Technical Design Report

— AUV_Windy

Abstract

This is our first year to participate in the RoboSub competition. As a team founded less than two years ago, we are willing to challenge ourselves and pursue the limits, and through participating in various competitions, we have accumulated a lot of experience in robot design and production. We have completed the first generation of AUV-Windy, which is equipped with some basic sensors for Rough Seas, Enter the Pacific, Path Tracking, Hydrothermal Vent, Ocean Temperatures, and according to the plan, we will complete the assembly of the robot on the 15th of June, and the construction of the robot on the 1st of July. The robot was assembled on the 15th of June, and the AUV was tested for autonomous operation on the 1st of July, followed by automated programming and model training for specific tasks. This thesis will describe the mechanics, circuitry, automation programming, and testing of our robot based on the tasks we will be completing in terms of the propulsion system, control system, and automation programming.

Catalog

1. Competition Strategy

Our competitive strategy revolves around leveraging the strengths of our AUV base design to maximise scoring through task selection and efficient execution. Our goal was to balance the complexity and reliability of the system, and to make the pre-existing functionality as stable as possible to ensure robust performance under competitive conditions.

As we were in our first year of competition and did not have sufficient development experience related to underwater robot acoustics, to avoid unnecessary complexity we focused on optimising the existing capabilities of the robot rather than adding new features. This approach ensured that each subsystem was fully tested and reliable.

We decided to complete only the first 3 tasks that could be localised using vision. Another big influence was our time and personnel. Complex projects often require more people to develop and test, and with only 5 juniors as our main R&D effort, we were not able to do some of the more complex engineering in robot development. In addition, we did not have enough time to prepare, we only had about 3 months to design and build our AUV, and many of our proposals were proposed but could not be systematically verified. For example, we wanted to use the strength of the signal received by a single hydrophone to localise the Pinger, but due to the lack of a team member's tech stack and the uncertainty of equipment procurement, we were not able to complete this in time and had to shift our focus to basic robot identification and control development.

The order in which we completed our selected tasks was undoubtedly based on path-guided sequencing. We focused on testing and optimising the stability of the robot's path tracking to ensure that it could function properly in the face of disturbances such as sunlight, water jolts, etc., which laid the foundation for us to get a sufficient number of scores in all three tasks.

We aimed to stabilise performance across tasks and minimise potential failure points. We designed internal redundancies in key systems such as identification and communication to continue to operate in the event of failure without affecting mission execution.

2. Design Strategy

2.1. Task Analysis and Design Considerations

2.1.1. Validation Gate Navigation:

Redundancy and Compactness: We adopted a compact design to enhance our robot’s ability to navigate through tight spaces. The dimensions were chosen to maximize stability and minimize drag, supported by computational fluid dynamics simulations to ensure optimal performance under varying water conditions.

Dimension Constraints: The compact dimensions facilitate easier passage through the validation gate, reducing the risk of collision. This was achieved by performing detailed volume and space utilization calculations, ensuring that every component fits perfectly within the specified dimensions.

2.1.2. Color-Based Object Recognition:

Initial Approach: We initially utilized OpenCV to extract features based on the distinctive colours of the validation gate’s sides and the corrugated flat surfaces. However, this traditional method proved sensitive to environmental changes, affecting reliability.

Transition to Deep Learning: Recognizing the limitations of traditional methods, we implemented a target detection algorithm using deep learning. This shift enhanced accuracy and robustness against environmental variations. Comparative tests demonstrated superior performance, with an average increase in detection confidence.

Corrugated Flat Color Analysis:

Red vs. Blue Object Detection: Through systematic analysis, we observed that the red targets consistently yielded higher confidence scores than the blue ones. This finding informed our decision to direct the robot through the Hot/CW side, optimizing for reliability and precision. The use of statistical analysis and confidence interval calculations provided a robust justification for this choice.

Deep Learning Implementation Across Tasks:

Generalized Application: Encouraged by the success of the Enter the Pacific task, we expanded the deep learning framework to other object recognition tasks. By leveraging transfer learning, we efficiently trained models for various targets, significantly reducing development time and complexity.

Performance Evaluation: Rigorous testing across multiple scenarios confirmed the deep learning approach’s effectiveness, with high accuracy and low false-positive rates, ensuring consistent system performance.

2.1.3. Exclusion of Mapping and Sample Collection:

Mechanical Simplicity: We strategically opted out of the Mapping and Collect Samples tasks, eliminating the need for complex mechanisms like manipulators and torpedo systems. This decision streamlined the robot’s design, reduced its volume, and minimized potential failure points.

Impact on AUV Volume: By excluding these tasks, we achieved a more compact AUV, enhancing agility and speed. Volume reduction calculations showed a significant decrease, contributing to the robot’s overall performance.

2.1.4. Ocean Temperatures Task Approach:

Simplified Actuation: For the Ocean Temperatures task, we employed a minimalistic approach by using a straightforward actuator to deploy markers. This decision, driven by development time constraints, ensured functionality without the complexity of a multi-joint manipulator, allowing for quicker prototyping and testing.

System Reliability: The simplicity of the actuator design increased system reliability, with fewer components to maintain and troubleshoot, aligning with our systems engineering principles of robustness and efficiency.

2.2. Creative Design Methodology

Integration of Visual Aids: We developed comprehensive flowcharts and diagrams to visualize the design and decision-making process. These visual aids facilitated team communication and ensured alignment on the design strategy, embodying a systems engineering approach.

3. Testing Strategy

The test strategy ensures thorough verification of AUV's core modules: airtightness, circuit, sensor, and control system. It includes two main test phases: bench tests simulate extreme water conditions in a lab setting, verifying subsystem performance. In-water tests validate system performance in real aquatic environments with varying complexities.

3.1. Air tightness test:

The airtightness test is mainly to verify the watertightness of the sealed compartment, to ensure that water ingress will not occur when the AUV is working in the water, and to protect the internal circuits and equipment.

- bench test:
  1. Assemble the seal chamber, install the watertight fittings, and apply lubricating silicone grease to each seal.
  2. Use a manual vacuum pump to extract air from the sealing chamber and observe a change in the instrument panel needle.
  3. Manually vacuum the instrument panel needle to 15in.Hg, stand for 15min, observe the value at 14~15in.Hg.
- In-water:
  1. Completely immerse the sealed compartment in water for 15min and observe that no air bubbles are produced.
  2. Remove the sealed compartment and test the internal dryness.

Airtightness testing through the standard in strict accordance with the above process, each test needs to record the process and results, including the negative pressure value, immersion time, whether the leakage, leakage location, etc., and at the same time, the test results are summarised and analysed to summarise the watertightness of this version of the sealed compartment.

3.2. Circuit testing

Circuit testing mainly verifies the electrical performance of the electronic design power system and control system to ensure that the subsystems can work properly and meet the design requirements.

- Bench test (Simulation of temperature, humidity and electromagnetic interference in water in the laboratory)
  1. Test the output voltage and ripple noise of the power management circuit to verify that the voltage divider modules work properly.
  2. Test the output characteristics of the load driving circuit to verify the load driving capability, and work under load for half an hour to observe the state of each sub-system and the temperature rise.
  3. Test the output voltage, current, power and other indicators of the motor drive, to the motor can be initialised and can output a set of pwm control speed shall prevail.
  4. Test the communication protocols, through the host computer, the host computer, the sensor to send and receive data between the serial communication protocols to test the reliability of the iic communication protocols, to verify the integrity of the data and the transmission rate.
- In-water（Tested in a real pool environment）
  1. All electrical components are sealed in a watertight compartment that has been tested for airtightness.
  2. The hull is fully submerged and the water depth is gradually increased to the maximum working depth.
  3. Simulation of manoeuvring conditions to test the immunity and stability of circuits

operating in underwater environments.

Various indicators are to meet the design requirements, the subsystems work reliably, then can pass the circuit test.

3.3. Sensor testing

The test is mainly to verify the sensor performance of the depth sensor (manometer) and the 10-axis IMU to ensure that it can work stably in the underwater environment and provide reliable reference data for AUV movement.

- Bench test
    1. Depth gauge: Test output values at different pressures (0-10 MPa) to calculate measurement range and resolution. 10-axis IMU: Test attitude output at different angles, calculate measurement range and resolution.
    2. Test the output value at different temperatures(-10~60℃)and calculate the temperature error.
- In-water
    1. Place the sensor element in a watertight chamber that has been tested for airtightness.
    2. Submerge the waterproof chamber in water, gradually increase the water depth to the slow range and record the output of the sensor at different depths.
    3. Record the output of the sensor at different temperatures as the temperature in the chamber increases with operating time.
    4. Simulation of manoeuvring conditions in water to test the response speed and immunity of the sensors.

During testing, sensors with output errors within 5% are deemed reliable. This data defines our operational range. We record, summarize, and analyze sensor performance to select the best fit for our AUV.

3.4. Control system testing

This test is mainly to verify the fault tolerance of the control system algorithms for visual recognition and thrust solving, and to observe how well the actuator outputs conform to the preset states, to ensure that the AUV can move according to the established logic.

- Bench test
    1. Build a complete system model of AUV in ros simulation environment.
    2. Set up different working conditions, such as current speed, water depth, etc.
    3. Setting up the mission simulation environment according to the requirements of the competition mission.
    4. Test the stability indicators of the control system, such as response time, overshoot, rejection ratio, etc.
    5. Testing of control system robustness indicators, e.g. setting up a simulation of external disturbances, testing of immunity to disturbances.
    6. Tests the compliance of the control system outputs with the commands.
- In-water
    1. Task props in real waters.
    2. The AUV is moved in a circle along the line to test the stability of the AUV's navigation (patrolling) in real waters.

3. AUV dives to test the accuracy and effectiveness of attitude maintenance in changing water depths.
4. Conducting mission-specific simulations to measure the navigational response and stability of AUVs in carrying out their missions.

The control system test directly affects mission quality. Its results adjust algorithmic parameters for consistent AUV performance. Passing the test signals completion of our mission sooner.

4. Acknowledgements

As a team less than two years old, our research and development of the robot and the AUV competition project can not be carried out successfully without the support of the school and the resources provided by the instructors. First of all, we would like to thank Mr Wang Chao for providing us with rich practical experience and valuable technology, and has been supporting us since the beginning of the team, witnessing our achievements from the zero start to today. In addition, we would like to thank Mr Yang Tao and Mr Zhang Hai Chuan for helping us to plan the overall programme and giving us many innovative design ideas, which saved us a lot of time in research and development. At the same time, we would like to thank the school for providing us with the experimental space and equipment, creating good conditions for our practical activities and giving us a platform for development. Of course, we also want to thank every team member for their hard work and selfless dedication, it is because of your efforts and persistence day and night, we can achieve today's results.

Once again, I would like to express my heartfelt thanks to all of you who have trusted and supported our team!

References

[1] Lou, H., Duan, X., Guo, J., Liu, H., Gu, J., Bi, L., & Chen, H. (2023). DC-YOLOV8: Small-Size Object Detection Algorithm based on Camera Sensor.Electronics, 12(10), 2323.https://doi.org/10.3390/electronics12102323

[2] Zhang, L. J., Fang, J. J., Liu, Y. X., Le, H. F., Rao, Z. Q., & Zhao, J. X. (2024). CR-YOLOv8: Multiscale object detection in traffic sign images.IEEE Access, 12, 219–228.https://doi.org/10.1109/access.2023.3347352

[3] Xu, W., Cui, C., Ji, Y., Li, X., & Li, S. (2024). YOLOV8-MPEB Small Target Detection Algorithm based on UAV images.Heliyon, 10(8), e29501. https://doi.org/10.1016/j.heliyon.2024.e29501

[4] Ammar, M. (2024). Enhancing real-time instance segmentation for plant disease detection with improved YOLOv8-Seg algorithm.International Journal on Information Technologies and Security, 16(2), 27–38. https://doi.org/10.59035/bcnl3199

[5] of a Novel Flight-Style AUV with Bow-Wings: Insights from Drag Polar Curves and Thrust Estimations.Journal of Marine Science and Application 23, 352-365 (2024).https://doi.org:10.1007/s11804-024-00420-7

[6] Hariri, A., Basharie, S. M. & Abd Ghani, M. H. in10th Asian International Conference on Fluid Machinery. 36-46 (2010).

[7] Zuo, M. J., Wang, G. D., Xiao, Y. X. & Xiang, G. A Unified Approach for Underwater Homing and Docking of over-Actuated AUV.Journal of Marine Science and Engineering 9(2021).https://doi.org:10.3390/jmse9080884