Technical Design Report for RoboBoat 2026

PRU-İDA / Piri Reis University

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Abstract - CHAKA USV is a newly developed autonomous Unmanned Surface Vehicle (USV) by the PRU-İDA Team for competition and research in inland waters. This paper presents its design and integration, emphasizing a modular trimaran hull, a four-thruster propulsion layout (two forward + bow/stern lateral thrusters) for precise maneuvering and station-keeping, and a ROS 2–based autonomy stack. Onboard perception combines stereo vision with deep-learning object detection to support navigation and task interaction. CHAKA also includes integrated top and water shooting mechanisms to address competition-specific delivery and engagement scenarios. The platform is engineered for scalable mission execution, and its software and subsystems are validated through staged integration and scenario-based testing focused on control stability, perception consistency, and communication continuity.

Index Terms - Autonomous Unmanned Surface Vehicle (ASV/USV); navigation and control; field tests; mission autonomy

I. INTRODUCTION

PRU İDA is a student-led team under the Piri Reis University Robotics Club, founded in 2023 in İstanbul, Türkiye, to compete in national and international USV competitions. The team is developing a new competition-oriented autonomous USV, CHAKA.

This TÜBİTAK-supported project focuses on original, competition-driven engineering across mechanical design, electronics integration, and autonomy software, with CHAKA optimized for maneuverability, modularity, and mission versatility. It also provides hands-on multidisciplinary experience and supports long-term development in autonomous marine systems.

Mechanical design and production: The vehicle features a trimaran hull designed for stability and maneuverability. Hull molds were 3D-printed and used for carbon fiber composite layup. Directional control is achieved through a rudderless, thruster-based architecture, and hydrodynamic and structural durability tests on the final hull are ongoing.

Electronic and communication studies: The USV communicates with the GCS via a custom interface using telemetry, Wi-Fi, and 4G/LTE links. A Pixhawk-based autopilot handles low-level control, while an NVIDIA Jetson Orin Nano Super runs onboard perception and autonomy. Power is provided through a custom distribution board and a redundant dual 22.4 V, 16,000 mAh battery setup for stable competition operation.

Software and autonomous system development: Autonomy software is developed in Python on a ROS 2 modular architecture. Stereo vision–based perception with deep learning is fused with RTK GNSS/IMU data to generate real-time navigation and mission commands. The stack is validated through scenario-based tests and staged integration for reliable competition deployment.

Test and Simulation Studies: Verification follows a structured plan combining simulation and staged field trials. Subsystems are tested throughout development, with final-phase integrated autonomous missions executed under operational conditions.

CHAKA builds on experience gained with the TALAZ platform in Njord Challenge 2025 and TEKNOFEST 2025. Technical and operational lessons were reviewed and carried forward into the new vehicle's mechanical layout, system integration, and autonomy design, resulting in a more competition-focused platform with improved development efficiency and overall performance.

II. VESSEL DESIGN

The USV design process began with preliminary studies on propulsion, control, and mechanical configuration. Before detailed design, multiple hull forms were assessed, and a trimaran layout was selected for its speed potential, improved stability, and operational flexibility. The resulting dimensions and overall mechanical arrangement of the CHAKA USV are summarized in Figure 1.

Draft (mm): ~100

Length x width x depth (mm): ~1100 x 750 x 330

Projected weight (kg): ~40

Width of a single hull (mm): ~80

Distance between hull centers (mm): ~325

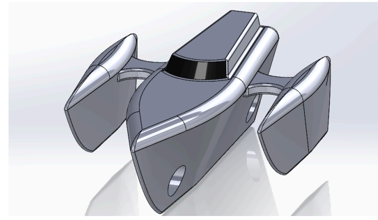

Figure 1: CHAKA USV's mechanical design, 3D rendering

A. Hull Design

The USV uses a trimaran hull optimized for maneuverability, stability, low resistance, and manufacturability. Multiple hull–outrigger geometries were iteratively evaluated, and three alternatives were compared using regression-based assessments and resistance trade-offs; Model A was selected as the best balance of maneuverability, cruising speed, and structural weight, while Models B and C were eliminated due to displacement/robustness and integration limits.

Final dimensions and propulsion layout were set for precise low-speed control and balanced thrust, aligned with applicable standards. Weight and CG analyses applied a 10% margin, supporting up to 40 kg payload within trim/CG limits, and hydrodynamic performance was evaluated using the Slender Body method with resistance trends consistent with expected operational behavior.

Figure 2: Mechanical mold, prototype and final production processes

Prototype fabrication used 3D-printed molds and composite layup (Figure 2). Initial hydrodynamic and load tests verified stability, resistance trends, watertightness, and structural integrity. After integrating batteries and propulsion, system tests confirmed T200/T500 maneuvering performance, enclosure waterproofing, and the emergency kill-switch, with further refinements ongoing for competition readiness.

B. Propulsion

The propulsion system consists of two T500 main thrusters integrated with the hydrodynamic layout, supported by two T200 auxiliary thrusters located at the bow and stern. This bow–stern thruster configuration enables efficient lateral motion and provides precise maneuvering and positioning, particularly at low speeds [1].

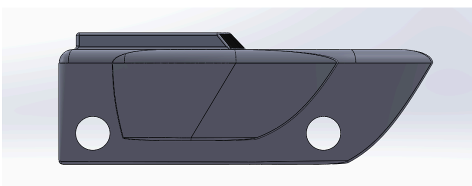

Figure 3: CHAKA USV's thruster system including propulsion, 3D rendering

C. Batteries

CHAKA USV is powered by two 6S LiPo packs connected in parallel (22.2 V nominal, 32 Ah total) to increase capacity and provide redundancy, allowing operation on a single pack with reduced runtime [2]. Charging is performed with a balance-capable smart BMS charger, and 22 mm² power cables were selected based on current and voltage drop tests. Battery voltages are monitored by a microcontroller, and the system includes both remote and manual safety switches as shown in Figure 4.

D. Sensors

The new-generation USV is equipped with advanced sensing and processing components to support robust autonomous operation and reliable perception in dynamic marine environments.

- **Stereo Camera (ZED 2i):** Primary perception sensor providing RGB and stereo depth for real-time detection, distance estimation, and target alignment [3].
- **RTK GNSS (HERE4):** Centimeter-level positioning integrated with Pixhawk V6X for reliable navigation and waypoint tracking [4].
- **Inertial Measurement Unit (IMU):** Autopilot-integrated attitude and motion sensing to support stable estimation and sensor fusion [5].
- **Onboard Processing Unit (Jetson Orin Nano Super):** Runs perception, autonomy, and control modules in real time for responsive onboard decision-making.

E. Hardware Implementation

The hardware architecture of the USV consists of interconnected subsystems including Situational Awareness, Communication, Control, Power Distribution, Propulsion and Battery units as illustrated in Figure 4.

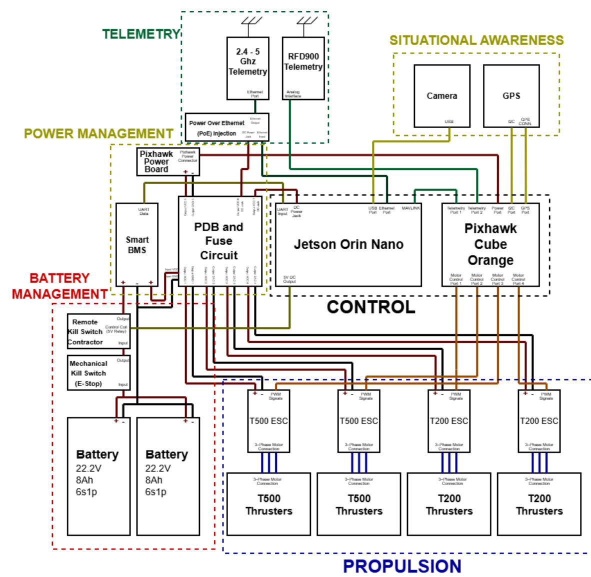

Figure 4: POYRAZ USV hardware system architecture

The situational awareness subsystem integrates the ZED 2i stereo camera and a Pixhawk-compatible GPS. The control unit combines a Jetson Orin Nano Super and Pixhawk V6X, communicating via MAVLink, where Jetson handles perception and autonomy while Pixhawk manages real-time motor control. Communication is provided through

RFD900 telemetry and Wi-Fi for robust data exchange.

Power is managed via a regulator array feeding onboard electronics. Propulsion uses four thrusters (two T500, two T200) with dedicated ESCs; T500 units provide main thrust while T200 units enable directional control. Overall, the modular system supports reliable autonomy and remains scalable for future mission upgrades.

III. SOFTWARE

This section summarizes the USV software architecture, covering mission autonomy, perception and control integration, and the transition to a ROS 2–based distributed framework. It also briefly introduces vision-based image processing for object detection, docking behavior, and operator interaction via the GUI.

A. Software Design

The software stack is developed in Python and runs on a Linux onboard computer using a ROS 2 distributed architecture. Functions are implemented as ROS 2 nodes, with MAVROS linking autonomy outputs to the Pixhawk V6X while safety-critical actuation remains on the autopilot. Perception combines YOLOv8n with ZED 2i stereo depth to estimate object position and distance for navigation and mission logic, as shown in Figure 5.

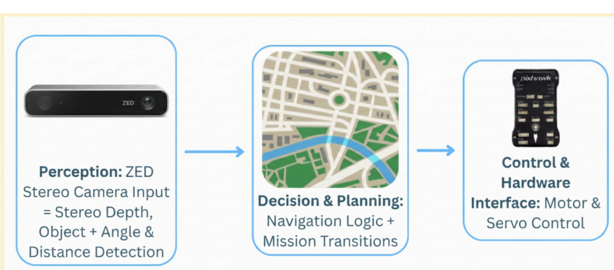

Figure 5: Software design of the USV system

- **Perception Layer:** Runs on the Jetson Orin Nano Super to perform stereo vision–based detection, depth-based distance estimation, and target alignment for autonomy [6], [7]. Figure 6 shows an example of real-time stereo depth and distance estimation.

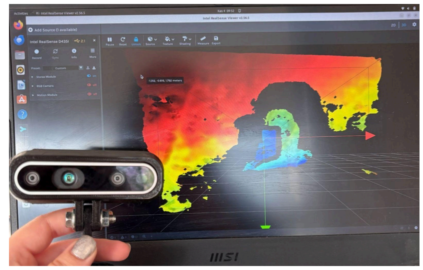

Figure 6: Real-time stereo depth and distance estimation.

- **Decision and Planning Layer:** Generates real-time navigation and mission state transitions from perception and localization data, producing heading and velocity commands [8].
- **Control and Hardware Interface Layer:** Uses MAVROS to interface with the Pixhawk V6X for motor/servo commands and IMU/GNSS telemetry feedback [9].

B. Architecture

The system uses a ROS 2 distributed architecture where high-level perception, mission logic, and navigation run as nodes on the Jetson Orin Nano Super, while the Pixhawk V6X handles low-level motor control and safety-critical functions.

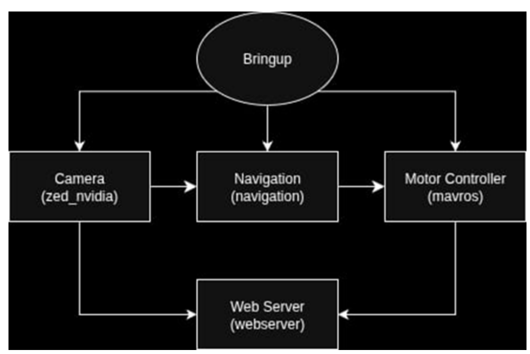

Figure 7: ROS2 Node based design of the USV system

ROS 2 DDS communication ensures reliable data exchange, with MAVROS bridging autonomy outputs to the autopilot [10]. As shown in Figure 7, a centralized bring up coordinates the node-based stack and supports future extensions.

C. Implementation

Software components run as independent ROS 2 nodes on the onboard computer. Perception combines YOLOv8n with ZED 2i stereo depth for real-time awareness, feeding planning for navigation and mission transitions, while MAVROS executes actuator commands. Synchronization and Jetson–Pixhawk reliability issues were mitigated through DDS communication, standardized MAVROS interfaces, and modular design.

D. GUI

The USV Dashboard is the primary web-based GUI for real-time mission monitoring, while Mission Planner is used for low-level configuration. It displays live telemetry, mission progress, waypoints, and vehicle position on an interactive map, streaming data from the ROS 2 stack via lightweight real-time mechanisms [11], [12]. Figure 8 shows the modular panel layout for efficient supervision.

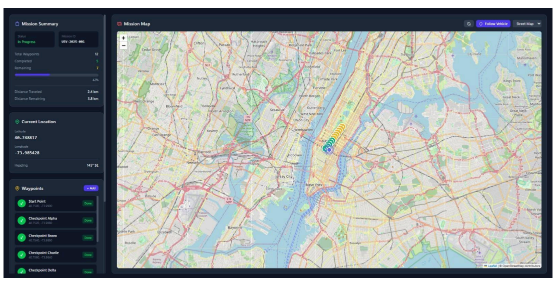

Figure 8: Web-based USV Dashboard for real-time mission and telemetry monitoring.

IV. COMPETITION STRATEGY

The PRU-İDA Team prioritizes reliability over added system complexity under limited preparation time, treating start gate transit as the baseline capability with conservative control and clear fallback behavior. After the gates, tasks are attempted in a staged order using the same autonomy core (vision-based perception, RTK GNSS/IMU localization, and modular mission logic): navigation channel first, then speed challenge only if perception confidence and vehicle health remain stable.

Higher-risk objectives are conditional—supply drop (front payload bay + shooting mechanisms) and docking are executed only when alignment and station-keeping meet strict thresholds—while Harbor Alert is an always-on override that interrupts any task and routes to the commanded zone. Given limited working hours, effort is concentrated on verification and integration hardening, supported by the ROS 2 modular architecture that isolates perception, planning, control interface, and reporting.

V. INNOVATIVE ASPECT

The CHAKA USV presents a fully in-house developed and competition-focused autonomous surface vehicle architecture. Its **trimaran hull combined with a four-thruster, rudderless propulsion system** enables precise low-speed maneuvering, lateral motion, and station-keeping without mechanical steering components. The hull is manufactured using **3D-printed molds and carbon fiber composite layup**, allowing rapid design iteration and structural optimization.

The autonomy stack is built on a **ROS 2–based distributed architecture**, where high-level perception and mission logic run on an onboard computer while safety-critical control is handled by the autopilot. **Stereo vision fused with deep-learning object detection** provides real-time, depth-aware perception for navigation and task execution in dynamic maritime environments. Together, these innovations deliver a modular, reliable, and scalable platform optimized for RoboBoat missions.

VI. TESTING

This section covers the general tests conducted of the presented project while representing the Hardware & Software, and Integrated tests etc.

A. Vessel Testing

The USV's hydrodynamic behavior was initially evaluated through simulations and

Computer Aided Design (CAD) based analyses. Additionally, physical tests were conducted in a training pool to observe the hull's performance without onboard electronic components.

B. Hardware Testing

Hardware testing followed a structured process to ensure reliability and mission readiness. Key components (GPS, camera, control units, power distribution, and communication modules) were first verified individually for electrical stability and data integrity. Scenario-based tests then evaluated long-duration operation, power cycling, dynamic sensing, and communication continuity, including controlled fault cases such as sensor disconnects and voltage variations. Finally, full integration tests confirmed real-time data flow and overall system stability, indicating suitability for autonomous operation in RoboBoat competition environments.

C. Software Testing

Software testing targets mission-critical competition behaviors. Perception is validated with recorded image/depth data to check detection stability, distance estimation, and alignment, while navigation and mission logic are tested with waypoint/task sequences for correct heading, speed, and state transitions. ROS 2–Pixhawk communication is verified under continuous operation by monitoring command delivery, telemetry feedback, timeout handling, and safe fallback behavior to ensure reliable deployment.

D. Integrated Testing

To validate the interaction between hardware and software components in a coordinated environment, full-system integration tests have been conducted following module-level tests. The USV has been tested in mission-like scenarios designed by the team to address key functional requirements and identify potential failure points. Testing remains an ongoing and integral part of the development process. After financial support is secured and all system components are fully procured, more comprehensive and competition-focused tests will be conducted with the newly developed CHAKA platform, aiming to achieve more accurate, reliable, and robust results.

VII. CONTRIBUTIONS

PRU-İDA is an interdisciplinary team organized into Mechanical, Electronics, Communication, and Software subgroups, composed of students from Naval Architecture and Marine Engineering, Computer Engineering, and Electrical-Electronics Engineering under faculty supervision. Tasks were distributed by expertise and executed largely in-house, with additional support from university laboratories, BAP-funded academic advisors, local shipyard designers, and defense industry professionals, particularly for advanced communication solutions.

Table 1: Team Member Contributions

Team Member Name	**Contribution**
Erhan ÜRKMEZ	Team Leader; responsible for project procedures, hardware integration and overall coordination.
Ertuğrul BAKIR	Organizational planning and overall system coordination.
Elif Nur YILDIZ	Development of image processing algorithms.
Muhammed Musa ÇİÇEK	Electronic systems, communication infrastructure, and power delivery integration.
Arda Recep KIVANÇ	Electronics and power distribution system design.
Eren ERİMLİ	Mechanical design.
Medine ÇELİK	Mechanical system manufacturing and prototyping.
Abdulkerim AKTEN	ROS 2 autonomy architecture and navigation development.
Ufuk Serdar POLAT	Custom GUI development.
Alper ŞAL	MAVROS–PX4 communication and mission integration.
Efe ÖZYILMAZ	Communication hardware, RF optimization, and battery systems.

Team Member Name	Contribution
Ahmet Efe ZEYTUN	Software–hardware development and system integration.
Sümeyye ÇEKİÇ	Image processing algorithm and website development.

As seen in Table, team contributions name by name emphasizes the team's structure ensured that all design, development and integration phases were completed with internal capabilities while benefiting from expert feedback and institutional resources where necessary.

ACKNOWLEDGEMENTS

This study was supported by the State Planning Organization (DPT) Grant No:

- BAP-L-2024-07: Development of Communication System for Unmanned Surface Vehicles (USVs).
- BAP-L-2024-08: Development of Electronic and Power Distribution Systems for Unmanned Surface Vehicles (USVs).
- BAP-L-2025-02: Development of Control and Navigation System Unmanned Surface Vehicles (USVs).
- BAP-L-2025-04: Development of Integrated Communication and Interface for Unmanned Surface Vehicles (USVs).
- BAP-2026-01-04: Design and Development of a Modular Electrical ControlSystem and a ROS2-Based Software Infrastructure for Autonomous Surface Vehicles
- BAP-2026-01-06: Development of Propulsion and Energy Systems with Hydrodynamic Optimization of Hull Design for Autonomous Marine Vehicles

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