RoboSub 2025 Technical Design Report

Singapore University of Technology and Design – UnderWater Unit

Abstract – The Underwater Unit (UWU) focused its 2025 efforts on enhancing the reliability of its Autonomous Underwater Vehicle (AUV), Blobfish. The team adopted a modular and well-documented integration and testing approach while meeting the functional goals of RoboSub 2025. This year's design and testing strategy centers on the development of a new motion planner, a visual navigation system, and improved hardware architecture. These advancements position UWU with a competitive edge and lay the groundwork for future AUV development in the years ahead.

I. Acknowledgements

We would like to express our gratitude to the individuals and sponsors who supported the development of our underwater robot, Blobfish, for the 2025 RoboSub competition.

Professor Malika Meghjani for guidance and lending equipment in-kind

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MINDEF for allowing us to use funds originally intended for RobotX

II. Introduction

The UnderWater Unit (UWU) is a student-led robotics team from SUTD participating in RoboSub 2025 with its autonomous underwater vehicle (AUV), *Blobfish*. This year marks a strategic transition from earlier iterations of the vehicle which were originally developed for the Singapore Autonomous Underwater Vehicle Challenge (SAUVC) to a more robust and competition-focused platform tailored for RoboSub's complex mission environment.

Blobfish was redesigned with a systems engineering mindset; emphasizing modularity, field-reliability and sustainable team development. With a partially new team, limited weekly build hours and a constrained budget, UWU focused on core performance improvements such as visual odometry recovery, depth estimation correction and exploration autonomy. The redesigned AUV reflects lessons learned from previous testing and integrates a blend of off-the-shelf components and custom-engineered systems.

This report outlines UWU's strategic competition vision, technical design approach, testing methodology and software enhancements all built to meet the demands of underwater autonomy in a structured and reliable manner.

III. Competition Strategy

Strategic Vision

Our team's strategic vision for RoboSub 2025 is to develop a reliable, modular, and robust autonomous submersible that prioritizes consistent task execution and real-world engineering experience over overextending system complexity. We aim to gain practical exposure to system-level robotics while performing well in selected competition tasks. Our design and testing efforts are guided by the principle that a reliable, well-validated system capable of completing a focused set of tasks will outperform a feature-rich but unstable vehicle.

This strategic vision reflects both our competition goals and our engineering growth objectives. With a relatively young team and limited time, we are deliberately applying a systems engineering approach to scope, schedule, and test only what we can confidently deliver.

Goals

- Gain hands-on engineering experience in underwater robotics, autonomy, and system integration.
- Successfully complete Tasks 1, 2, and 6.
- Attempt Task 3.
- Reach the semi-finals through consistent scoring and reliable autonomy.

To translate our strategic vision into reality, the vehicle design was centered around subsystem reliability, ease of integration, and maintainability. Each subsystem from the vision pipeline to the actuator and compute layout was scoped and developed with clear functional boundaries. The following constraints shaped these design decisions.

Constraints	Details
Time	Team members can commit an average of only 8 hours per week. This necessitates tight scheduling, early validation of core functions, and limited late-stage feature additions.
Manpower	Core team of 5 members, supported by 6 newcomers, most of whom are still in training. This limits parallel development and places greater emphasis on knowledge transfer, modular documentation, and clear task ownership.
Experience	The current team recently took over from senior members, which means institutional knowledge is still stabilizing. Systems must be easy to understand, debug, and hand off between developers. Formal documentation is also lacking.
Budget	Total project budget of $20,000, excluding flights, shipping, and accommodation. This requires cost-efficiency in hardware upgrades, with careful justification of high-impact purchases such as the Jetson Orin NX.

Task Selection and Complexity Management

We have selected tasks that play to the strengths of our current hardware (e.g., vision-based localization, 6-DOF control), can be segmented into discrete mission phases, and allow for measurable, iterative testing in a pool environment. Tasks requiring acoustic sensing or complex actuation were deferred to prevent overextension and focus effort on achievable goals

Trade-Offs Between Complexity and Reliability

Our design process reflects explicit trade-offs to balance capability with reliability under the constraints of time, manpower, and testing access:

Trade-Off	*Decision*	*Justification*
Advanced Manipulation	Used electromagnetic dropper	Reduced waterproofing risk; faster to test; aligns with Task 3 goals.
System Scalability	Avoided custom PCB for now	Allows quick modification and extensive testing, for curing design to PCB later.
Processing Performance	Upgraded to Jetson Orin AGX	Enables visual SLAM and task detection; accepts higher power draw.
Feature Count vs. Testing	Focused on 3 core tasks + 1 stretch	More time allocated to tuning and validation, rather than broad integration.
Component Thermal Limits	Moved compute unit outside tube	Prevents heat buildup; learned from SAUVC overheating issue.

This strategy minimizes integration risk from interacting subsystems and allows us to meet deliverables within known constraints.

Conclusion

Our competition strategy is shaped by experience, present constraints, and future team sustainability. By deliberately narrowing system scope and rigorously validating each feature, we increase our likelihood of successful task execution, semi-final qualification, and establishing a technical foundation for future RoboSub teams. Our design favours clarity, testability, and maintainability not just for scoring points, but for growing engineering capability year-over-year.

IV. Design Strategy

Objective

The 2025 design of *Blobfish* reflects a systems engineering approach where each subsystem mechanical, electrical and software was designed with clear functional interfaces and performance targets. Design choices were scoped by integration risk, testability and mission-critical performance. Emphasis was placed on modular construction, internal documentation and robust subsystem isolation to ensure development could proceed in parallel and system-level debugging would be straightforward. This section outlines major hardware, electronics, manipulator and software upgrades each motivated by lessons learned and system-level performance goals.

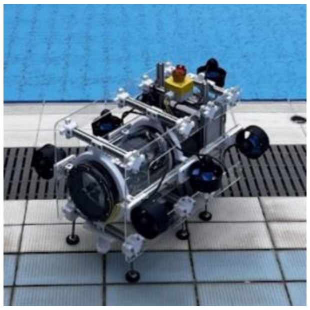

FIGURE 1: BLOBFISH AS OF SAUVC 2025

System Overview

Our current system comes with:

- Power system using a single 4S 6000mAh Lithium-Polymer battery.
- Propulsion system using 7 thrusters, 4 for forward/yaw, 2 for roll/vertical control, 1 for pitch/vertical control.
- Forward facing depth-camera and pressure sensor for depth control.
- VectorNav IMU for orientation.
- Jetson Nano used for sensor fusion as well as ROS.
- Arduino Nano RP2040 for low-level motor control and for the real-time control loop.
- Custom PCB for power delivery and interface with microcontroller.
- Tether for connection to a ground station for data collection and debugging.
- Structure using:
    - Laser-cut acrylic plates, aluminum extrusions, 3D-printed PLA parts.
    - 5mm Acrylic tube, acrylic and aluminum end caps from BlueRobotics.

Upgrade Strategy

To prepare the vehicle for RoboSub 2025, the design team is implementing significant hardware, electronics, as well as software enhancements, given our time constraints. These improvements focus on structural integrity, thermal management, modularity, futureproofing, and intelligent task execution.

Hardware Enhancements

a. Frame Sturdiness

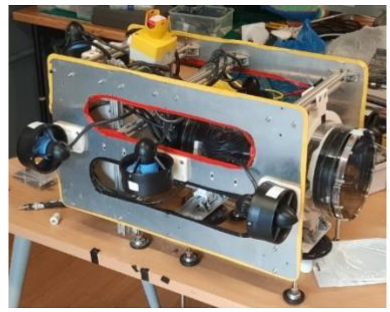

FIGURE 2: BLOBFISH AS OF JUNE 2025

Acrylic-to-Aluminum Sheet Replacement: Acrylic parts, while lightweight, lacked structural rigidity and resistance to flexing under load. Replacing them with aluminum sheets improves mechanical robustness, particularly important during collisions with gates or obstacles.

PLA-to-ABS Upgrades: PLA components degraded in water and softened under heat. ABS provides greater toughness and better thermal resistance, essential in submerged operations with hot components.

Switch to Off-the-Shelf Parts: The previous design had been fraught with many custom-made 3D-printed PLA components, which had many issues as described above. The legs, were particularly unstable as they were made in this way, as opposed to an off-the-shelf component.

b. Waterproofing
   Penetrator Replacement: Older penetrators had higher leak risk due to seal degradation. New, wet-link connectors improve safety and reliability, as well as improving ease of installation.
c. Improving Heat Dissipation
   Moving Jetson Out of Tube: During SAUVC, internal heating led to performance throttling. Relocating the Jetson Orin AGX outside the primary sealed compartment isolates its heat generation from other components and sensors.

Electronic Enhancements

a. Power and Signal Robustness
   Custom PCB → Terminal Blocks + Stripboard: Modularizing the power and signal connections enables faster repair and debugging. Isolating high/low voltage paths improves electrical noise resistance and safety. The signal circuit was also etched into the PCB, which made it difficult to switch or identify PWM channels for debugging purposes.

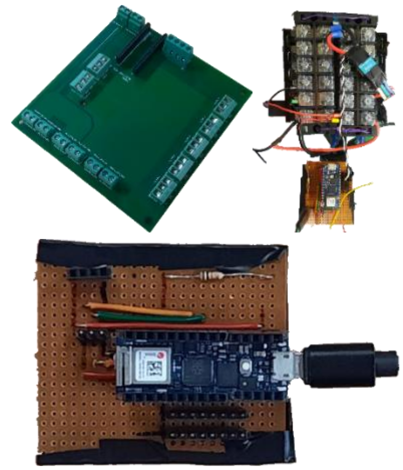

FIGURE 3: CUSTOM PCB AND NEW MODULAR SOLUTION

   Correct terminal sizing: Original PCB terminals were mismatched for 16 AWG and created risk of overheating, poor power delivery, and disconnections during assembly. The new setup, which uses fork connectors and terminal blocks, is a step toward future continuous 30A operation, removing a bottleneck in high-load scenarios like sprints while performing computations.
b. Processing Upgrade
   Jetson Xavier Nano → Jetson Orin AGX: Higher onboard processing power is required for real-time computer vision, SLAM, and intelligent decision-making.
   - Increase in power draw (15W → 40W) will require re-evaluation of the battery sizing and possibly thermal design.

Manipulator System Design

a. Electromagnetic Manipulator:
   Chosen for its simplicity — no moving joints or complex sealing

needed. This reduces waterproofing complexity and failure points.

b. Downward-Facing Camera: Added to support visual servoing or alignment, specifically to achieve task 3.

Software enhancements

a. Visual Odometry Recovery
To maintain localization integrity during complex maneuvers or visual occlusions, we implemented recovery strategies for the visual odometry pipeline. This allows the vehicle to resume accurate navigation after temporary tracking failures, which we experienced many of, during SAUVC 2025, crucial for tasks like pipe slaloms and gate alignment.

b. Computer Vision Pipeline Refinement
The computer vision pipeline has been optimized for real-time object recognition, task-specific target detection (e.g., gates, pipes, marker bins), and environmental segmentation. Improved preprocessing and model tuning reduces false positives and increases task success rates.

c. Camera System Calibration
We conducted thorough intrinsic and extrinsic calibration of all onboard cameras. This calibration ensures geometric consistency in stereo depth estimation and multi-camera fusion, which is essential for reliable object localization and mission planning.

d. Vision-Language Model (VLM) Integration
As part of forward-looking research, we are exploring the use of a lightweight Vision-Language Model to interpret high-level task cues, environmental patterns, and visual semantics. This allows for more context-aware decision-making and introduces modular interfaces for future task scaling.

e. Multi-Camera Architecture
We are implementing a synchronized multi-camera system (e.g., front and downward-facing cameras) to enable multi-perspective perception. This is particularly beneficial for tasks requiring both forward navigation and vertical precision, such as marker drops and BRUV alignment.

V. Testing Strategy

The testing strategy for *Blobfish* was developed using a phased approach to validate individual components, subsystem integration and full-system functionality under realistic conditions. Each phase was structured around clear objectives, controlled environments and measurable outcomes. Testing emphasized early validation of reliability and safety especially for waterproofing and autonomy-critical components.

Component Testing

- Individual components including thrusters, power distribution boards, the electromagnetic dropper and sensors were first validated outside the robot chassis.

- The terminal blocks and stripboard were tested for power loss, connection reliability and fuse triggering under simulated load conditions.
- The electromagnetic manipulator was evaluated for actuation consistency at different voltages and for failure under prolonged energization.
- Depth and IMU sensors were monitored through ROS 2 topics to verify range, noise characteristics and responsiveness.
- Each test was recorded in a shared log with retesting required if parameters deviated >10% from expected values.

Strategy Testing (Simulation)

To de-risk integration, the mission control logic and some perception algorithms were tested in a virtual environment using Gazebo sim.

- Camera input was simulated using prerecorded footage or placeholder topics to verify image-based detection triggers.
- Control loops were tested with feedback disabled to verify timing and loop stability before connecting real motors.

This allowed debugging of sequencing and state transitions without needing full robot availability.

Pool Testing

Pool tests were structured as milestone-driven integration events. Each session was preceded by a dry-run checklist and focused on a specific subsystem:

- First stage: Testing buoyancy, trim, and basic 6-DOF thruster control.
- Second stage: Testing sensor accuracy and camera visibility under water.
- Final stages: Testing autonomous routines with a reset-and-replay loop.

Failures were logged with video, and regression plans were created before next deployment.

Seal Testing

Given the critical role of waterproofing, dedicated seal tests were conducted:

- All enclosures were submerged in a test tank for 1 hour and then inspected for moisture.
- Penetrator seals were tested under pressure using a hand pump.

Testing revealed previous designs had recurring ingress at custom 3D-printed parts, which were replaced with off-the-shelf aluminum solutions.

VI. References

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