Roboboat 2026: Technical Design Report

KAPSUL YAZGIT PRUVA

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Abstract: **KAPSUL YAZGIT PRUVA RoboBoat 2026 entry is an autonomous unmanned surface vehicle developed based on experience from previous competition cycles and extensive simulation studies. Designed to meet competition requirements such as reliable navigation, docking, and emergency response, the system follows a modular and task-oriented architecture. The vehicle integrates computer vision-based perception, acoustic event detection, and mission-specific actuation to achieve fully autonomous operation. Control and navigation are managed by a Pixhawk-based autopilot, while perception and decision-making run on an embedded computing platform. This report presents the competition strategy, design rationale, and testing methodologies validating the vehicle's autonomous capabilities for RoboBoat 2026.**

Picture 1. Vehicle Model

1. Competition Strategy

Task 1: Evacuation Route & Return

The USV is configured to operate until all gates are completed. In each cycle, the closest red and green buoy pair to the USV is detected and identified as a passage gate. Using the identified gate as reference, the midpoint between the two buoys is calculated and set as the target point. The USV proceeds toward this midpoint. After completing the gate passage, the same sequence is repeated, and the task is terminated once all gates have been passed.

Task 2: Debris Clearance

Buoys on the course are detected and classified by color. While navigating along the channel, the vehicle follows a safe route by avoiding black obstacles. Evasion maneuvers are performed around detected red buoys while maintaining a safe distance, and a controlled circular route is followed around the green buoy. After the scan of the task area is completed and the relevant buoys are passed, the vehicle autonomously returns to the starting point by following the traversed path.

Task 3: Emergency Response Sprint

In this task, the USV detects the nearest red and green buoy pair using RGB images from the camera to identify the passage gate. The centerline of the

gate is calculated through color-based image processing, and the vehicle passes through the gate in a stable manner along this line. After passing through the gate, the yellow buoy and the color indicator on it are detected. If the indicator is red, the buoy is circled from the right; if green, from the left. After completing the maneuver, the exit gate is detected and the USV completes the course in the shortest time. At the end of the task, the detected indicator color and total task duration are reported.

Task 4: Supply Drop

The vehicle identifies targets in the operation area in real-time using advanced image processing algorithms. The distance to the detected target is continuously monitored using camera data, and the vehicle continues approaching until it enters the effective range of the firing mechanism. Upon reaching the ideal firing distance, the onboard movable aiming mechanism is activated to center the target. Once lock-on is achieved, a water shot is autonomously executed in accordance with the task definition.

Task 5: Navigate The Marina

In the marina task, the dock compartment with a green availability indicator is detected using RGB and depth data obtained from the ZED2i camera. While the appropriate compartment is identified through deep learning-based object detection, the occupancy status of the compartment is verified using stereoscopic depth data. The distance and angular position to the target compartment are calculated, ensuring the vehicle approaches the dock entrance at a perpendicular angle and safely along the centerline. The task is successfully completed when the ideal stopping point is reached through continuous distance monitoring.

Task 6: Harbor Alert

Data from the acoustic detection system is processed in real-time to detect an emergency situation. In this case, the system immediately halts the ongoing task and triggers an emergency interrupt. Depending on the number of detected sound signals, the vehicle abandons its current route; upon detection of a single short sound, it is directed to the emergency response zone defined in Task 3, and upon detection of two short sounds, it is directed to the marina zone defined in Task 5. The navigation process toward the new target is initiated, ensuring the vehicle's safe and controlled transit to the relevant zone.

2.Technical Design
2.1 Computer Vision

Our system combines YOLOv11 as the primary CNN-based detector with RT-DETR, a Transformer-based model excelling at detecting occluded and small objects. For deployment on Jetson Orin NX, we apply INT8 quantization with quantization-aware training and knowledge distillation to RT-DETR. Model outputs are fused using Weighted Box Fusion and refined with Gaussian Soft-NMS, while Test-Time Augmentation enhances multi-scale detection robustness.

Our maritime dataset contains 12,847 images with 48,392 annotations (75-15-10 split), captured using ZED2i stereo camera across university test pool, lake, and marina environments under varied weather and water conditions. The dataset covers eight classes: red, green, and black buoys, gates, targets, docks, and dock availability indicators. Annotations follow a double-annotation protocol, with augmentations including geometric transforms, mosaic, mixup, and maritime-specific effects like water reflection and sun glare.

2.2 Architectural Design Philosophy
The system is built upon a modular and task-distributed architecture. The computational

workload is divided between two main processing units: the Pixhawk Orange Cube handles low-level vehicle control and autonomous navigation, while the Jetson Orin NX is responsible for vision processing (ZED 2i camera) and artificial intelligence tasks. This separation ensures that even if the vision or AI subsystem becomes unresponsive, the vehicle can maintain its fundamental mobility and navigation capabilities through the Pixhawk, thereby significantly enhancing overall system reliability.

2.3 Energy Management and Power Distribution System (PDB)

All system power is supplied from a single centralized source: a 6S 22.2V, 16,000 mAh battery. The Power Distribution Board (PDB) steps down and distributes this high voltage according to the requirements of different subsystems:

Regulation: Both linear and switching regulators are employed to generate 12V and 5V rails. Linear regulators (LM2940 – 12V) are used in noise-sensitive lines to ensure low ripple, while switching regulators (LM2596 – 5V, XL4016 – 12V) are utilized for higher efficiency in power-demanding branches.

Isolation: Noisy loads such as motors and sensitive electronics (MCU, sensors) are powered from separate regulator paths in order to minimize electromagnetic interference and conducted noise coupling.

2.4 Control and Communication Layer

The control and communication infrastructure is based on the MAVLink protocol for data exchange among system components and is realized through a bidirectional communication architecture between the ArduRover autopilot running on the Pixhawk Orange Cube and the NVIDIA Jetson. Communication between the vehicle and the Ground Control Station (GCS) is established via an RFD telemetry module; security-critical control commands are transmitted using TCP with MAVLink2, while low-latency telemetry data and RTK correction data received from the Here 4 GNSS are delivered over UDP, enabling stable vehicle guidance with centimeter-level positioning accuracy.

2.5 Safety and Hardware Emergency Stop (E-Stop)

The safety architecture is designed in a multi-layered and hybrid structure. The system provides both manual and remote intervention capability through a three-stage protection mechanism:

Manual Physical Cut-Off: A physical emergency stop button is installed on the vehicle, directly accessible to the operator. This button mechanically disconnects the main power line from the battery, completely shutting down the entire system.

Remote Hardware-Level E-Stop: An emergency signal transmitted via the LoRa link is processed by an external MCU located on the PDB. Operating independently from the main autonomous software, this MCU directly triggers power relays and cuts off the motor supply at the hardware level, ensuring a fail-safe shutdown even in the event of a software malfunction.

2.6 Mission-Oriented Subsystems:
2.6.1 Intelligent Water Discharge and Pressure Management

Task4: As detailed in Picture 6, the architecture implements a closed-loop control system for controlled water storage, pressurization, and discharge. During system start-up, all components are initialized in a safe state. To prevent unintended water discharge and pressure buildup, all valves remain closed while the pump and compressor are deactivated. Before entering active control modes, the operational states of the valves, pump, and compressor are verified to ensure system availability and provide a fail-safe start.

A) Level Control: The tank water level is continuously monitored using minimum and maximum level sensors. When the water level falls below the minimum threshold, the inlet valve is opened and the pump is activated to refill the tank. Refilling continues until the maximum level is reached, after which the inlet valve and pump are deactivated to maintain system stability during firing operations.

B) Pressure Control: System pressure is monitored via a pressure sensor. If the pressure drops below the operating threshold of **6 bar**, the compressor is activated to restore nominal pressure. Once the pressure returns to the operating range, the compressor is deactivated and the system remains in a ready condition.

C) Fire and Standby Control: After completing the level and pressure control processes, the system enters the READY STATE and waits for a target detection command. Upon receiving the command, the fire outlet valve is opened to discharge pressurized water.During firing, water level and system pressure are continuously monitored. If the water level drops below the minimum threshold or the pressure becomes insufficient, firing is terminated and the outlet valve is closed to protect the system. The system continues operating within this loop until a predefined timeout condition occurs.

2.6.2 Acoustic Sound Detection System
The system captures environmental acoustic signals via an omni-directional microphone on the Jetson platform. These signals are enhanced by a low-noise preamplifier to optimize the SNR and digitized through ADC sampling in compliance with the Nyquist criterion. The digital data is then forwarded to the software layer for continuous monitoring and real-time processing. Digital band-pass filters centered at 600 Hz, 800 Hz, and 1000 Hz perform noise suppression and frequency separation. The Goertzel algorithm efficiently calculates the amplitudes of these target frequencies, which are then compared against predefined thresholds for target frequency validation. This stage filters out background noise to prevent false triggers. Validated signals undergo time-window analysis and blast counting to identify short-duration, high-energy events. Once the acoustic event verification layer confirms the signal meets all temporal and duration constraints, it produces a processed acoustic data output. This final output triggers a software layer emergency interrupt, ensuring reliable, closed-loop real-time decision-making. (Picture 7)

3. Design Strategy
3.1 Design Purpose
A small-scale Unmanned Surface Vehicle (USV) has been developed to autonomously execute tasks for RoboBoat competitions. The vehicle features a compact and stabilized architecture, engineered to integrate various sensors, control units, task mechanisms, and propulsion systems seamlessly.

3.2 Structure and Geometry
The vehicle features a monohull structure, which provides excellent maneuverability while also offering ease of manufacturing and portability.The sensory array and electronic communication modules are integrated into the top deck, while Status Indicator Lights (SIL) and antennas are positioned on the superstructure to ensure optimal visibility and signal range. The entire geometric model was developed using SolidWorks CAD software.

3.3 Dimensions and Mass Distribution
The vehicle's dimensions were determined in strict accordance with the competition regulations, with comprehensive technical drawings provided in the appendices. (Picture 4) Critical components such as batteries and the water tank are strategically integrated within the lower hull to maintain a low Center of Gravity (CoG). This configuration significantly enhances the hydrostatic stability and operational balance of the vessel.

3.4 Material Selection and Fabrication
To achieve an optimal strength-to-weight ratio and exceptional corrosion resistance, composite materials were selected for the hull construction. The fabrication process begins with a CNC-machined XPS foam mold to ensure geometric precision and minimize assembly tolerances. A gelcoat layer is applied to the mold surface to facilitate de-molding and to achieve a high-quality hydrodynamic finish. The hull is manufactured using a hand layup technique, where alternating layers of carbon fiber and fiberglass are impregnated with epoxy resin. Rollers are utilized during the process to eliminate entrapped air (voids) and ensure uniform laminate consolidation. Following the layup, the hull is cured at ambient temperature for a predetermined period

before de-molding. This manufacturing strategy enhances structural durability, optimizes production costs, and ensures reliable performance under maritime competition conditions.

3.5 Structural Analysis and Hydrostatic Conditions

Within the scope of structural analysis, the weights of electronic components and potential static loads during operation were meticulously accounted for. The evaluation of buoyancy and floating conditions was conducted using the Ansys Hydrodynamic (AQWA/Fluent) module. These simulations validate the vessel's stability and structural integrity under various loading scenarios. Detailed analytical results, including stress distributions and displacement data, are provided in the appendices.(Picture 5)
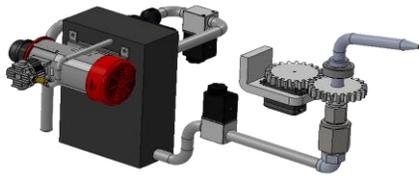
Picture 2. Intelligent Water Discharge and Pressure Management Mechanism

3.6 Mission Mechanism

To execute mission-specific tasks, the vehicle is equipped with an integrated water delivery system consisting of a reservoir, a high-efficiency water pump, an air compressor, a discharge nozzle, and a servo actuator. Water is drawn through an intake port located at the hull's keel using the induction pump. Once the reservoir is filled, the system is pressurized via an onboard compressor to ensure high-velocity discharge through the nozzle. A servo motor is integrated into the assembly to provide precision pointing and directional control for the nozzle, allowing for dynamic targeting during operations. (Picture 2)

4.Testing Strategy
4.1 Simulation Tests

Within the scope of this project, simulation studies were conducted to validate the task algorithms of the developed USV system before transitioning to the real environment. The simulation environment was established on VRX infrastructure using ROS 2 and Gazebo platforms, and the simulation was developed within this environment. In the simulations, the system structure and sensors of USV were modeled, motion commands were transmitted via ROS 2, and heading algorithms along with color-based target detection were tested using camera data. Through this approach, potential errors in the task algorithms were identified in advance, system stability was enhanced, and significant validation was achieved prior to real field tests.
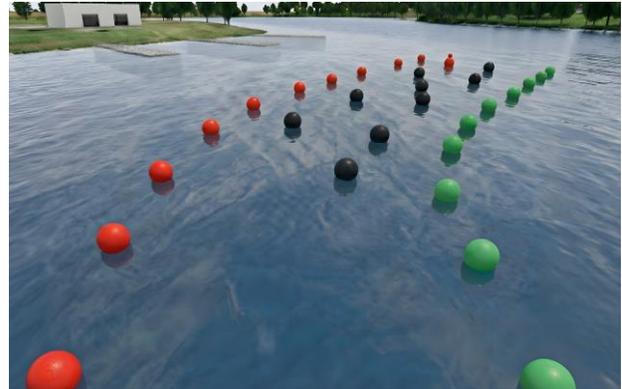
Picture 3. Parkour Simulation

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APPENDIX A
Table1: Material List Table

| Component	Functions	Model/Type	Specs	Cost	Year of Purchase
USV Hull Platform		**Carbon Fiber**	Fabric 93g/m²	**935 USD**	**2025**
RTK Base Station Module	Dual-band RTK GNSS module providing centimeter-level positioning accuracy.	**CubePilot Here 4 Multiband RTK GNSS**	20 Hz RTK fix, cm-level accuracy (<0.01 m)	584 USD	2025
Compass	RTK base station module designed to provide high-precision spatial reference.	**Pixhawk Base Here Module RTK GNSS**	u-blox F9P dual-band RTK GNSS	257 USD	2025
Controller Unit	Professional-grade flight control system for advanced autonomous operations.	**Cube Orange+ Autopilot Standard Set**	STM32H743 (32-bit ARM Cortex-M7, 480 MHz)	966 USD	2025
Teleoperation	Long-range telemetry radio modem for robust communication links.	**RFDesign RFD900x Telemetry Modem**	40 km long-range telemetry, 1 W (+30 dBm)	700 USD	2025
CPU	High-performance computational platform for image processing, AI integration, and control algorithms.	**NVIDIA Jetson Orin NX Developer Kit**	512-core Volta GPU (64 Tensor Cores), 8-core NVIDIA Carmel ARM v8.2 CPU	327 USD	2025
Camera	High-resolution camera for depth sensing and 3D image processing.	**Zed 2i Stereo (IP66)**	5 MP CCD=1/3 inch,F:2.2	3150 USD	2025
Power System	High-capacity UAV battery optimized for multi-rotor endurance.	**Leopard Power 16000 mAh 6S LiPo**	6S 16000 Mah 22.2V 25C	215 USD	2025
Motor Controls	Waterproof brushless Electronic Speed Controllers	**Flycolor Waterproof**	50A Brushless	184X2=368 USD	2025
Propulsion	Underwater propulsion unit (3–6S) capable of delivering 8Kgf of thrust at 24V.	**Degz MitrasUnderwater Thruster**	6S 8Kgf 24V	514X2=1028 USD	2025
Remote Controller	Remote control and receiver system.	**Radiolink AT9S Pro Radio & R9DS**	12-channel 2.4Ghz DSSS/FHSS	343 USD	2025
Water Release Mechanism	Custom-engineered mechanical assembly for executing the designated water release mission.	**Water Release Mechanism**	---	150 USD	2025

APPENDIX B
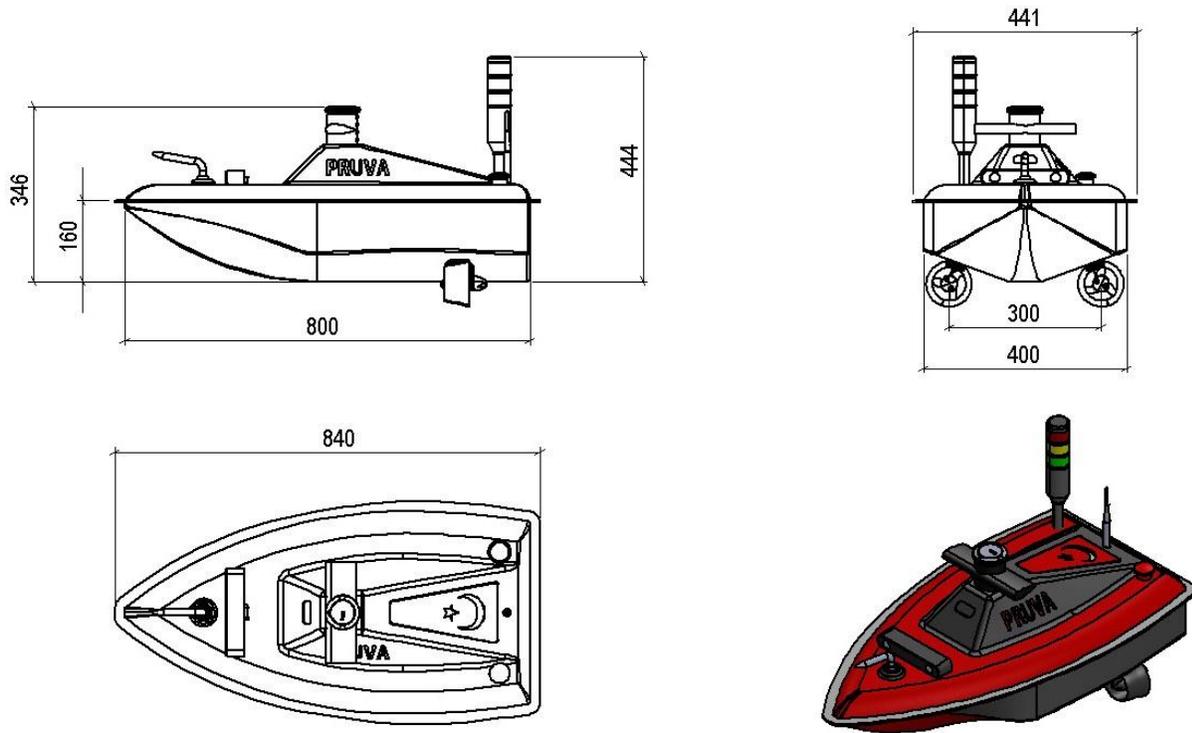
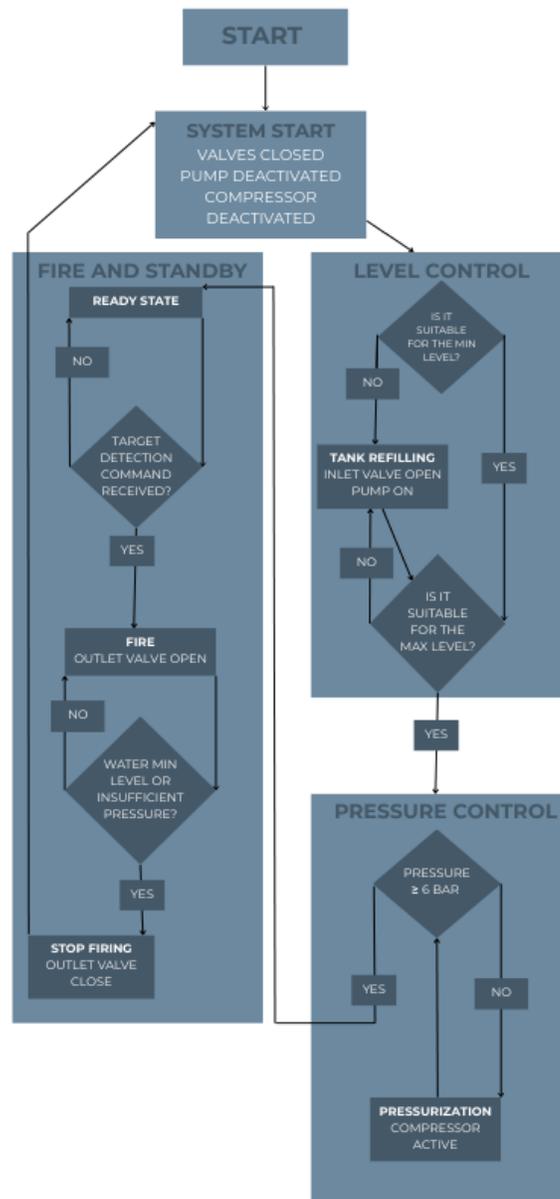All dimensions are in millimeters (mm).

Picture 4. Vehicle Mechanics Technical Details
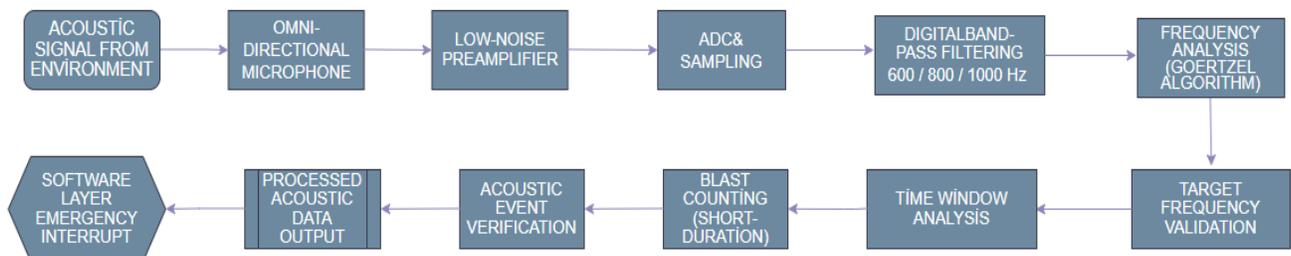
APPENDIX C
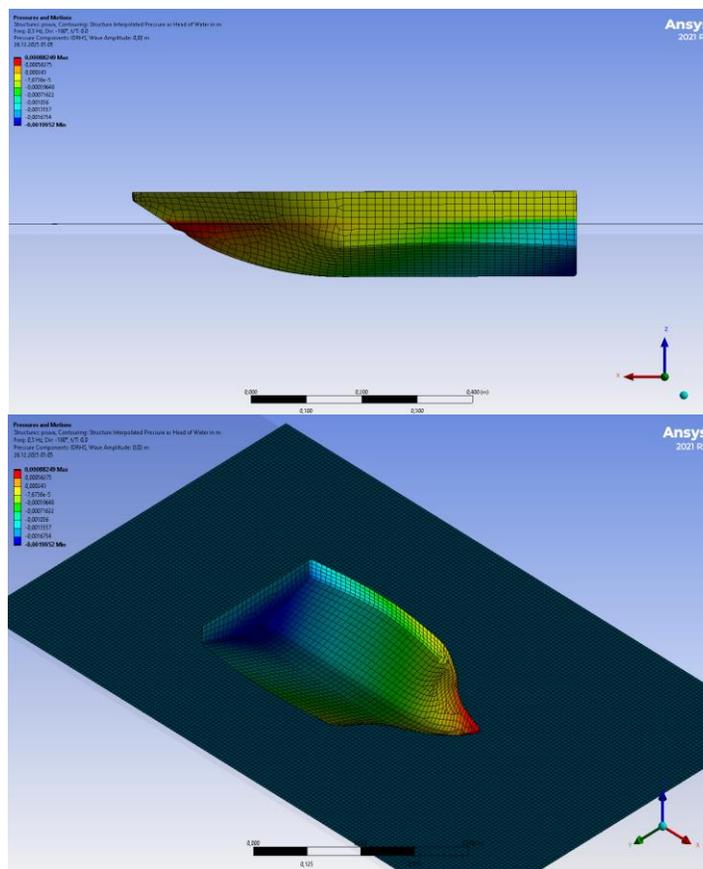
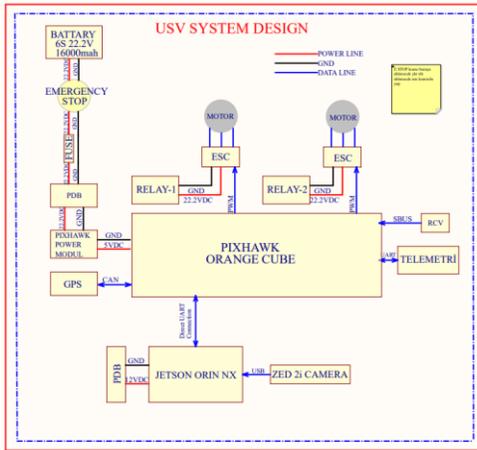*Picture 5. Vehicle Mechanics Ansys Analysis Results*

APPENDIX D

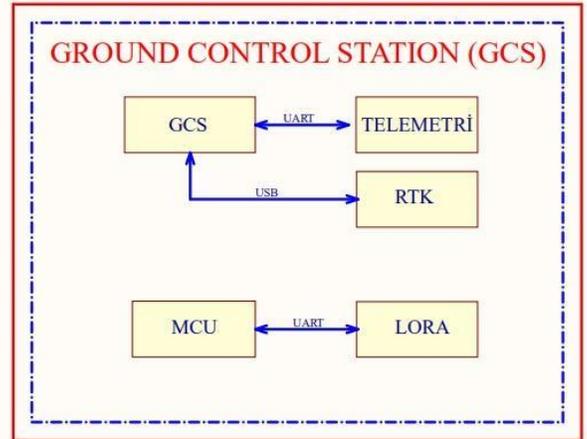*Picture 6. Intelligent Water Discharge and Pressure Management Control Flow Chart*

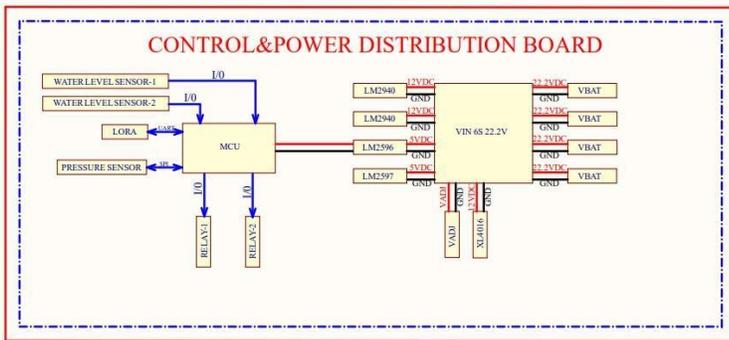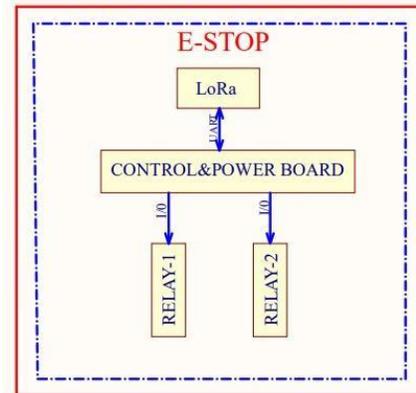*Picture 7. Acoustic Sound Detection System Software Diagram*

APPENDIX E

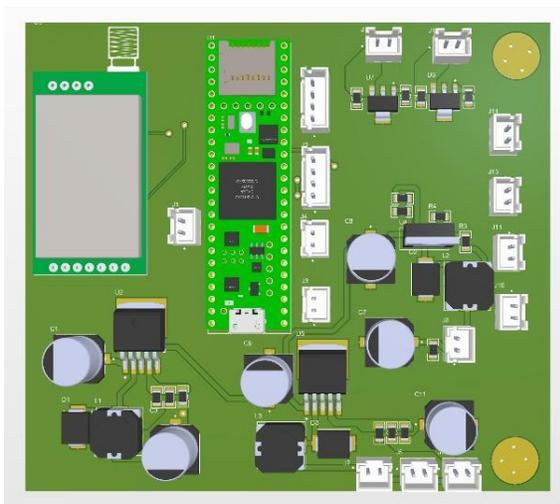Picture 8. General Architecture of the USV

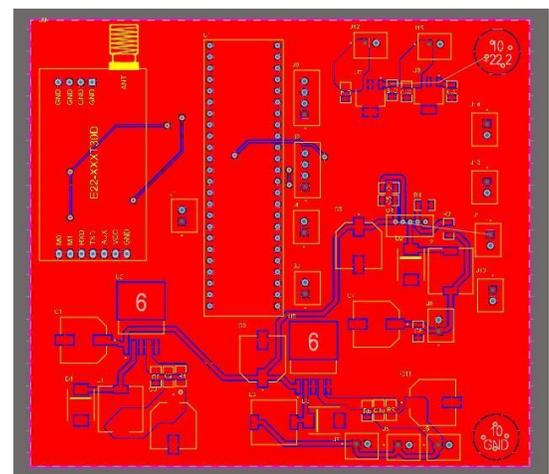Picture 9. Ground Control Station Schematic

Picture10. Control&Power Distribution Board

Picture 11. E Stop Schematic

Picture 12.3D Rendering Of The Populated Control & Power Distribution Circuit Board Assembly

Picture 13. Top-Layer PCB Layout Design For The Custom Control & Power Distribution Board.