RoboSub 2026: VantTec Technical Design Report

UUV VTec - U4

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Abstract

This technical report presents the design and implementation of an autonomous Unmanned Underwater Vehicle (UUV) developed by VantTec for the RoboSub 2026 competition. As a first-time physical participant, the core strategy focuses on system reliability and consistent execution of baseline tasks over mission complexity. To support this approach, a robust mechanical rib-cage chassis is paired with an asymmetric buoyancy configuration for passive stabilization. The electrical architecture utilizes a custom power distribution PCB and a dual-battery parallel setup to maximize operational runtime. The software stack, built on ROS 2 Humble, employs a modular finite-state machine for mission logic, an Adaptive Sliding Mode Controller (ASMC) for robust trajectory tracking under disturbances, and deep-learning-based YOLO models for real-time underwater perception. System validation through a Gazebo-based digital twin establishes a scalable foundation for future autonomous underwater platforms.

Index Terms—Unmanned underwater vehicle, robotics, autonomy, computer vision, ROS2, finite-state machine.

I. COMPETITION STRATEGY

As a first-time physical participant in RoboSub, the primary objective of the team is to validate the reliability of the vehicle architecture, autonomous navigation system, and underwater control algorithms under real competition conditions. Rather than maximizing mission complexity, the strategy focuses on achieving consistent and stable execution of fundamental tasks while gathering performance data for future iterations of the platform.

The competition approach prioritizes robustness and mission completion over aggressive scoring. The UUV is designed to attempt the basic interaction required for each obstacle in the course, including detection, alignment, navigation, and execution. This allows the team to evaluate the integration between perception, guidance, control, and mission logic subsystems across different scenarios.

To improve reliability during operation, the mission logic follows a modular finite-state machine structure capable of adapting to detection failures and navigation uncertainty. This strategy increases the probability of maintaining autonomous operation despite environmental disturbances and perception limitations.

Additionally, the modular ROS 2 software architecture enables rapid debugging, subsystem isolation, and iterative development during competition testing. The experience obtained from this participation will serve as the foundation for future improvements in localization, control robustness, perception accuracy, and mission complexity for subsequent RoboSub competitions.

II. VEHICLE DESIGN STRATEGY

A. UUV Mechanical Design

The UUV design is based on the 2020 VantTec submarine online participation. The design's main characteristic is the rib cage design. This design allows to properly secure the components inside while shielding them from external impacts. The design also allows a better stability of the vehicle from the strong torque forces applied by the floating and mass centers and manipulation and translation of the vehicle. The changes that allow the improvements include the addition of one more rib for resistance and adding modifications. Narrowing of the submarine dimensions, and simplification of the assembly process.

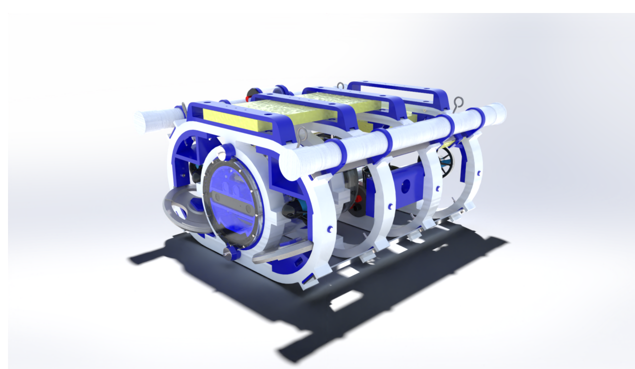


Figure 1: SolidWorks submarine render.

1) Rib cage chasis

The ribs form the main structure of the submarine and make the frame remain 30% more rigid and robust. The material of the ribs, nylamid, was chosen for its strength, the ease in manufacturability, and the ease of making modifications. It can be machined without much difficulty, which allows us as a team to add new holes, screws, or any mounting points that are needed. This is helpful for a first competition vehicle, since many components may require some small adjustments after testing and integration.

The submarine uses the flat metal rails along the four corners of the frame. These rails serve as long mounting surfaces where different components can be attached, such as flotation, supports for other parts, or other mechanisms. This makes the vehicle more modular, since parts and mechanisms can be easily added without changing the whole structure. The rails also help organize the layout of the submarine, which makes future upgrades easier and gives the team more flexibility at the time of integration.

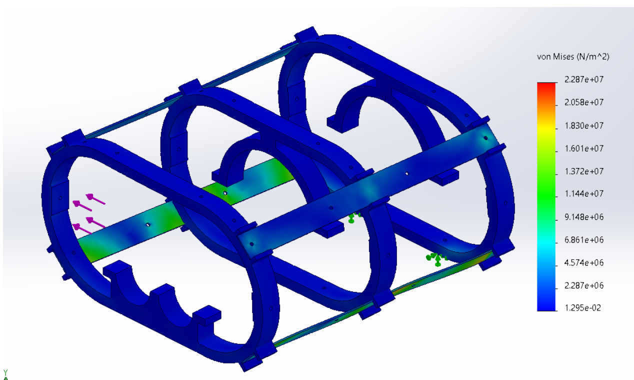


Figure 2: SolidWorks Strain simulation.

2) Electronics rack

The enclosure was designed to be removed from the submarine efficiently, which allows quick access to electronics, seals, and internal components during testing and maintenance. This helps us reduce preparation time and simplifies inspections before and after the submarine trials. Inside the enclosure, the electronic systems are placed on a compact rack formed by two circular plates connected through linear shafts. With the shafts, several components can be mounted in a limited space while keeping the internal layout organized, and secure.

3) Floating System

The offset design of the enclosures creates an imbalance in the vehicle. To counteract the unwanted torques, the vehicle's top side is less dense than the low side heavy side. The polyurethane and the air filled hard balloons give the submarine top side a specific density of 0.22 compared to water. The lower side, filled with batteries and ballast weights, has a specific density of 2.57. The interaction between the floating force and the weight of the submarine negates any pitch or roll instabilities, helping stabilize the vehicle.

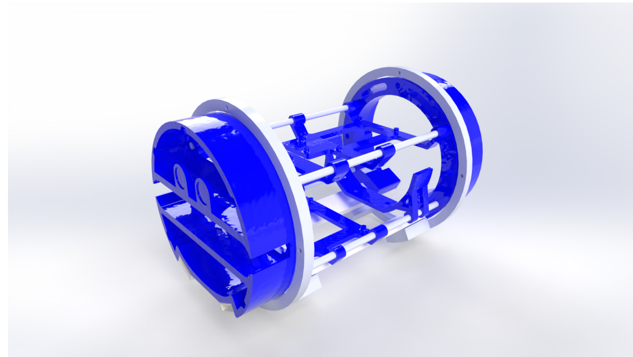


Figure 3: Electronics rack render.

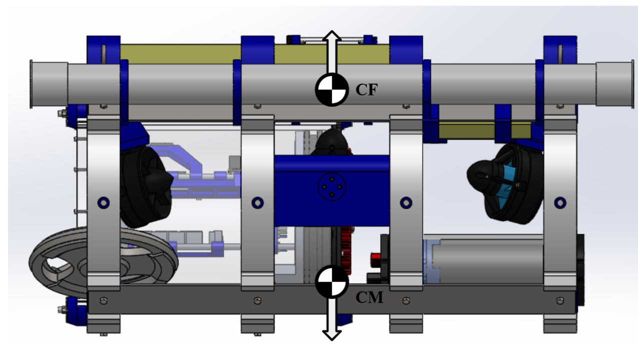


Figure 4: Submarine center of buoyancy and mass.

B. UUV Software Design

The vehicle software is based on ROS 2 Humble. A main node is in charge of the vehicle decision-making and movement definition. Satellite nodes are specialized in the different tasks that the submarine needs to perform.

1) Architecture

The focus of the software architecture is on simplifying the system. The software architecture follows a modular ROS 2 design, where each subsystem is separated into independent nodes responsible for perception, navigation, control, and task execution. This structure simplifies debugging, improves scalability, and allows the UUV to coordinate multiple autonomous behaviours simultaneously. The mission handler operates as the central decision-making node, coordinating perception, navigation, control, and task execution modules through ROS 2 topics and services.

Figure 15 shows the ROS 2 node architecture used in the UUV. The graph illustrates the communication between the perception, navigation, control, and mission systems during operation.

The mission handler coordinates the overall behavior of the UUV. Navigation nodes generate and follow trajectories, while perception nodes analyze camera data and provide obstacle information. Control nodes convert navigation objectives into thrust commands that are later distributed to the thrusters.

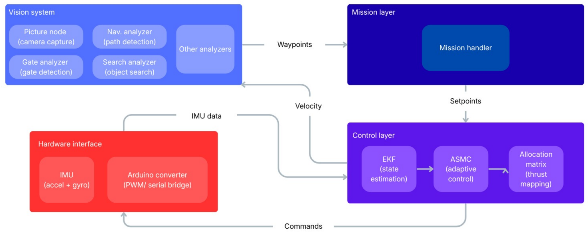


Figure 5: ROS 2 node architecture and communication diagram.

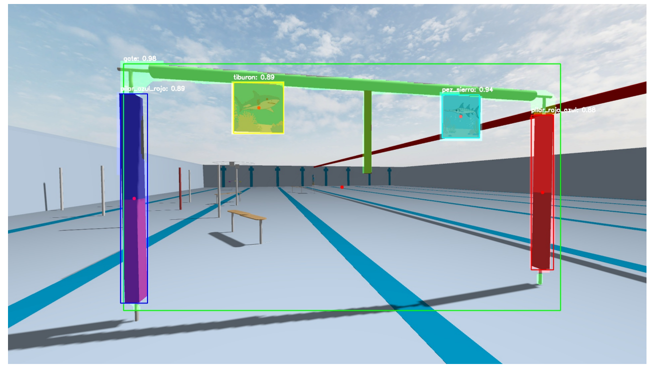


Figure 6: Yolo image segmentation for navigation state.

2) Mission Logic

The mission logic is implemented as a finite state machine (FSM), allowing the vehicle to transition between searching, navigation, alignment, and execution states depending on the current obstacle and task progress. The robot logic consists of a searching, navigation, and action phase. When the searching phase is active, the submarine will scout for the uncompleted obstacles, identifying them via YOLO models.

3) Searching, Navigation, and Action

The submarine will start in the searching phase where it will rotate scouting information of the obstacle course. When enough information is available, the submarine will decide which obstacle to solve entering the navigation state, in which it will navigate toward the desired obstacle using visual servoing, rotating then to align, and finally moving forward to the obstacle. Once in proximity of the obstacle the action state activates.

The submarine will choose its specific node for each obstacle type. The node communicates with the master through ROS 2 services following an event-driven approach instead of continuous polling, reducing computational overhead and improving memory efficiency. All satellite nodes work with a pivot, aligning and execution phase. First, the pivot translates and rotates the submarine in a circular perimeter using the obstacle as the center point. Subsequently, the alignment translates the robot to align it with the key features. Finally, during the execution phase, the UUV carries out the desired task.

The logic uses information provided by a YOLO model trained to identify each object's specific features. This approach allows the UUV to separate general navigation perception from obstacle-specific feature detection, improving both flexibility and detection accuracy. Once the desired trajectory is generated, the control subsystem is responsible for stabilizing and moving the UUV toward the target.

4) Dynamic model and control

The submarine physics are simulated using a custom dynamic model based on Fossen's underwater vehicle equations [1]. Initially, the implementation directly followed the standard Fossen formulation for six-degree-of-freedom underwater dynamics. However, the model was later adapted to better fit the physical behavior and computational requirements of the vehicle [2]. The modification simplified some environments, such as drag, buoyancy, inertia, and thrust response. This adaptation reduced computational complexity and improved controller tuning and simulation stability during real-time testing [3] [1].

SolidWorks Flow Simulation was used to estimate hydrodynamic coefficients required by the model. These coefficients were later integrated into a Gazebo plugin responsible for simulating underwater dynamics and computing the vehicle response to thrust inputs and external forces.

A Gazebo plugin implements these simplified underwater dynamics, computing the vehicle response from the thrust inputs generated by the control subsystem. This simulation environment enabled the team to validate navigation strategies, obstacle interaction, and controller performance before hardware deployment. Figure 7 illustrates the adapted dynamic model used by the simulator.

$$\begin{aligned}\boldsymbol{\tau} = (\boldsymbol{M}_{RB} + \boldsymbol{M}_{A})\dot{\boldsymbol{v}} + (\boldsymbol{C}_{RB}(\boldsymbol{v}) + \boldsymbol{C}_{A}(\boldsymbol{v}))\boldsymbol{v} \\ + \boldsymbol{D}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{g}(\boldsymbol{\eta})\end{aligned}$$

Figure 7: Equation used to calculate simplified underwater dynamics.

To achieve stable trajectory tracking under underwater disturbances and modeling uncertainties, the controller was upgraded from a PID controller to an Adaptive Sliding Mode Controller (ASMC). Sliding mode control was selected due to its robustness against nonlinearities and parameter uncertainty, which are common in underwater environments [4]. The adaptive component allows the controller to dynamically compensate for disturbances and variations in the vehicle model during operation. This significantly reduced overshoot and oscillation during obstacle navigation, improving positioning precision and reducing the probability of collisions. The controller parameters were tuned and validated through simulations developed in Simulink using the adapted dynamic model.

In order to generate smooth trajectories between waypoints, we developed a navigation subsystem called the Line Of Sight (LOS) node. The purpose of this node is to receive a desired target position and generate a feasible path for the UUV to follow. Depending on the navigation requirements, the generated trajectory may consist of linear segments or Bézier curves. The LOS node continuously calculates intermediate reference points and sends them sequentially to the controller for trajectory tracking.

Once the ASMC computes the desired generalized forces and torques required to follow the trajectory, these values are transformed into individual thrust commands by a thrust allocator node. The allocator distributes the desired forces among the available thrusters according to the vehicle configuration matrix. Afterwards, a PWM conversion node transforms the thrust commands into PWM signals compatible with the ESCs and thruster hardware. These PWM values are then transmitted to an Arduino UNO, which interfaces directly with the propulsion system.

Finally, the global position of the UUV is estimated using acceleration and orientation data provided by the inertial measurement unit (IMU). The sensor measurements are processed through an Extended Kalman Filter (EKF), which estimates the vehicle state while reducing sensor noise and drift.

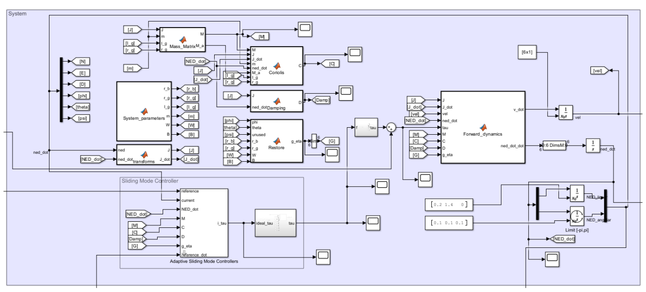


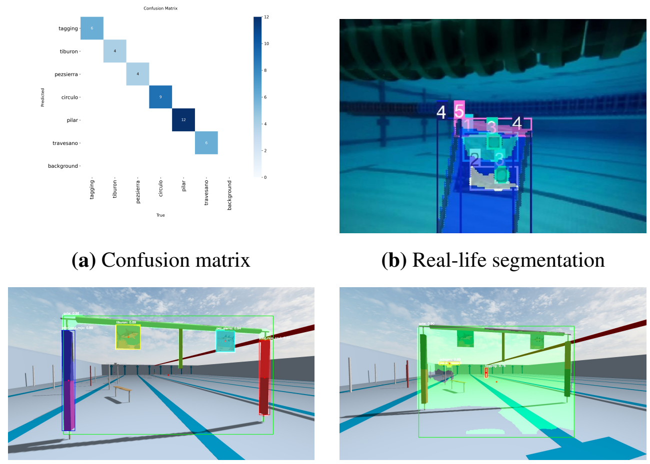
Figure 8: Simulink mathematical simulation for the dynamic model.

5) Perception

To perceive and interpret its underwater surroundings, the submarine relies on deep learning-based computer vision models integrated within the ROS 2 architecture. A forward-facing stereo camera captures live video during operation. The camera stream is managed by a dedicated ROS 2 node called `picture_node`, responsible for maintaining the latest frame available for other subsystems. This event-driven approach reduces memory usage and avoids unnecessary image streaming between nodes. When needed, the latest frame is sent via service request to the client node.

Obstacle detection is performed using YOLO models trained specifically for the competition environments. The perception pipeline is divided into two stages: a general-purpose model for obstacle identification and navigation, and specialized models for detecting obstacle-specific features for task execution [5].

The detected bounding boxes and object centroids are transformed into positional and rotational error estimates used by the navigation subsystem for visual zeroing, alignment, and trajectory correction. If no obstacle is detected, the mission handler activates a search behavior consisting of forward motion and incremental rotations until the target is reacquired. This modular perception architecture improves flexibility, reduces computational overhead, and increases detection accuracy during autonomous operation.



(a) Confusion matrix

(b) Real-life segmentation

(c) Gate state detection

(d) Navigation state detection

Figure 9: YOLO training and detection results.

C. UUV Electrical Design

1) Centralized Power Distribution

For the system's electrical architecture and power distribution, a dual-battery parallel configuration was implemented. The parallel configuration provides the submarine with double the navigation time compared to the series configuration lengthening the mission duration to 1 hour of active operation.

Power is distributed throughout the system through a custom PCB designed specifically for the submarine, which serves as the central power distribution and safety component. The batteries connect directly to the PCB, allowing energy to pass through cut off relays and overcurrent fuses before arriving at the associated ESC or voltage regulator.

The Jetson Nano supplies power directly to the Arduino Uno, leak sensor, and vision camera, while also serving as the primary high-level processing unit. This architecture enables a more organized and controlled power distribution strategy, improving system integration and simplifying energy management across all electronic subsystems. For added safety, battery cables are connected through XT30 connectors, prioritizing robust and safe connections.

2) Thrusters Integration and Control

For the submarine's movement system, 6 Blue Robotics T200 thrusters [6] are used and integrated through their respective ESCs using independent control. The thrusters are controlled through the Arduino UNO, which communicates

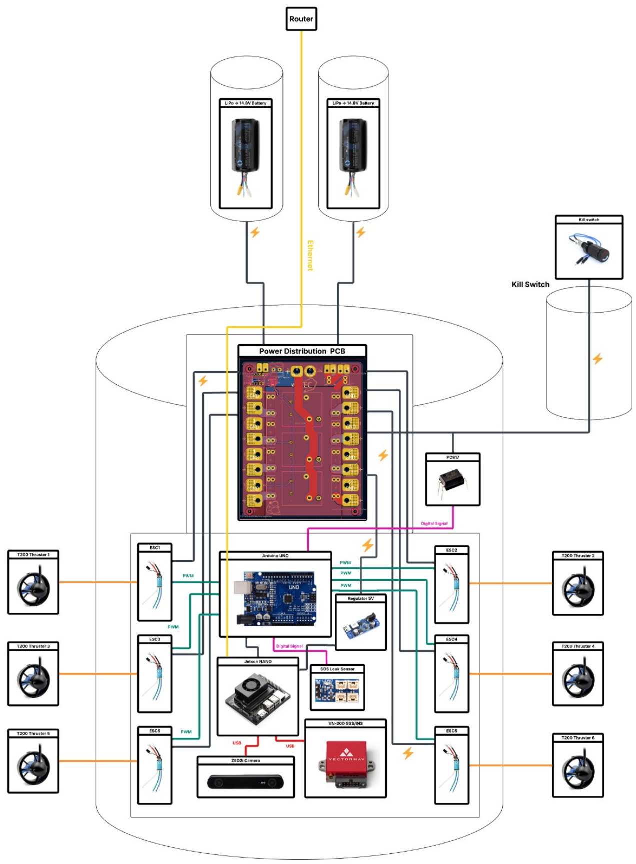


Figure 10: UUV electric and electronic schematic.

directly with the Jetson. The cables entering the main enclosure are fixed to the enclosure lid, allowing the wiring layout to be simplified and reducing human assembly errors. For the wiring between each thruster and its respective ESC, bullet-type connectors were selected to facilitate the assembly process and ensure immediate identification during connection.

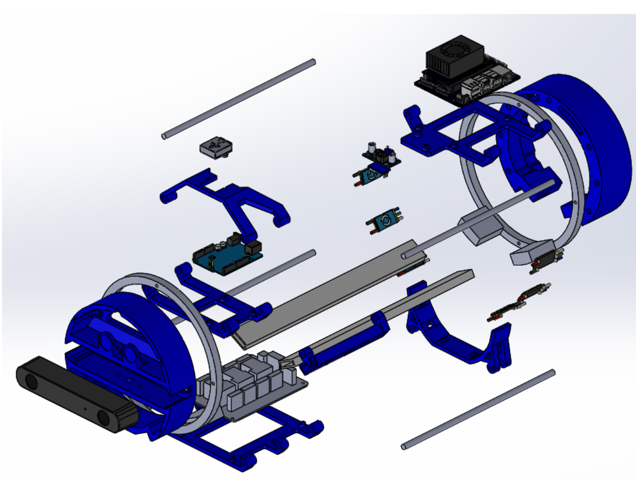


Figure 11: Electronics rack exploded view.

3) Waterproofing and Safety Systems

For the leak prevention system, the implementation of a SOS leak sensor was selected, allowing the software system to be directly notified of any indication of a possible leak. This sensor connects directly to the Arduino UNO which receives the water signal. Once activated, the message is sent to the Jetson via UART initializing the recovery procedure. The leak system implementation contributes to a safer system beyond vacuum testing procedures.

In terms of the wiring entering the enclosures, the use of penetrators is reinforced with 2 component epoxy in order to create a solid waterproof system. The components protected with this coating include the thrusters, the cables leading to the battery enclosures, and the ethernet cable fixed to the lid of the electronics enclosure. As a result, leaks are prevented and cable management becomes significantly easier in terms of organization and robustness.

As a part of the safety systems implemented in the UUV electronic, a kill switch was also developed and integrated directly into the PCB with the purpose of providing a mechanism capable of shutting down the thrusters located away from the motors, featuring a housing that allows its cap to be rotated in order to disable the system. The result is a design that is simple to operate while remaining functional for the submarine's underwater environment.

III. SYSTEM VALIDATION AND TESTING

Before every test, a vacuum test is carried out: after closing and sealing every enclosure, a partial vacuum is created and pressure is measured to confirm that it is not increasing (that is, that it does not let air in). Then, the UUV is submerged for thirty seconds to further confirm the former test. Afterwards, motor mapping is conducted. As motors may be connected in an unintended order, their direction of thrust and their index on the thrust allocator are checked and mapped. The UUV is then ready for testing.

IV. CONCLUSIONS

The team organization and competition strategy for RoboSub 2026 leverage VantTec's multidisciplinary expertise while prioritizing a reliable platform and the Gate and Octagon challenges. The vehicle integrates a robust mechanical frame, a decentralized electrical architecture, and a modular ROS-based software stack. A digital twin enabled software validation despite hardware limitations, achieving successful simulation of all targeted challenges. The lack of time and knowledge led to limiting the robot challenge solving capabilities. Future work will focus on improving actual capabilities with better in-water testing, implementing more powerful algorithms like ORB-SLAM and DeepSORT for better perception and incorporating DVL and hydrophone-based localization for better pose sensing.

ACKNOWLEDGEMENTS

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I. APPENDIX A

Sponsor list

A. Title Sponsors

Técnologico de Monterrey (School of Engineering and Science & Department of Mechatronics) — For their crucial cash support, equipment procurement, and academic assistance for our project.

B. Platinum Sponsors

Collabtree — For providing us with cash and allowing us to participate in the competition in person for the first time.

C. Gold Sponsors

SIEMENS — For granting us the licenses to design the various components of the submarine.

D. Silver Sponsors

Anmark 3D — For providing us with materials for 3D printing.
Meca Labs — For providing us with 3D printing services.
All Ways Sunny — For providing us with epoxy resin and other materials needed to build the vehicle.

II. APPENDIX B

Component Specification

Table 1: Component specifications.

Component	Vendor	Model	Specifications	Qty	Cost (USD)
Frame	Own design	UUV VTec - U4 frame	Nylamid	1	1500
Main enclosure	Blue Robotics	8" Series	11.75 in length	1	598
Secondary encl.	Blue Robotics	3" Series	8.75 in length	2	524
Thruster	Blue Robotics	T-200	16 V @ 24 A	6	1380
ESC	Blue Robotics	Basic ESC	7–20 V	6	240
Battery (thruster)	Blue Robotics	Li-Ion	14.8 V @ 18 Ah	2	850
CPU	NVIDIA	Jetson Nano	GPU + 4 GB RAM	1	250
IMU	VectorNav	VN-200	9-DOF	1	900
Stereo Camera	StereoLabs	ZED2i	1080p stereo	1	499
Leak Sensor	Blue Robotics	Leak Sensor	3.3 - 5 V	1	35
Kill Switch	Blue Robotics	Switch	–	1	28
Software: Vision	–	YOLO v11 / v8	Darknet / Ultralytics	1	0
Software: Control	–	Non-linear PID + LOS	ROS2 node	1	0
Software: Sim.	–	RViz / Gazebo	–	1	0
Team size	–	–	15 members	–	0
HW:SW ratio	–	–	7:10	–	0
Sim. hours	–	–	20:30 h	–	0
Pool hours	–	–	30:00 h	–	0
				Total estimated cost	**$6,639**

I. APPENDIX C

Hardware Test Plan

Hardware Test List	
Situation	**Procedure**
Assembly	1. Count and install each penetrator and cap O-ring 2. Confirm tightness of every penetrator 3. Confirm position and connection of every cable 4. Verify horizontality of camera and verticality of enclosures 5. Screw caps and ensure flatness with flange
Dry test	1. Perform vacuum test to ensure watertightness 2. Seal with 2 layers of electrical tape the floaters
Wet test	1. Check water leaks inside floaters 2. Check for waterdrops inside the enclosures

II. APPENDIX D

Software Test Plan

Software Test List	
Situation	**Procedure**
Assembly	1. Connect batteries 2. Check power to the Power Distro board, jetson, arduino, imu and camera
Dry test	1. Git pull new modifications 2. Perform motor remapping to ensure correct directions and positions 3. Perform camera and imu test 4. Activate killswitch

III. APPENDIX E

A. Community Activities

At VantTec, we strive to make the most of the technological innovations we develop in our vehicles. That is why the UUV, alongside the USV, is part of the AWAS (Autonomous Water Administration System) program, which aims to implement autonomous systems to collect and analyze real-time data that enables efficient water management and prevents ecological risks. The goal is to participate in a project that leverages innovative technology to raise awareness about the conservation of this resource.

In addition to this, we collaborate with educational programs that allow us to share everything we learn through the UUV project with children interested in robotics. At SMALC (Sin Miedo a la Corriente), students who are part of the UUV team actively apply the knowledge and skills developed throughout the project to design and teach robotics and technology classes for children and teenagers between the ages of 12 and 18 every Saturday.

We have also participated in competitions and initiatives focused on technology, innovation, and social impact. One of these is ExpoIngenierías, organized by Tecnológico de Monterrey, where the UUV project has received awards not only for the implementation of innovative technology, but also for its overall approach and the positive social impact it generates.

Lastly, we participated in the Xignux Challenge, an initiative aimed at promoting student-led projects that address Mexico's major environmental, social, and industrial challenges, while aligning with the United Nations' Sustainable Development Goals (SDGs) established in the 2030 Agenda. Through this experience, the UUV project further strengthened its focus on developing technology with meaningful real-world and social impact.

Beyond these initiatives, VantTec also developed C.I.M.A, a workshop focused on menstrual health, self-awareness, and STEM education for children and adolescents, created to address the lack of open conversations surrounding menstruation in Mexico. The initiative provides a safe and educational environment where participants can learn about menstrual care, body awareness, empathy, and respect, while also exploring the role of technology in everyday life. Through introductory programming activities, VantTec members demonstrate how engineering and technology can be applied to health and well-being, encouraging participants to view STEM as an accessible tool for creating positive social impact. By combining health education, empowerment, and technology, C.I.M.A reinforces VantTec's commitment to using innovation not only for technical development, but also for meaningful community engagement and social awareness.

Figure 12: Social Service Classes

Figure 13: Xignux Challenge ceremony award.

Figure 14: Collaborative expo with our Roboboat team.

Figure 15: C.I.M.A workshop.