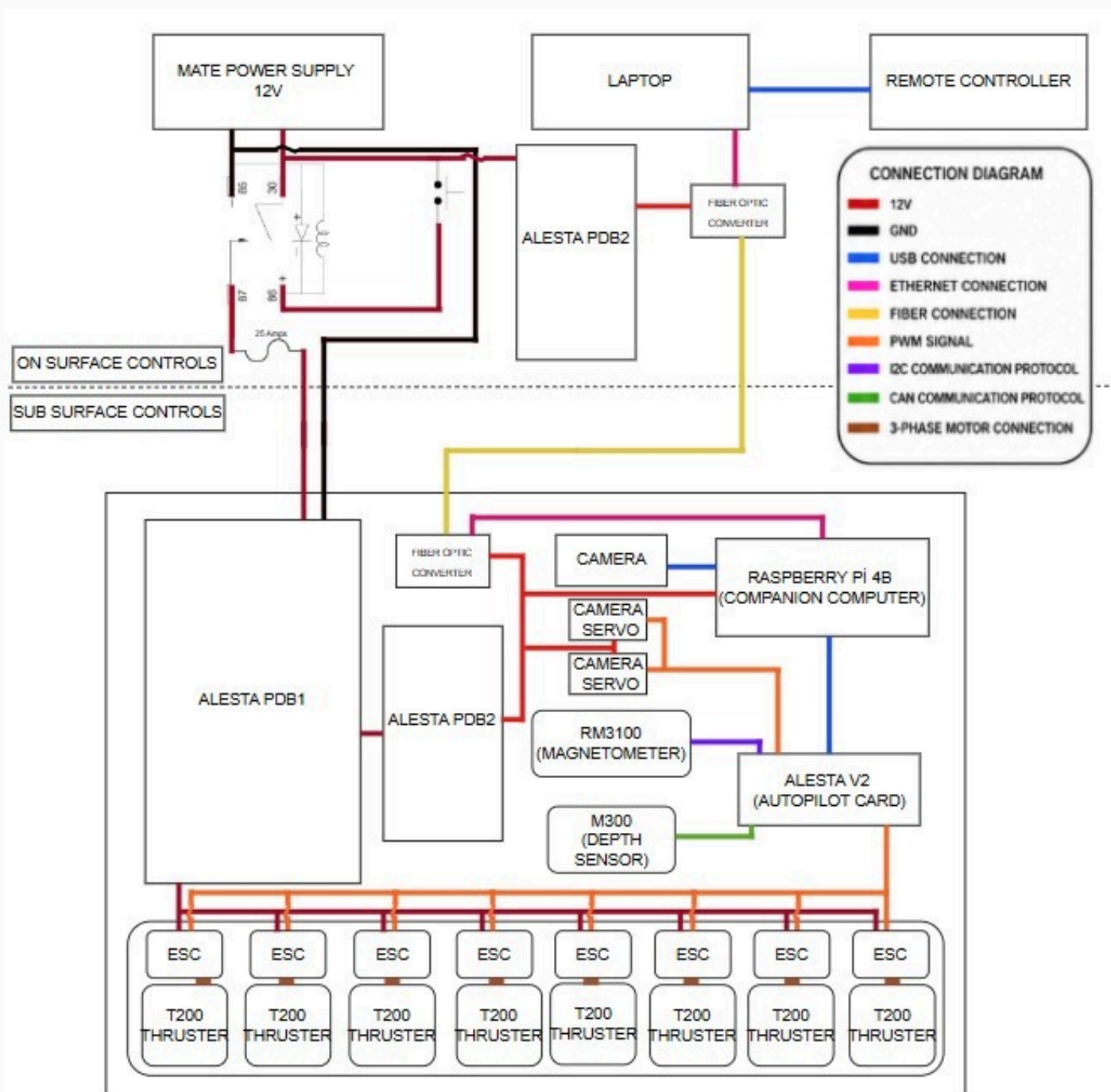


Figure-13

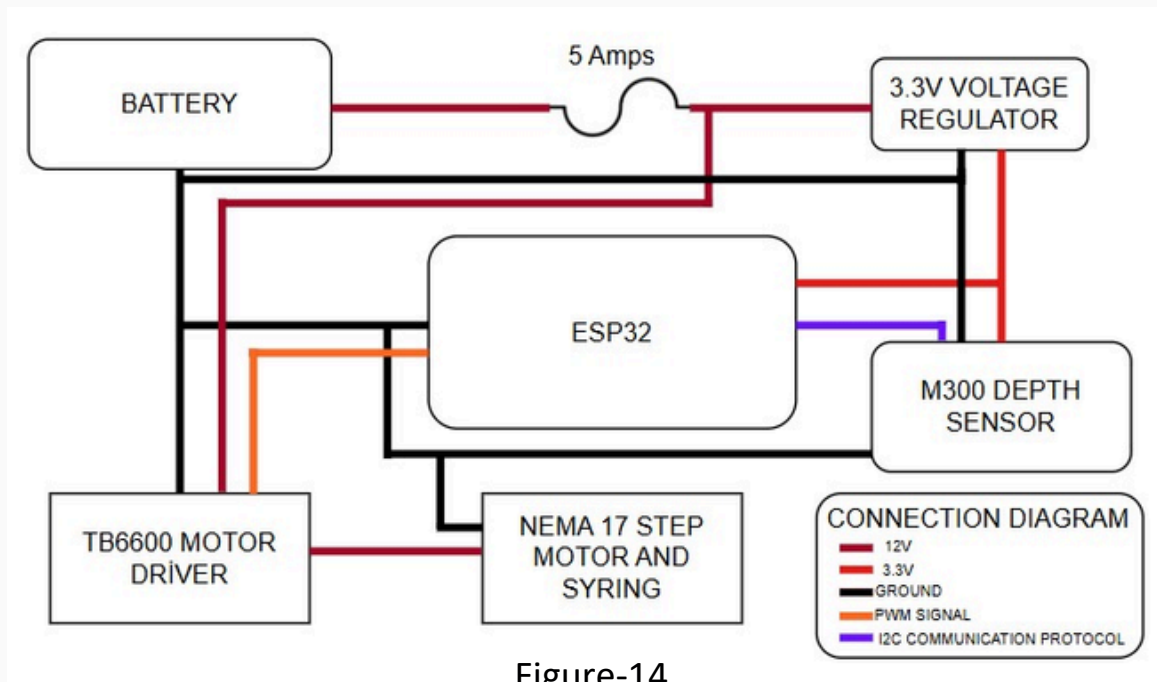


Figure-14

5. TESTING AND TROUBLESHOOTING

 Hazard	 Probability	 Effect	 Interjection
Water leak	Medium	High	Use of O-ring seals, epoxy insulation, and waterproof connectors
Short circuit	Low	High	Use of fuses, complete insulation of cables
Engine failure	Medium	Medium	Maintenance of a spare engine and conduct of testing procedures
Cable breakage	Low	High	Use of flexible cables and provision of appropriate cable lengths
Emergency stop system error	Low	High	Conducting system tests prior to the competition
Mechanical part loosening	Medium	Medium	Screw fastening and regular inspection
Loss of image underwater	Medium	Medium	Ensuring camera connections are redundant and protected
Overheating	Low	High	Ventilation and Fuse Protection

Figure-15

Testing is a core part of our Iterative Engineering Cycle. To ensure absolute reliability we use a comprehensive two-phase testing approach and rely on real-world data to guide our design changes.

5.1. Testing Methodology

Our testing methodology is divided into two strict phases: dry testing and wet testing. During dry bench testing, all custom PCBs are rigorously checked with multimeters and monitored with thermal imaging under simulated loads to ensure electrical stability. Concurrently, the topside pneumatic system undergoes a 10minute static pressure test at 35 PSI to verify the absence of air leaks in the lines and fittings. Once dry testing is successfully completed, the vehicle proceeds to wet pool testing. We initially balance the ROV's natural buoyancy with high-density weights. Following this, we execute aggressive underwater maneuvers to monitor the transient current spikes of the T200 thrusters, ensuring maximum dynamic loads do not overwhelm our electrical infrastructure.

5.2. Subsystem Testing Data

To tune the ESP32's depth-hold PID algorithm for our autonomous profiler, Storm, we tested its syringe actuator in a deep tank to map the exact water volume needed for a safe descent. When the syringe is completely empty (0 ml intake), the float maintains a positive buoyancy of +45g and rests stably at the surface. Drawing in exactly 25 ml of water achieves perfect neutral buoyancy (0g), allowing the vehicle to hover securely at 0.00 m/s. At its maximum intake of 60 ml, the float reaches a negative buoyancy of -35g, resulting in a smooth, controlled descent velocity of 0.28 m/s until the PID algorithm locks it at the target depth.

5.3. Troubleshooting Case Studies

During initial pool testing, our original copper Ethernet tether suffered from severe video lag and data packet loss whenever the pilot engaged full thruster power. We determined that the massive currents from the thrusters were inducing Electromagnetic Interference (EMI) across the copper data lines. To solve this, we completely transitioned to a fiber optic tether system. Because fiber optics transmit data via light waves, they are fundamentally immune to EMI, which permanently resolved our video and telemetry latency issues.

6. SAFETY

SAFETY CHECKLIST

Vehicle Safety

- ☒ Sharp corners get rounded.
- ☒ Vehicle is designed to be completely watertight, suitable for underwater conditions.
- ☒ Water ingress is prevented by using rubber seals at the body and lid connection points.
- ☒ Waterproof penetrators are used to ensure safe cable entry and exit points within the vehicle. This isolates the motor and sensor connections from the external environment.
- ☒ To prevent damage from irregular cable movement, fastening elements are used and the cable layout is optimized. This reduces the risk of both mechanical damage and water contact.

Electronic System Safety

- ☒ To protect electronic components, the entire system is located within a closed and insulated space.
- ☒ To reduce the risk of possible short circuits, connections are insulated and appropriate cable selection is made.
- ☒ Furthermore, precautions have been taken against sudden current changes in the system, ensuring the safe operation of the components.
- ☒ The placement is designed to completely prevent contact of electronic equipment with water.
- ☒ A fuse is added to prevent excessive current draw.

Emergency Button

- ☒ The control station includes a button connected to a relay designed for use in emergencies.

Pneumatic Safety (Topside-Isolated)

Emergency Shut-Off

A manual 2/2 shut-off valve is installed immediately after the topside compressor, allowing the deck crew to instantly isolate the air supply in an emergency.

Pressure Regulation and Relief (PRV):

The working pressure is mechanically limited to 35 PSI by a regulator equipped with an analog gauge for visual inspection. As a redundant fail-safe, an in-line Pressure Relief Valve (PRV) set to 50 PSI will automatically vent air if the regulator fails, preventing the 145 PSI-rated polyurethane tubes from ever over-pressurizing.

Thruster Shrouds

All eight thrusters are fully enclosed with robust mechanical shrouds (propeller guards). This prevents accidental finger contact during deck testing and protects the propellers from entangling with pool debris or mission props.

Ergonomic Finishing

All machined aluminum edges and plexiglass cuts are meticulously deburred, chamfered, or sanded. Zip-ties are cut completely flush to eliminate sharp protrusions that could cut team members during transport or deployment.

Waterproofing and Isolation:

All critical PCBs and logic components are housed within a pressure-tested, watertight acrylic enclosure sealed with redundant O-rings. Furthermore, PCBs are conformally coated to prevent short circuits caused by internal condensation.

7. BUDGET

Our company is a student-led engineering firm formed by nine dedicated members from Adana Science High School. With seven years of experience in competitive robotics, our team specializes in designing and developing innovative Remotely Operated Vehicles (ROVs) for real-world applications, such as underwater search and recovery operations. Throughout our history, we have consistently focused on improving both our technical performance and our collaborative teamwork.

To ensure efficient project management and maximize our operational success, each team member is assigned specific roles that perfectly align with their individual strengths. Through this structured approach, we ensure that all aspects of the project are carefully managed across our four main departments. The Software Department develops the vehicle's core algorithms, writes the operational software, and implements artificial intelligence and image processing capabilities. The Mechanics Department engineers the physical design and assembly of the ROV, guarantees watertight integrity and sealing, and manages the vehicle's overall stabilization. The Electronics Department designs the internal electrical architecture, conducts system troubleshooting when problems arise, and handles the direct piloting of the vehicle. Finally, the Public Relations (PR) Department promotes the company across social media platforms, manages advertising campaigns, and secures vital financial sponsorships to support our operations.

Our primary objective extends beyond simply completing competition mission tasks. We view this project as a platform to cultivate practical engineering skills, advanced problem-solving abilities, and effective communication within the team. By continuously learning from our previous experiences, our company remains committed to improving our designs and achieving higher performance standards each year.

8. COST ACCOUNTING

Name	Amount	Price
Fiber Media Converter	1	40,50\$
Raspberry Pi 4 8GB	1	229,52\$
Alesta V1	2	173\$
8 AWG Red Power Cable	40 Meters	77\$
8 AWG Black Power Cable	40 Meters	77\$
M300 Pressure Sensor	2	450\$
RM3100 CAN Magnetometer	2	261\$
CAN Digital Power Monitor	2	93,38\$
Microsoft Xbox Controller	1	101,26\$
Shielded Fiber Optic Cable	50 Meters	10,35\$
Degz BLU30A ESCs	8	152\$
PDB1	2	52,30\$
PDB2	4	136,90\$
T200 Thrusters	8	1.840\$
Nema17 Stepper Motor	1	13,46\$
Stepper Motor Driver	1	2,43\$
35KG Digital Servo Motors	5	117,90\$
Plexiglass Tube and Dome	4	225\$
Aluminum Plug	4	112,50\$
TOTAL		4129,50\$

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