Voyage to Autonomy: Development of an Autonomous Surface Vessel for RoboBoat 2024

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Abstract—Autonomous vessels are being used to free up human resources by collecting data for marine research, surveying, weather forecasting, port maintenance, deploy other vehicles, work on hazardous environments, and security. This growth is creating a demand for engineers with a knowledge of and passion for marine robotics. To provide an opportunity for students to gain experience in this realm, several maritime robotics competitions have been started. One of these, the RoboBoat competition, requires teams of high school and undergraduate students to design and implement an autonomous surface vessel to complete tasks related to those being tackled in the industry today, such as vision and navigation. To complete these tasks, teams from Lake Superior State University and Florida Atlantic University have partnered to create an autonomous surface vessel. The resulting vessel has a catamaran-style hull, two stationary thrusters providing differential thrust, and a Guidance, Navigation and Control system.

I. Introduction

Team Autonomous Maritime Operations and Robotics Engineering (AMORE) is a multidisciplinary team of students from Lake Superior State University (LSSU). Team AMORE is in its third season of Robonation competitions , having competed in Virtual RobotX (VRX) 2021 and 2023, RobotX 2022, and RoboBoat 2023. For the mutual benefit of both clubs, Team AMORE and the Marine Robotics Club (MRC) from Florida Atlantic University (FAU) decided to collaborate for Roboboat 2024. Working together, these two teams have designed an Autonomous Surface Vessel (ASV) for the competition. Team AMORE was responsible for the software and the electrical hardware and sensors, while the MRC was responsible for the propulsion system and the hull.

II. Competition Goals

When Team AMORE attended its first RoboBoat competition in 2023, the team's strategy was to focus on tasks which were closely related to tasks attempted at RobotX 2022 a few months before [1]. The action plan for the competition was based on past observations that using GPS waypoints was the quickest way to complete individual tasks, but was not viable for semi-finals and finals rounds that required the completion of multiple tasks in one time period [1]. To be competitive in semi-finals and finals, it was concluded that the best approach was to use vision to dynamically navigate [1].

This year, Team AMORE will follow a similar strategy as shown in Figure 1. The team's goal is to initially focus on reliable GPS navigation and gradually shift into using vision to complete all of the navigation, obstacle avoidance, and docking tasks. This strategy consists of collecting both vision and GPS data from trial runs on the course, completing tasks using GPS waypoints while using vision for dynamic obstacle avoidance, and then finally completing tasks using solely vision data. This strategy will leverage software developed for the 2023 VRX competition, where Team AMORE placed 5th.

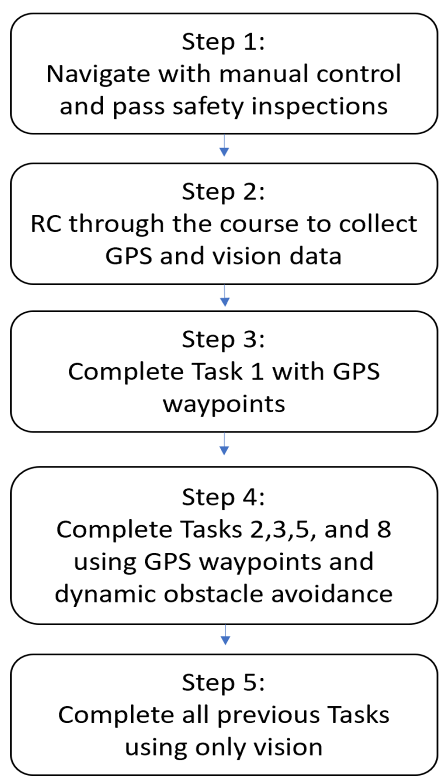

Fig 1. Team AMORE's competition strategy.

III. Autonomous Surface Vehicle Design.

To complete the strategy laid out in the previous section, Team AMORE developed an ASV optimized for robust control and easy implementation of vision-based autonomy. A custom hull (A) was developed by FAU to fulfill the RoboBoat requirements, with a propulsion system (B) designed to mount to the hull. LSSU developed a simple Guidance, Navigation, and Control (GNC) system (C) which used a commercially available controller to allow the team to focus on the vision system (D). Finally, both groups worked closely to ensure a reliable Safety System (E). The strategy behind the design was to focus on vision implementation.

A. Hull

The FAU team was responsible for the design of the ASV hull. The design had to be capable of withstanding various saltwater conditions while also fulfilling the requirements of RoboBoat and student projects at FAU.

I. Constraints

The hull design had three main constraints: physical construction, testing, and budget. To construct the hull, FAU's SeaTech campus provided the team with resources such as CNC machinery. The campus also provided intercostal water access to test the hull. This left the main constraint as a budget of US$2,800. To stay within the budget, the team maximized the time and material available by diligently planning the design and build process ahead of time.

II. Criteria

The team's criteria for the hull design included those necessary to compete in the RoboBoat competition, as defined in the competition requirements [3]:

- Must fit within a 1.829 x 0.914 x 0.914 m box
- Must have a mass of less than 63.5 kg

Additional criteria were set by the team team to help with the design process and to allow the vehicle to be used in multiple scenarios:

- The capability to operate at 1 m/s
- The capability to operate in 10 m/s headwind
- The capability to operate in a marina environment with fairly flat waters with an occasional wake from passing vessels
- Sufficient strength to accommodate caused by the use of docking machinery
- Protection of electronics from the water by enough height above the waterline to prevent splashing the deck in stated operating conditions

III. Development

To design a hull that met all the constraints and criteria above, the team decided to focus on optimizing five characteristics: buoyancy, stability, structural integrity, maneuverability, and the ability to be repurposed for a variety of uses.

After comparing several possible hull layouts, the decision was made that the most ideal hull to fit these characteristics overall would be a separate catamaran style hull with a deck in between. The resulting design, shown in figure 2 , had a length of 1.52 m, an overall beam of 0.660 m, and a centerline beam of 0.445 m. The hull was designed to carry 22.7 kg of electronics for optimal efficiency. This configuration results in a calculated draft of 7.62 cm (excluding the thrusters). At this draft the deck of the vessel sits at 12.7 cm above the waterline. . This is sufficient to protect the electronics in the proposed operating conditions.

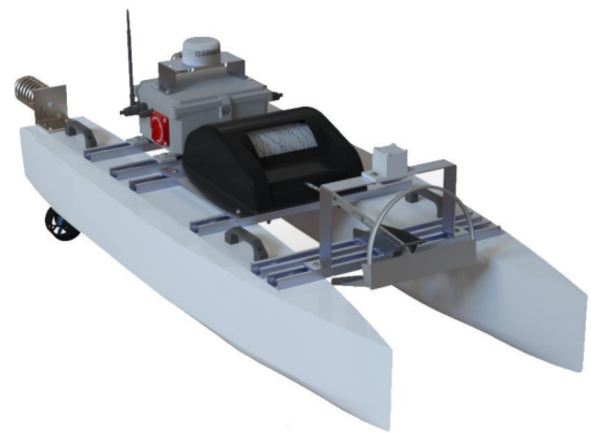

Fig 2. Rendering of the hull with propulsion and electronics added.

The deck of the vessel consists of six cross-members of C-Channel Aluminum stock, which provide rigidity to the hull structure. They also provide easy attachment points for electronics boxes, sensors, and any future modular systems.

IV. Construction

To construct the hull, the pontoons were split into eight sections to accommodate the table size and cutting capabilities of the available Chevalier CNC machine, as shown in Figure 3. Each pontoon was divided in half lengthwise and then widthwise for cutting. The four bow sections were cut from foam blocks. The foam pontoons were joined using epoxy, and then aluminum plates were epoxied to the top for the deck to bolt into. The hulls were then covered in a hand-laid layer of fiberglass, and coated in marine epoxy. Finally, a layer of putty was added to smooth any irregularities in the fiberglass and the hulls were painted. Aluminum C-Channel cross-members were machined and bolted to the plates on top of the hulls. Each pontoon was leveled to ensure perpendicular alignment of the platform rails. Each pontoon was also leveled prior to the assembly.

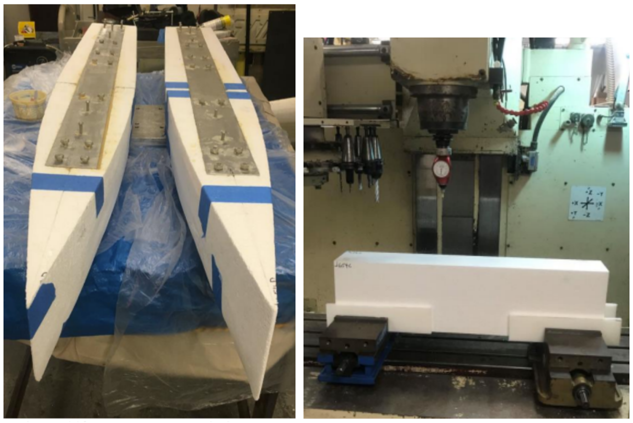

Fig. 3 (Left) the foam pontoons joined and attached to deck mounting plates. (Right) Machining a piece of a pontoon.

B. Propulsion

The ASV's propulsion system, developed by FAU in tandem with the hull, is differential drive. Two Blue Robotics T200 thrusters, shown in Figure 4, were mounted to the stern of the ASV with one on each hull. These thrusters provide 36.4 N of thrust [4], which fulfills the criteria above. Each thruster is controlled by an individual T200 ESC, which receives a control signal sent from the GNC system.

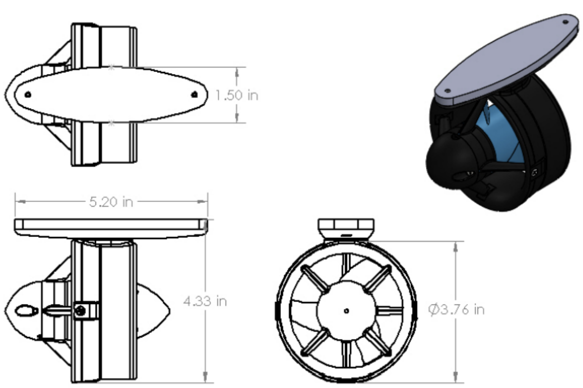

Fig. 4 Blue Robotics T-200 thruster

C. Guidance, Navigation, and Control System

To control the ASV, a robust GNC system had to be developed to integrate the vehicle's various processors, sensors, and communications. This GNC system draws heavily from the strengths of previous GNC systems developed by Team AMORE for the 2022 RobotX Challenge [2] and the 2023 RoboBoat Competition [1], but simplifies these systems substantially with a commercially available controller. The two divisions of the GNC system are the GNC box and the vision subsystem.

I. GNC Box

The GNC hardware is mounted in a designated electronics box on the deck of the ASV. Its main components, shown in Figure 4, are the Jetson Orin, Pixhawk, Wifi router, and RC receiver.

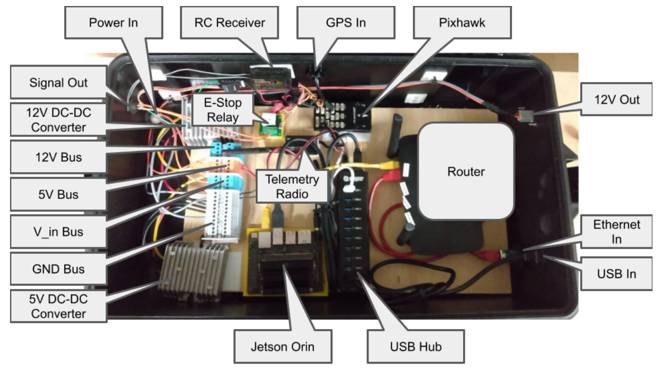

Fig. 5 The GNC box with components labeled

The Jetson Orin is the main processor of the ASV and runs the autonomy code, it runs Ubuntu 20.04 operating system, and ROS Noetic. It contains the ROS drivers for communicating with the sensors and the Pixhawk. The inclusion of a Pixhawk C6 was a major improvement on Team AMORE's past GNC system and replaced the custom PID controllers developed by Team AMORE for previous competitions [1],[2]. It was selected because of its ease of use and because it simplified the GNC system by providing an existing, well-documented controller.The Pixhawk has internal sensors, including an IMU, GPS, compass, and altimeter [5] which it uses to determine its exact location and heading to maneuver autonomously, the Jetson Orin only needs to publish a desired coordinate to the Pixhawk and it will ensure the ASV reaches that location.

The Wifi router provides mid-range communication between the Jetson Orin and the ASV base station computer, which is sufficient for the scale of RoboBoat. A Radiolink R12DS receiver connects the ASV to the RC controller on shore. There is an additional telemetry radio used to connect to the Pixhawk in order to edit parameters on it from a computer near the ASV without having to be directly connected to the GNC box. . The GNC box also contains an RC controlled switch which is a part of the safety system below, and a USB hub which allows serial communication between the Jetson Orin and the rest of the GNC system. Finally, a pair of voltage converters divides an 18V input from the propulsion batteries into the 12V and 5V used by the GNC components.

The GNC box interfaces with the vision system by means of a USB connector for the camera and by ethernet for the LIDAR. The box interfaces with the propulsion system with a power input connector and a signal output connector. This was done to simplify the integration of the two universities' equipment. The signal connector carries two E-stop wires, three PWM channels (including a spare), and a PWM ground pin for noise reduction.

D. Vision System

Team AMORE used the same vision system, consisting of a VLP-16 LiDAR and a ZED 2i stereo camera, developed for previous RobotX competitions [2]. Details on the components can be found in Appendix A. The system uses the LIDAR for detecting and localizing nearby objects in the water with respect to the vessel, and maps them to an occupancy grid. The stereo camera identifies those objects based on color. Figure 6 shows a diagram of the vision system.

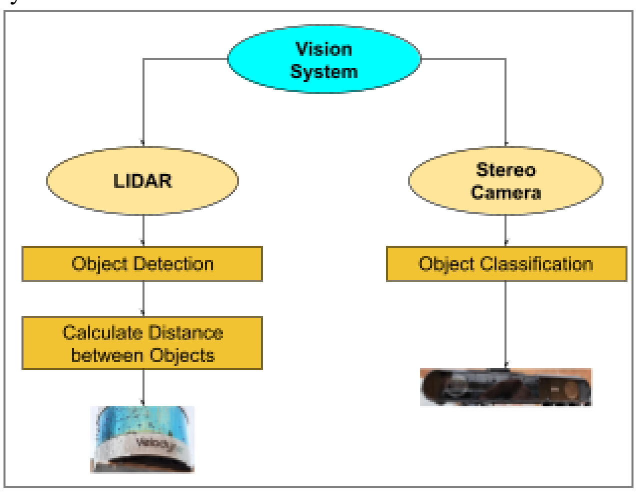

Fig. 6 diagram of AMORE's vision system from [2]

The LIDAR employs specific criteria for data filtering, encompassing parameters such as angle, height, and distance. The angle for detecting competition obstacles is set between 45º to -45º in North East Down coordinates, while the height and distance parameters will be fine-tuned during the competition based on the characteristics of the obstacles. To enhance the accuracy of the LIDAR data, the algorithm utilizes a median filter to calculate the object's distance and determine the distance to its midpoint. Upon completing object detection, an occupancy grid is generated to map the competition course. This grid serves as an input for the path planner, guiding the ASV along the mission-based path. Implemented with the PCL libraries and using the LIDAR's ROS driver, the algorithm publishes the results to a point cloud topic. Figure 7 illustrates the created occupancy grid, identifying a red buoy, along with the desired position for the ASV.

Once the location of objects in the water are known, the ZED 2i camera performs object classification. Utilizing image streams, it identifies colors by analyzing the object's position within the stream. Depending on the color detected, the algorithm proceeds to classify the objects accordingly. The color identification process relies on OpenCV libraries and involves defining HSV color ranges for each specific color, including green, red, black, orange, white, and blue. Figure 8 shows the vision algorithm correctly identifying a white buoy while being tested on the VRX Gazebo simulator.

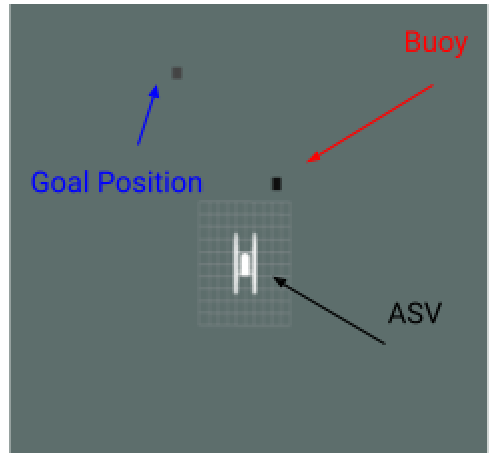

Fig. 7 Visualization of the occupancy grid derived from the LIDAR data

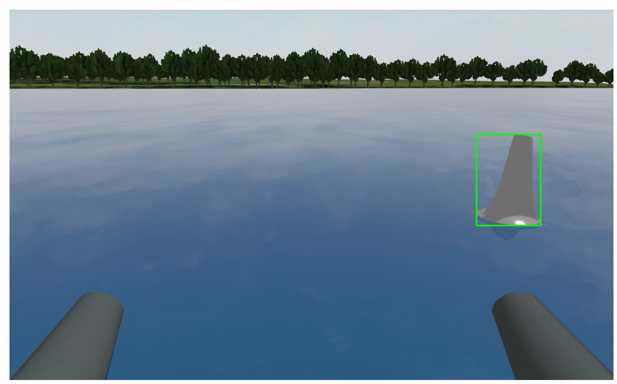

Fig. 8 Object Classification from VRX Simulator

E. Safety System

The rules for the RoboBoat competition require both physical and remote Emergency stops (E-stops) on the ASV [3]. To meet the physical requirement, an E-stop button was placed in series with the propulsion batteries before any other components. When the button is pressed, power is disconnected from the propulsion system. This E-stop is placed on top of the GNC box, where it is clearly visible and easy to access. A remote E-stop is present as a switch on the RC controller. When triggered, the battle switch acts as a relay to disconnect power. The remote E-stop also operates as a fail-safe, activating if connection to the RC controller is lost.

IV. Testing Strategy

Team AMORE's testing strategy deviates from conventional approaches due to the unique challenge of collaborating with another University. This necessitates a distinct testing approach, with each university being responsible for separate testing procedures. More details are outlined in the timeline included in Appendix B.

The LSSU team is responsible for testing the ASV's high-level software. The software was developed using the VRX Gazebo simulation. Mission planning, path planning, and vision components were developed and tested within Gazebo.

For software development, the team first tested the vision algorithm outlined previously. VRX competition elements, which closely resemble Roboboat competition elements, were used to test the detection and classification capabilities of the vision system. The team achieved an accuracy of 0.2m for object detection, seen in Figures 7 and 8, and 90% accuracy with detection.

Upon successful validation of the vision system using VRX competition worlds, the team proceeded to develop mission planning and path planning capabilities, incorporating perception. Testing of the path planning involved utilizing the Gazebo worlds designed for channel navigation and docking. Figure 9 and 10 are examples of the team's VRX simulations.

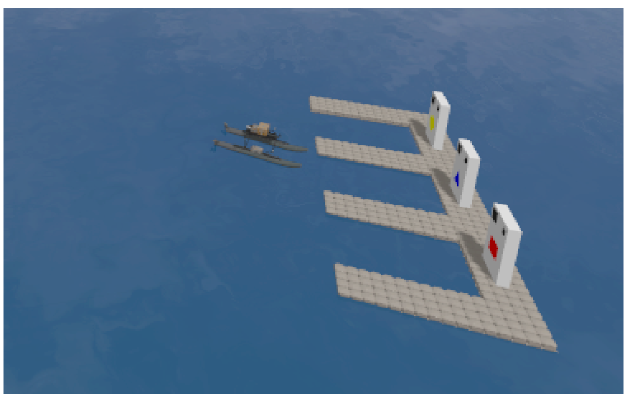

Fig. 9 VRX Simulation for Docking

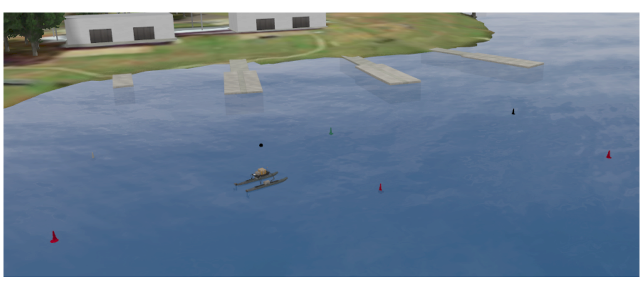

Fig. 10 VRX Simulation for Channel Navigation

The FAU team is responsible for testing the ASV's propulsion system and performing on-water tests This testing will begin in January 2024, after completing the hull and GNC box. The FAU team will first interface the GNC and vision systems with the Hull and perform the on-the-water tests in preparation for the competition. Before initiating these on-water tests, the team will conduct tests to ensure that the vehicle is waterproof. This will ensure the system's durability for on-water testing. Exact days for testing can be found in Appendix B.

V. Conclusion

Team AMORE has developed an ASV for competition in Roboboat 2024. The hull was created by FAU using a dual hull/catamaran as a base platform and includes many systems previously developed at LSSU for a RobotX WAM-V USV and previous RoboBoat 2023 ASV. The GNC system was substantially simplified from previous years by using a commercially available Pixhawk instead of developing a control system. The team is excited to participate in Roboboat 2024 and is looking forward to using the USV at the competition.

VI. Acknowledgements

Team AMORE would like to thank the Sault Tribe of Chippewa Indians, LSSU School of Engineering and Technology, LSSU Center for Freshwater Research and Education, FAU Department of Ocean and Mechanical Engineering, FAU SeaTech Research Facility, and all the other students and individuals who have supported us. Without their support, this project would not have been possible.

In addition, we would like to thank Lake Superior State University's Faculty advisor, Dr. Edoardo Sarda and Florida Atlantic University's Faculty Advisor, Dr. Pierre-Philippe Beaujean for their continuous support on this combined team for the 2024 RoboBoat robotics competition, and for challenging us to pursue excellence in our work. Finally, we would like to thank our universities, communities, and families for supporting us on this journey.

VII. References

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[3] *RoboBoat 2024 Team Handbook* , RoboNation, 2023. [Online]. Available: https://robonation.org/app/uploads/sites/3/2023/10/Team-Handbook_RoboBoat-2024_v1.0.pdf

[4] T200 Thruster. Blue Robotics. https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/ (Accessed December 26, 2023).

[5] Pixhawk 6C. Holybro. https://docs.holybro.com/autopilot/pixhawk-6x (Accessed November 30, 2023).

VIII. Appendix A: List of Major Components

Component	Vendor	Model/Type	Custom/ Purchased	Cost	Year of Purchase
Hull	N/A	N/A	Custom	1 x $2800	2021
Propulsion T200 Thruster Basic ESC Thruster Mounts	 Blue Robotics Blue Robotics N/A	 T200 T200 N/A	 COTS COTS Custom	 2 x $200 ea 2 x $36 ea N/A	 2021 2021 2021
GNC Box Enclosure Jetson Orin Pixhawk Wifi Router RC Receiver 5V DC/DC Convertors 12V DC/DC Convertors	 PolyCase Nvidia Holybro Linksys RobotShop Amazon Amazon	 WQ-77 Orin Nano Dev Kit 6C WRT1900ACS AT10ll N/A N/A	 COTS COTS COTS COTS COTS COTS COTS	 1 x $150 1 x $499 ea 1 x $290 ea 1 x $240 1 x $140 ea. 1 x $15.99 ea. 1 x $18.88 ea.	 2022 2023 2022 2023 2022 2022 2022
Vision Camera LIDAR	 Stereo Labs Velodyne	 Zed2i VLP-16	 COTS COTS	 1 x $549 1 x $4000	 2022 2022

IX. Appendix B: Testing Plan

I. Scope

Team AMORE designed different testing goals based upon tasks and what equipment was available to LSSU and FAU. The FAU electrical team will be key in the design and testing of the vessel, propulsion system, and the integration of the safety and GNC systems. Whereas, the LSSU software and electrical teams were influential in the software development and GNC box design.

II. Schedule

The schedule is based on LSSU developing GNC, and software and FAU implementing all the systems, and doing the final testing prior to the competition. Table 1 summarizes the timeline, and results for each of the testings.

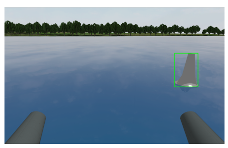
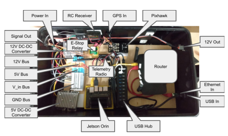
Start/End Date	**Documentation**	**Target**	**Result**	**Environment**	**Member Presence**
11/01/23 - 11/20/23		Software development: 1. Mission Planning 2. Path Planning 3. Vision	Object detection with a 0.2m accuracy	VRX Gazebo Simulation	LSSU Software Team
09/13/23 - 12/10/23		GNC Box finalized	Ready to test with the propulsion system	Lake Superior State University Lab	LSSU Electrical Team
12/15/23- 12/20/23		GNC Box Shipping	Box Ready to ship to FAU	Lake Superior State University	All LSSU Team
01/08/23- 01/15/23	N/A	Interface Propulsion, Safety and GNC	N/A	Florida Atlantic University - SeaTech	FAU Electrical Team
01/16/23- 01/27/23	N/A	Water testing with RC, and Auto	N/A	Florida Atlantic University - SeaTech	FAU All Team

Table 1. Team AMORE's testing schedule and results

III. Resource & Tools

The teams required different resources and tools throughout the testing schedule. FAU will be using anchored buoys for vision and navigation testing with the vision system, while they integrate it with the rest of the ASV. LSSU is using simulation tools like Gazebo for developing software, and lab equipment to design and build the GNC box.

IV. Environment

The software was tested using VRX Gazebo Simulation. This was utilized due to weather conditions at LSSU, ASV being in the process of being built while the software was being developed, and the distance between LSSU and FAU.

The on-the-water testing environment is the FAUs SeaTech Facility on the Stranahan River. Testing will occur in the protected marina where anchored buoys will be added to integrate the whole system and simulate competition tasks.

V. Risk Management

Both LSSU and FAU subteams realize the need for testing, however through recent events of a lithium battery explosion which caused a fire at LSSU's robotics lab, both teams actively recognize the need for safety while testing. As a result, safety protocols have been put in place to manage battery usage and charging. Additionally, there is great risk in using the marina due to wildlife access to it from the river.

In order to manage the risks associated with testing the vessel, students will need to work with SeaTech to coordinate testing sessions in the marina. Prior to each testing session, faculty will need to be notified of who will be testing, proper paperwork will be filled out to allow access to the facility, and the team will be briefed on the safety protocols of the facility, if something is to go wrong. After that debrief the team will begin the in-the-water testing.

VI. Results

Throughout the winter testing, the team will be able to obtain information that will help in updating the control system. Each session the marina will allow the FAU team to run the vehicle autonomously and implement all systems to the vessel. Having access to these environments will help enhance the testing process.