Riding the Waves of Innovation: An Autonomous Surface Vessel for the 2025 Roboboat Challenge

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***Abstract* – Team Autonomous Maritime Operations and Robotics Engineering (AMORE) from Lake Superior State University has developed an Autonomous Surface Vessel for the 2025 Roboboat Challenge. The project builds on prior efforts from past RoboBoat competitions and features a retrofitted kayak turned into an Autonomous Surface Vessel (ASV) to complete various tasks without human intervention. The ASV integrates an upgraded vision system; a Guidance, Navigation, and Control system (GNC); and several modular systems for specific tasks. This paper outlines the ASV design, integration, and testing, with a focus on maximizing performance at the 2025 RoboBoat competition.**

Keywords – Autonomous Surface Vessel (ASV); Light Detection and Ranging (LiDAR); Guidance, Navigation, and Control (GNC); Computer-aided design (CAD).

I. Introduction

Team AMORE (Autonomous Maritime Operations and Robotics Engineering) is a student-led competition team from Lake Superior State University (LSSU), located in the Upper Peninsula of Michigan, that competes in various marine robotics competitions, including the Maritime RobotX Challenge and RoboBoat. Thanks to continuously growing support, AMORE has progressed from an entry-level team to a competitive team that consistently makes it to finals during competitions, placing in the top five most recently during RoboBoat 2024 and Virtual RobotX 2023. AMORE's work has spanned four engineering senior design projects, a research course, international collaboration with other robotics institutions, and published academic research in both robotics and biology across the Laurentian Great Lakes region [1],[2].

For the 2025 RoboBoat Challenge, the team is bringing a significantly improved ASV previously developed for 2023 RoboBoat. This is the first RoboBoat where the ASV features a dedicated GNC system and electrical system mounted on a platform the team developed.

I. Competition Strategy

AMORE developed a competition strategy based off of the previous work towards preparing the vehicle for ecological research and past RoboBoat competitions. This is the first year that both the platform and all additional systems were developed by AMORE. This allowed AMORE to focus on developing subsystems to attempt every task for RoboBoat 2025. We incorporated multiple aspects from each design iteration of the ASV for this year's competition. Fig. 1 highlights the design of the ASV that AMORE has used for each RoboBoat competition.

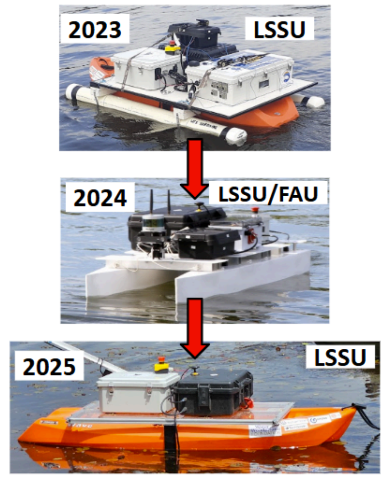

Figure 1. ASV design iterations for RoboBoat

For RoboBoat 2023, AMORE utilized the control system from their 2022 WAM-V design iteration and adapted a kayak hull for the competition. The hull was fitted with a wooden deck and additional flotation for stability. For RoboBoat 2024, a dedicated control system was developed for the ASV and was mounted to a hull and deck that was developed in partnership with Florida Atlantic University (FAU). The control system for RoboBoat 2025 features an upgraded main processor, but maintains most key components from the RoboBoat 2024 iteration. For RoboBoat 2025, a new deck, made of 6000 series aluminum extrusion was developed to hold the systems developed for RoboBoat 2024. The perception system also underwent major changes for RoboBoat 2025. The perception mast, LiDAR and stereo camera, stayed the same throughout each competition. The Jetson Tx2 used for vision processing was replaced with a more powerful processor, the Jetson Orin AGX. This is important since tasks 1, 2, and 4, each require navigating colored buoy pairs and avoiding certain obstacles in the water. AMORE focused on integrating a robust perception system to identify colored buoys and game features with the new vision processor. This allows for more complex vision algorithms and improved path planning. With improved perception and navigation systems, AMORE plans to identify the correct dock and avoid any occupied bays for Task 3. Maintaining position and heading in the dock would be difficult for the ASV since it is under-actuated, so the ASV will only focus on maintaining its position once it is in the bay. Additionally, a newly developed racquetball launcher and water delivery system was integrated to complete Task 5; this poses a challenge to the ASV, because of its under-actuation. The ASV cannot proficiently maintain heading and position at the same time, so the heading of the ASV is only maintained if it is within a designated distance to the correct position. To achieve this, minor changes to the code for the low-level controller for station-keeping was required. The upgraded perception system will prove crucial to identifying the orange and black vessels present throughout tasks 2, 3, 4, and 5. Task 6 requires the ASV to avoid obstacles and return back to the launch point after attempting tasks. Using an obstacle avoidance algorithm developed for the WAM-V, AMORE will use the algorithm with the improved perception system to avoid any game features and successfully return to the launch point.

II. ASV Design Strategy

The ASV is a 6-foot kayak with a raised, stable platform and a payload of 130 pounds [3]. The kayak is made of durable high-density polyethylene, which is lightweight and has a high strength-to-density ratio. This platform, seen in Fig. 2, is designed for children's play, but can handle many of the surface conditions found on the Great Lakes, which is where AMORE conducts testing. This led to the ASV's use being expanded beyond the competition to also include biological research [2].

Figure 2. ASV design before RoboBoat 2025

On the base hull, AMORE has added a variety of systems for unmanned operation. The first being the GNC system seen in section A. Section B explains the ASV motion with the propulsion system and its control. The perception system in Section E, including vision, enables the ASV to make decisions based on its surroundings. The communication system (section D) allows monitoring of the ASV from shore. There is a safety system outlined in Section E. Finally, there is a modular racquetball launcher developed specially for RoboBoat, seen in Section F. A model of the design of the ASV for RoboBoat 2025 is shown in Fig. 3.

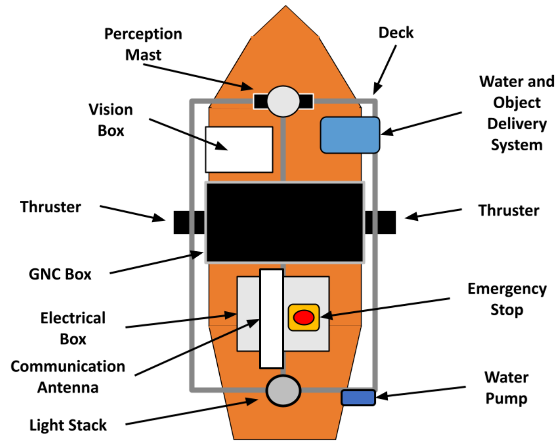

Figure 3. ASV design for RoboBoat 2025

A. Guidance, Navigation, and Control System

The GNC box is located aboard the deck and is responsible for all communication aboard the ASV. The GNC box (Fig. 4) houses the Jetson Orin Nano computer, a Teensy 4.1 microcontroller, a Pixhawk 6C flight controller, and the integrated safety system (Section E). The main function of the GNC box is to act as a management device for all sensors and components aboard the ASV. This is achieved using Robotic Operating System (ROS) as middleware to communicate between various sensors and components in software. Using ROS, the low-level controllers aboard the ASV have access to vital peripheral data, such as the current GPS location, that may be used to dynamically adjust the propulsion system's output to reach a desired state and respond to changing environmental conditions. This setup allows the ASV to achieve accurate and reliable movement, essential for tasks such as navigating complex waterways, performing scientific data collection, and conducting autonomous operations. The overall GNC architecture developed for the ASV is shown in Fig. 5.

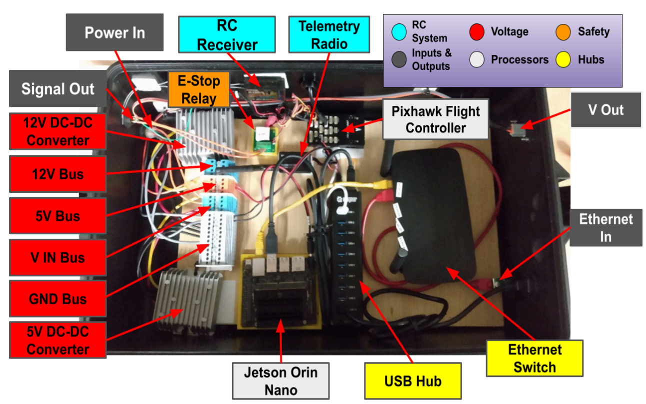

Figure 4. ASV GNC Box

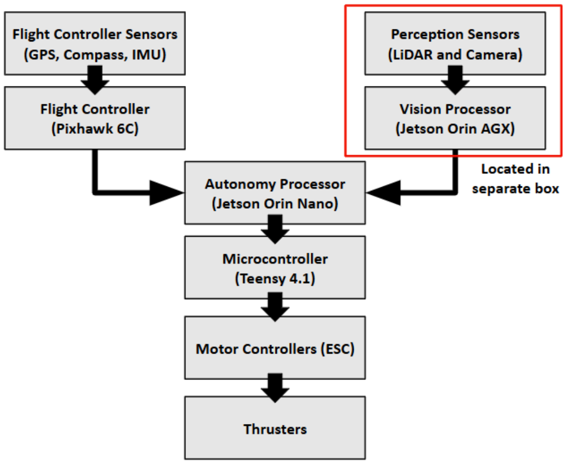

Figure 5. ASV GNC Architecture

B. *Propulsion and Control*

The ASV's propulsion system, developed for RoboBoat 2023, utilized two bidirectional thrusters mounted on opposite sides of the hull. The thrusters were placed towards the center of the ASV to simplify the control software and to enable the ASV to rotate efficiently. With the current propulsion system configuration, it was determined that the ASV would utilize differential thrust, where each thruster uses varying thrust outputs to reach a desired state. The thrusters used for the ASV were Hawk Hobby 24V bidirectional thrusters; these thrusters are capable of 89 N of force each, providing sufficient thrust for the ASV. Fig. 6 shows the thrusters used for the ASV.

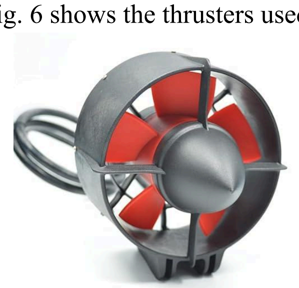

Figure 6. Hawk Hobby thruster

In order for the ASV to operate autonomously, a low-level controller is required to dictate the behavior of the vessel while operating in autonomous mode. There are two separate Proportional Integral Derivative (PID) controllers that fill this role. During waypoint navigation, a Heading and Speed controller utilizes the thrusters with differential thrust, providing sufficient speed and maneuverability. For Station keeping, the thrusters operate similar to the Heading and Speed controller, using differential thrust to maintain position and heading.

a) *Heading and Speed*

The Heading and Speed controller is a PID controller that utilizes the thrusters with differential thrust to navigate over long distances. The parameters governed by the Heading and Speed controller are velocity and heading. Given a desired point, the ASV will hold its heading to face the point as it navigates. As the ASV approaches the point, its velocity decreases to allow for a smooth transition between the Heading and Speed controller and the Station Keeping controller. The maximum velocity allowed for the ASV during the use of the Heading and Speed controller is directly proportional to the distance to the point. For both controllers, the output is desired forces T_x and T_y and the moment M_z on the vehicle. Since the Heading and Speed controller utilizes both thrusters, the output of the controller is transformed into thrust for the port and starboard thrusters, Fx_{PT} and Fx_{STBD}.

The free-body diagram of the forces from the thrusters during the use of the Heading and Speed controller is shown in Fig. 7.

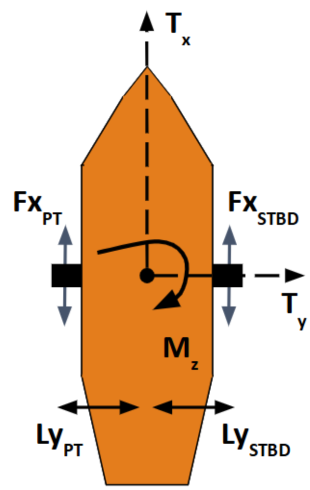

Figure 7. Force Output from Heading and Speed Controller and Station Keeping Controller

The derivation of the thruster forces from the desired state for the Heading and Speed controller adapted from the AMORE WAM-V can be found in reference [2].

b) *Station keeping*

The station keeping controller is a PID controller that utilizes both thrusters simultaneously to hold the ASV at a desired point. The motions governed by the controller are position and heading. Since the ASV only has two thrusters while having 3 degrees of freedom (surge, sway, and yaw), the ASV is considered under-actuated, which generates the thruster output Fx_{PT} and Fx_{STBD}. With the vessel being underactuated, it is difficult to control both heading and position at the same time, so the controller was designed to focus on the heading of the vessel once it was within the area of the desired point. This method allows the ASV to get into position before correcting its heading. The free-body diagram of the forces from the thrusters during the use of the Station Keeping controller is shown in Fig. 7.

The derivation of the thruster forces from the desired state for the Station Keeping controller adapted from the AMORE WAM-V can be found in reference [2].

C. Perception

Unlike in previous years, the perception system AMORE developed for Roboboat 2025 is not unique to the ASV. It is designed to be modular and can be removed and used for Team AMORE's WAM-V. The Perception system consists of two main components: the vision box, and the perception mast. The perception mast consists of a VLP-16 LiDAR (1) and a Zed 2i stereo camera (2) as seen in Fig. 9.

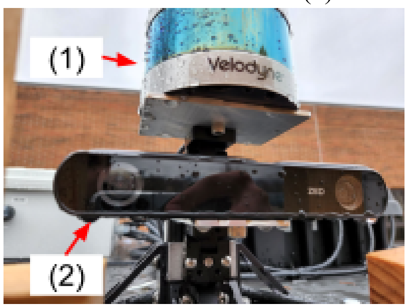

Figure 9. Perception mast previously mounted on Team AMORE's WAM-V

Inside the vision box, we provide an ethernet hub for connection to the GNC Box, a brand-new Jetson Orin AGX processor, and a VLP-16 LiDAR Control subsystem. Fig. 10 shows the configuration of the vision box.

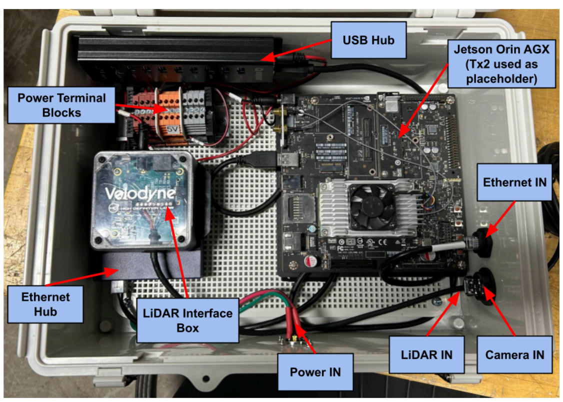

Figure 10. ASV Vision Box

The LiDAR is used to detect and localize data within an area in front of the vessel within a $\pm$ 45 degree angle of the vessel coordinate frame and a certain distance. As shown in our testing strategy, this will need to be re-tuned for the ASV at the competition venue. An occupancy grid of the is generated to map the course. This map is an input to the path planner, used to calculate the necessary trajectories and avoid obstacles. Once the objects in front of the ASV are mapped, then the stereo camera classifies them. Here the path planner gains information about navigating buoys based on rules defined based on particular missions, such as following general buoy rules or identifying buoy pairs for competition tasks.

The Zed 2i Camera is then used in order to classify the detected object. Using a combination of opencv and convolutional neural networks the system can determine the size, shape, and even pattern of each detected object providing task data directly to our control system.

D. Communication

Team AMORE made significant adjustments to their communication systems during the 2024-2025 school year. The previous ASV design relied on two 5G Linksys Routers that connected directly to team members' computers on land and to the router inside the GNC box. Through live testing on the water, the team determined that this solution was not viable for long-term competition goals. The Linksys routers suffered from range limitations, with a maximum effective range of only 200 feet. This caused intermittent loss of contact during competitions and added challenges to the testing phase. To resolve this issue, starting in RobotX 2024, the team experimented with a long-range 5G Ubiquiti network.

The new system featured two Rocket M5 antennas, set to auto-tune to 5 GHz frequencies, and the land-based system which included a narrow beam Ubiquiti antenna, designed to cast out a stable 5 GHz Wi-Fi network that could connect both the ASV's antenna and team members' laptops. This configuration allowed direct access to the GNC and Perception Jetsons from land. As a result, the team experienced a significant increase in range and communication stability. The ASV's antenna is an Omni-Directional Ubiquiti model. Due to height constraints at the Roboboat Competition, the team retrofitted the communication mast and found positioning the antenna at a specific angle allowed it to maintain a steady, robust connection with the land-based system, further enhancing communication reliability during competition.

E. Safety

To comply with the RoboBoat safety guidelines laid out in [6], the ASV is equipped with an integrated safety system which shuts off power to the propulsion system when triggered. This may be done in three ways: by pressing the red E-stop button on top of the ASV, by pressing the E-stop switch on the ASV RC on shore, or automatically when the GNC box loses connection to the RC controller on shore. The last two events trigger a remote relay in the GNC box (Fig. 4).

The ASV features an integrated light stack indicator with three distinct colors: green to indicate the ASV is autonomous, amber to indicate it is under remote control, and red to indicate it has been emergency stopped.

F. Launcher

Roboboat Task 5 requires the ASV to identify and distinguish between orange vessels and black vessels provided on the course. Once detected, the ASV must decide how to properly respond. Whether it's aiming to shoot water or squash balls, the system leverages its onboard vision system to classify the targets accurately and use its onboard turret (Fig. 11) accordingly. Upon identifying an orange vessel, the ASV is programmed to shoot water as a friendly, non-aggressive response, symbolizing assistance or acknowledgment. Conversely, when detecting a Black vessel, the ASV aims to launch Racquetball as a deterrent, simulating an assertive reaction to a potential threat. This dynamic targeting and response system is designed to demonstrate the ASV's improved capability to interact intelligently with its environment while fulfilling the task requirements of the Roboboat competition.

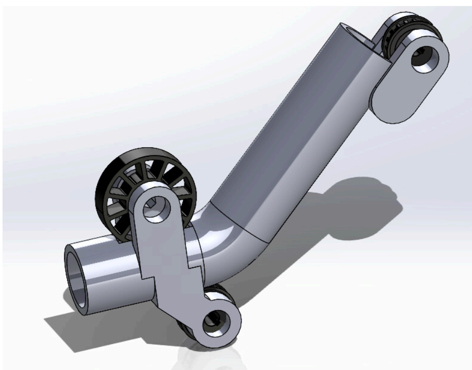

Figure 11. Racquetball Turret without electrical components and mounting platform

IV. TESTING STRATEGY

To ensure that the ASV was prepared for the competition, a rigorous testing phase was undertaken for the main components of the ASV. The propulsion system and perception system were updated for RoboBoat 2025, and are critical to the success of the ASV during the competition

A. Propulsion and Control

In preparation for the competition, Team AMORE carried out rigorous water testing to ensure their propulsion system could handle the demanding conditions expected during the event. By testing with a full payload in strong winds and currents, the team assessed the system's resilience, identifying areas for improvement.

The St. Marys River in Sault Ste. Marie, MI provided an opportunity for stress testing the propulsion. The observations gathered from testing allowed the team to optimize their propulsion controllers for the competition, ensuring the system was prepared to perform under challenging conditions. The stress testing of the propulsion system provided valuable insight into how the vehicle may fare in Sarasota, FL for RoboBoat 2025.

With the propulsion system validated, a testing plan was developed to validate the low-level controllers while in Sarasota, Florida. This testing plan is shown in Table 1.

Table 1. Propulsion and Control system testing plan

Step	Description	Focus	Validation
1	Dry Testing	Controller Response	Thruster and ROS functionality
2	Pool Testing	Heading and Speed	PID controller output
3	Pool Testing	Station Keeping	PID controller output
4	On-site Testing	Heading and Speed	ASV Behavior and PID controller output
5	On-site Testing	Station Keeping	ASV Behavior and PID controller output
6	Dry Testing	PID Controller Switching	PID controller output
7	Pool Testing	PID Controller Switching	PID controller output
8	On-site Testing	PID Controller Switching	ASV Behavior and PID controller output
9	Pool Testing	Vision Integration	Trajectory Generator Output
10	On-site Testing	Vision Integration	Trajectory Generator Output

B. Perception

A new perception system was implemented on the ASV with a new vision processor, so the perception system required modification to ensure its functionality for the competition. The first step to testing the perception system was the validation of its functionality through the use of Gazebo and Virtual RobotX (VRX). Gazebo is an open-source simulation software for robotics [7]. VRX is an open-source simulation environment tool for Gazebo used to test autonomous maritime robotic solutions [7]. VRX models realistic environmental conditions, such as wind and current, that the WAM-V could face when operating. VRX also has models of game elements such as buoys and light stacks. This tool was used to ensure the code developed for the detection of the buoys worked as expected. The results from the testing signaled that the object detection code was able to identify the buoy. This can be seen in Fig. 12.

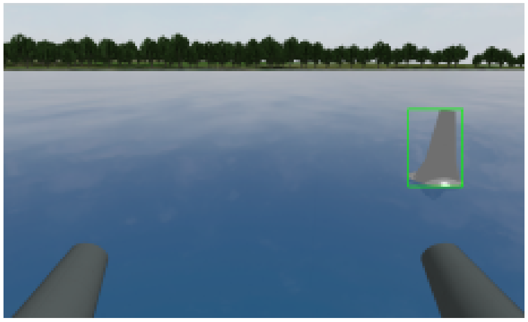

Figure 12. Object detection of buoy in VRX

The next step for testing the perception system was by conducting in-person testing. The ASV was placed in the water with a green and red buoy in front of the vessel and had to identify each of the buoys. The green buoy was located on the starboard side of the vessel and the red buoy was located on the port side. This setup mimicked the configuration of the gates and buoys at RoboBoat and RobotX. The ASV was able to identify both buoys, so the next step was to test the path planning algorithm. Fig. 13 shows the detection of the red buoy by the stereo camera.

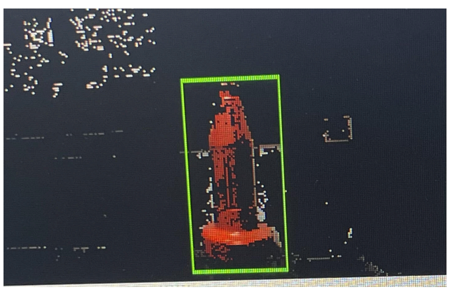

Figure 13. Detection of red buoy using stereo camera

To test the path planning algorithm, the buoys were set up similar to the gate configuration seen for dynamic channel navigation at RoboBoat [6] and RobotX [8]. The path planner output was viewed in real-time to see if a path was generated for the ASV to navigate through the buoys. The ASV was able to successfully locate the buoys using the LiDAR and identify the color of each. The ASV path planner generated a point between the buoy gate which the ASV navigated to. With this result, the perception system was determined to function as expected and would be ready for RoboBoat 2025.

V. CONCLUSION

AMORE's ASV showcases advancements in maritime robotics, focusing on system integration and reliability for the 2025 RoboBoat Challenge. Testing of the ASV confirms the system's reliability for competition tasks such as channel navigation and rescue deliveries. This work positions the team for success in RoboBoat and shows some of the broad applications of marine robotics in the real world.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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