Navigating the Ocean: Artificial Intelligence Based Aeronautical Swarm Robotics

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***Abstract*—This paper presents the advancements and integration strategies employed by Team Owltonomous in the 2024 Maritime RobotX Challenge, focusing on the integration of Artificial Intelligence (AI) for enhancing the navigation capabilities of an Unmanned Surface Vehicle (USV) and an accompanying Unmanned Aerial Vehicle (UAV). The team has extended the capabilities of a pre-existing USV platform through the addition of a UAV to form a collaborative aerial-surface robotic system. Key innovations include the integration of AI-based vision and control algorithms to enable robust object detection, localization, and obstacle avoidance for autonomous maritime navigation. The AI-enabled vision system utilizes both LiDAR and camera sensors on the USV and UAV, leveraging K-Means clustering and YOLOv9 for effective real-time classification and localization. Additionally, the team employed an improved Artificial Potential Field (APF) algorithm for obstacle avoidance. This collaborative multi-agent robotic system demonstrates improved accuracy and robustness in the challenging maritime environment.**

Keywords*—*Wave Adaptive Modular Vessel (WAM-V) 16; Unmanned Surface Vehicle (USV); Unmanned Aerial Vehicle (UAV); Artificial Intelligence (AI); Artificial Potential Field (APF); Swarm Robotics; YOLOv9; LiDAR.

I. INTRODUCTION

Integrating Artificial Intelligence (AI) into the vision and control systems of the USV is essential for success in the 2024 Maritime RobotX Competition. The adoption of AI in robotics facilitates continuous improvement and significant refinements. The team aims to establish a robust and progressively improving baseline of AI-enabled classification, localization, and control in the maritime domain. Beyond surface-level operations, the integration of the UAV enhances system robustness, particularly in object classification and localization. The UAV utilizes the same vision algorithms as the USV, optimized for aerial perspectives. The fusion of data from both the USV and UAV increases the accuracy and repeatability of the system for the competition.

Fig. 1. Team Owltonomous USV on Water Testing

II. DESIGN STRATEGY

The system design consists of the USV, each subsystem, and the UAV used for aerial tasks. The following sections review the mechanical, electrical, and software design for both vehicles.

A. *Unmanned Surface Vehicle Design*

a) Propulsion System

The propulsion system is composed of two 36V MinnKota Riptide Transom motors [2]. To integrate them on the USV, the Roboteq MDC1460 [3] motor controllers are used. In addition, this motor controller is controlling the servo used for azimuthing the thrusters, which is the Gearworx Torxis Servo !01855 [4]. A key enhancement for this year's competition is the integration of bow thrusters, providing a more robust, over-actuated system specifically for station-keeping purposes. The set of bow thrusters are Flipsky Inrunner thrusters [5], both are controlled by Mini FSESC4.20 ESCs [6]. The batteries used for both sets of motors/motor controllers are LBS 36V 40AH LiFePO4 batteries[7].

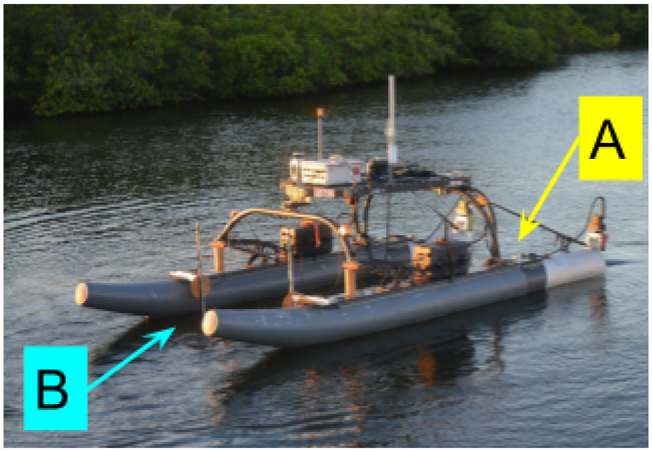

Fig. 2 a) MinnKota Propulsion System, and b) Bow Thruster

b) Mechanical Alterations

The main mechanical alteration is the addition of a tray underneath the original payload tray of the USV. The payload tray is now the landing area of the UAV. The electronics tray has been designed with a drawer mechanism for easier access of the electronics and batteries. The fiberglass board was mounted beneath using 5 sets of 3-inch 80/20 aluminum as standoffs. On this board, two rails are made out of HDPE. In addition, four sliders are also made out of HDPE on the bottom of a smaller fiberglass board to act as the drawer. Fig. 3. illustrates the mechanical design of the drawer system.

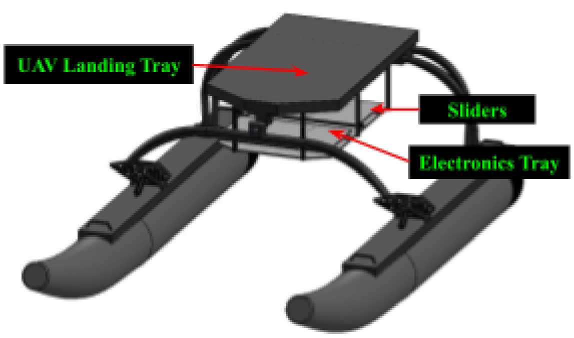

Fig. 3. CAD of the electronics tray design

c) Guidance, Navigation, and Control System (GNC)

The GNC system's hardware is housed in the following boxes, located on the electronics tray of the USV: Primary GNC Box, and GNC Battery Box.

The Primary GNC Box holds most of the electronics. Major components included in the box are, one Jetson Orin AGX 32GB [8], and one Jetson Xavier AGX [9] as the main processors. Jetson Orin is used for the High-Level such as Vision System and Path Planning, and the Jetson Xavier is used for the Low-Level such as sensor data processing and control of the USV. One Pixhawk 6C with a U-blox F9P RTK GPS [10] is used for the GNSS system of the USV. Linksys WRT1900AC WiFi Router [11], Futaba RC receiver [12], two Teensy 4.1 microcontroller [13] responsible of generating the PWM signal for the propulsion system, and finally it contains a custom PCB that manages voltage protection, safety system and voltage converters for the different devices. Fig. 4. shows the contents of the Primary GNC Box.

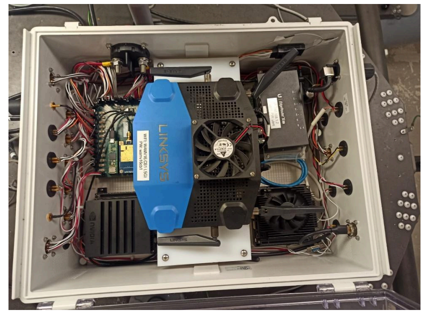

Fig. 4. The Primary GNC Box holds the majority of the electronics onboard the USV.

Additionally, the GNC Battery Box is used to power all of the necessary electronics. One LiFePO4 Battery(12-14.6V) is used to power the GNC system. This battery box is fused, and has a toggle switch.

The GNC software is executed on a Jetson Xavier and a Teensy 4.1 microcontroller. The Jetson Xavier runs most of the USV control software while the Teensy 4.1 outputs the propulsion system signal thrusters. These two processors communicate using ROS2. USV control comes from the Remote Controller (RC) when in manual mode and Jetson Xavier when in autonomous mode.

The low-level control strategy employs Proportional-Integral-Derivative (PID) controllers, widely recognized for their simplicity, effectiveness, and adaptability. The autonomy of the USV consists of a PID-based station-keeping controller[14] and heading-speed controller.

Station-keeping controller consists on maintaining positions and heading over time, minimizing the error ε (1). The control output for the forces τ , and moment M_z, can be calculated using (2).

$$\varepsilon = \eta_d - \eta \tag{1}$$

$$where\ \eta = [x\ y\ \psi]^T\ and\ \eta_d = [x_d\ y_d\ \psi_d]^T$$

$$\tau = K_p \cdot \varepsilon + K_d \bullet \frac{d(\varepsilon)}{dt} + K_i \int_0^t \varepsilon\, dt \tag{2}$$

Since the USV is over actuated, it needs to develop a control allocation scheme to translate the output of the controllers to the appropriate thrust output, the detailed approach can be found in [15].

Heading-speed controller consists of maintaining heading and speed over time. The control outputs are the force T_x, w.r.t to the body frame, and moment M_z.They can be calculated using (4). The control allocation for this controller can be found in [16].

$$\varepsilon = \eta_d - \eta \tag{3}$$
$$where\, \eta = [v_x\ \psi]^T \, and\, \eta_d = [v_{x_d}\ \psi_d]^T$$

$$\tau = K_p \cdot \varepsilon + K_d \bullet \frac{d(\varepsilon)}{dt} + K_i \int_0^t \varepsilon\, dt \tag{4}$$
$$where\, \tau = [T_x\ M_z]^T$$

The strategy consists of using both controllers for navigation [16]. The algorithm consists of calculating the vectors representing the directions between the waypoints, A, B, and C (5). Once the vectors are determined, their dot product is computed (6), and the magnitudes of the vectors $\vec{AB}$, and $\vec{BC}$(7). Finally, the angle is found by applying the arccosine function to the ratio of the dot product to the product of the vectors' magnitudes. (8).

$$\vec{AB} = \left(x_B - x_A, y_B - y_A\right) \tag{5}$$
$$\vec{BC} = \left(x_C - x_B, y_C - y_B\right)$$

$$\vec{AB} \bullet \vec{BC} = \left(x_B - x_A\right) \bullet \left(x_C - x_B\right) + (y_B - y_A) \cdot (y_C - y_B) \tag{6}$$

$$||\vec{AB}|| = \sqrt{\left(x_B - x_A\right)^2 + (y_B - y_A)^2} \tag{7}$$
$$||\vec{BC}|| = \sqrt{(x_C - x_B)^2 + (y_C - y_B)^2}$$

$$\emptyset = cos^{-1}\left(\frac{\vec{AB} \bullet \vec{BC}}{||\vec{AB}|| \bullet ||\vec{BC}||}\right) \tag{8}$$

Station-keeping controller is used when the angle is from $0^\circ < \emptyset < 150^\circ$, and $-150^\circ < \emptyset < 0^\circ$, or when the magnitude of the vector is lower than 10 meters, otherwise the USV would use the heading-speed controller.

The Path Planning strategy is using an Improved Artificial Potential Field (APF)[17] for obstacle avoidance of competition objects. This method describes the environment with the potential field. A potential field is expressed as a sum of the attractive field due to the goal point $U_{att}(q)$ and the repulsive field $U_{rep}(q)$ (9), due to the obstacles, see Fig. 5.

$$U_{art}(q) = U_{att}(q) + U_{rep}(q) \tag{9}$$

The goal position is the global minimum of the artificial potential field, the function of the attraction field is explained in (10), and the repulsion field in (11). More details of the improved-APF method can be found in [17].

$$U_{art}(q) = \frac{1}{2} k \rho^2 (q, q_{goal}) \tag{10}$$
$$\rho(q,\ q_{goal}) = \sqrt{(x - x_{goal})^2 + (y - y_{goal})^2}$$

$$U_{rep}(q) = \{0.5\eta\left(\frac{1}{\rho(q, q_{goal})} - \frac{1}{\rho}\right)^2 \tag{11}$$
$$if\ \rho(q, q_{goal}) \le \rho_0$$
$$\text{Otherwise } U_{rep}(q) = 0$$

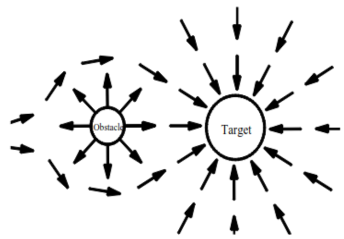

Fig. 5. APF model

B. Unmanned Aerial Vehicle Design

a) Frame and Mechanical Alterations

The UAV was developed by integrating a custom GNC box, mounts, wiring, and sensor assemblies onto the base frame, the Holybro X500 V2 [18]. With a payload capacity of 3.3 kg after accounting for the recommended battery weight, this frame meets the UAVs requirements. Key design considerations included functionality, safety, and modularity. The UAV kit allows for timely repair or replacement of parts. The GNC box is submersible up to 0.3 meters for 30 minutes and was designed to ensure positive buoyancy, allowing the system to float in freshwater. The complete UAV is depicted in Fig. 6.

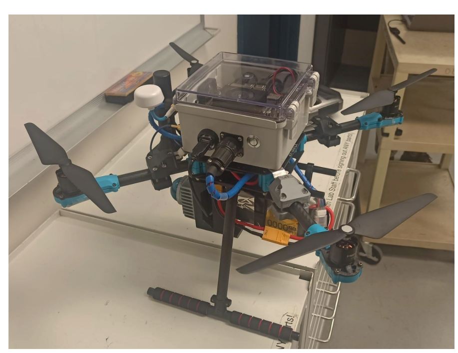

Fig. 6. Team Owltonomous UAV

b) Guidance, Navigation, and Control System

The guidance, navigation, and control system is all being handled by a Holybro Pixhawk 6C mini [19] and a Jetson Orin Nano [20]. The controller and sensor stack is all handled internally on the Pixhawk, utilizing the Px4 software. To communicate with the main processor of the UAV, Jetson Orin Nano, Mavlink is used. Mavlink is a serial protocol most commonly used to send data and commands between vehicles and ground stations. MAVROS, which is an extendable communication between computers running ROS2 for any Mavlink enabled autopilot, ground station, or peripheral, is used to communicate between Fig. 7 which shows a diagram on how the communication works between the Jetson Orin Nano and Pixhawk 6C Mini.

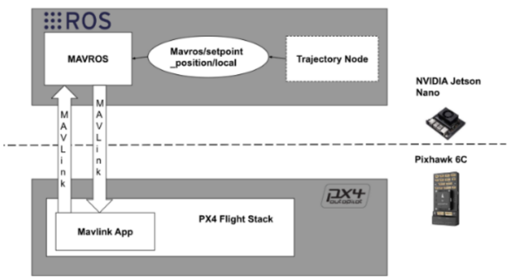

Fig. 7. Diagram of Jetson Nano and Pixhawk Communication

c) Electrical Integrations and Safety

The electrical system serves two primary functions: monitoring and reporting the system's power usage and individual cell voltages of the 4S LiPo battery that powers all motors and sensors. The main electrical components are listed in Appendix A. Safety mechanisms are configured within the flight controller settings, including path planning and mission override capabilities. Triggers such as loss of Wi-Fi or radio communication, activation of the emergency stop, deviation from the designated course, or low power levels initiate a controlled safety sequence. In such events, the system ascends to an altitude of 10 meters and returns to a predetermined location on land. Custom software serves as the primary driver for activating the safety system.

C. Vision System

The USV vision consists of two sensors; a ZED 2i Stereo camera [21] and a VLP-16 HighRes LiDAR [22], see Fig. 8. While the current vision system was inherited from previous teams, it provides sufficient sensing capabilities to meet the requirements of the 2024 RobotX Maritime Challenge. The UAV vision consists of two sensors; a single USB camera and a LIVOX mid-360 LiDAR [23], see Fig. 8.

These sensors were selected for their combined ability to classify and localize objects at low altitudes. With both systems having similar hardware, the software also shares similarities. K-Means clustering algorithms [24] were used on both LiDAR point clouds for object detection, basic-classification, and localization.

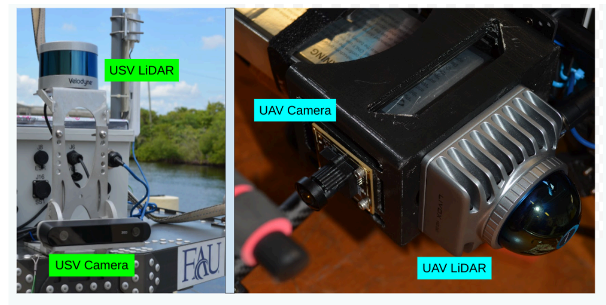

Fig. 8. USV and UAV Vision Systems

K-means clustering is an algorithm used to partition a dataset into k (12) clusters, minimizing the variance within each cluster. The key steps involve initializing k centroids, assigning each data point to the nearest centroid based on Euclidean distance (13), and updating the centroids by averaging the points in each cluster (14). This process repeats until centroid positions converge, meaning changes are smaller than a threshold (ϵ\epsilonϵ) (16). The objective function J (15) is minimized to ensure that the sum of squared distances between data points and centroids is as low as possible, leading to compact and well-separated clusters. This algorithm was then filtered based on cluster parameters for competition specific objects.

$$C = \{c_1, c_2, ..., c_k\} \tag{12}$$

$$S_i = \{ x_j : \| x_j - c_i \| \leq \| x_j - c_m \|, \forall m, 1 \leq m \leq k\} \tag{13}$$

$$c_i = \frac{1}{|S_i|} \sum_{x_j \in S_i} x_j \tag{14}$$

$$J = \sum_{i=1}^{k} \sum_{x_j \in S_i} \| x_j - c_i \|^2 \tag{15}$$

$$\| c_i(t+1) - c_i(t) \| < \epsilon, \forall i \in \{1, ..., k\} \tag{16}$$

You Only Look Once (YOLO) [25], a state-of-the-art object detection algorithm, has been integrated into Team Owltonomous' vision system to enhance both the USV and UAV performance using the camera. YOLO's architecture is designed for speed and accuracy, making it ideal for maritime environments where fast detection is essential. By processing an entire image in a single pass, YOLO achieves high-speed inference while maintaining a high level of precision, which is necessary for detecting buoys, vessels, and obstacles in real-time.

For the 2024 RobotX Challenge, YOLO has been fine-tuned using a custom maritime dataset, ensuring that the model can accurately classify competition-specific objects under varying environmental conditions, such as water reflections or low-visibility situations, see Fig. 9. When deployed on processors like the Jetson Orin AGX and Jetson Orin Nano. YOLO's lightweight design allows it to run efficiently on both the USV and UAV. This dual integration across both platforms enhances the team's capability to perform multi-view detection—merging water-level object detection with aerial perspectives, improving overall system accuracy and robustness. This combination of AI-based vision and advanced control systems enhances the overall system's accuracy and robustness in the challenging maritime environment.

Fig. 9. YOLOv9 Custom Model Detector Output

III. Competition Strategy

This section explains each task's strategies, in the order presented by the 2024 RobotX Team Handbook [26]. The USV begins by entering the course start gates and locating the light buoy. Once detected, the system classifies task regions. Once information from the light buoy is obtained, the system continues classifying task regions. The system then navigates to estimated points, an arc around the light buoy, until a satisfactory overview of the course is derived. The system then completes each task in a calculated order based on confidence and proximity. Point optimization based on our system strengths and weaknesses is the team's overall competition strategy.

A. Situational Awareness & Reporting

A Graphical User Interface (GUI) has been developed on the base station computer which displays both systems status and the task the system is performing. A heartbeat message is generated from that information using C++, reporting the necessary data to the competition judges.

B. Entrance and Exit Gates

Due to the absence of an acoustic system, the strategy for this task involves arbitrarily selecting entrance and exit gates.. The USV will use the vision system explained in the Design Strategy section, using LiDAR and stereo cameras with their respective algorithms to detect and localize the gates.

C. Follow the Path and Wildlife Encounter

The application of algorithms for object detection (described in the previous section), and autonomous navigation is using the APF algorithm for obstacle avoidance. Classification can be used to distinguish between different types of buoys so that cylindrical buoys can be recognized apart from spherical ones.

D. Scan the Code

The object detection and classification techniques allow the USV to navigate to the light buoy, where it will apply the same YOLO model that is being used in the other competition objects. Combining and fine tuning logic, the light buoy pattern can be recorded, reported, and displayed on the GUI while the USV is on station keeping.

E. Dock and Deliver

Unlike previous techniques relying on the LiDAR, this classification will rely predominantly on the camera, which will leverage color classification. Once the proper symbol is determined, the USV will use its LiDAR objection detection to calculate the centroid within the docking bay and then using the APF path planning the USV will switch to station-keeping controller.A ball launcher has not been incorporated into the system for this competition.

F. UAV Tasks

Our team developed the UAV launch and recovery strategy based on the path planning algorithm from [27] at Lake Superior State University. The UAV utilizes RTK GPS, LiDAR and camera for the recovery approach. In addition, the camera classification algorithm used in previous tasks will be used for the Search and Report task.

IV. Testing Strategy

Team Owltonomous testing strategy is composed of simulation, data extracted from the RoboNation data-sharing platform, and on-water testing.. The VRX simulation software has been used in the development of our systems controls and path planning. RoboNation Data sharing has given our team the ability to have access to more diverse data for training and verifying our vision systems algorithms. On-water testing facilitates the integration and application of developed systems, typically involving VRX code or algorithms previously tested on non-real-time data. This step is crucial for verifying software interactions under real-world conditions. The team adopts a strategy of minimal code alteration during testing, emphasizing data collection and post-analysis of system performance. This approach enables continuous improvement that can be quantitatively analyzed. More details are outlined in the timeline included in Appendix B.

A. Simulation

The simulated environment was used to integrate and continuously test mission planning along with path planning. The team used the Gazebo VRX simulator, designing specific worlds for each USV task. In Fig. 10 the USV is detecting the Light Tower and displaying the results on the GUI, and in Fig. 11 the USV is attempting the docking task.

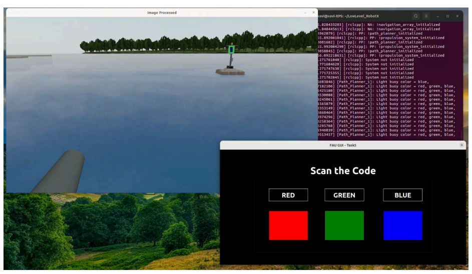

Fig. 10. Team Owltonomous GUI for Scan the Code

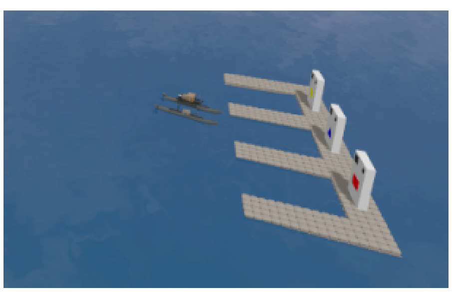

Fig. 11. USV attempting to dock using the VRX simulator

B. Data Sharing Testing

Team Owltonomous members are part of the RoboNation Data Sharing committee. The team has benefited from the data shared by other teams from past competitions. This data has been utilized to train, and test the AI YOLO model. In addition, the team utilized point cloud rosbags for developing the LiDAR detection algorithms and path planning for Follow the Path task. Fig. 12. shows a point-cloud in RViz using shared rosbags, and developing a path to navigate through a gate of buoys.

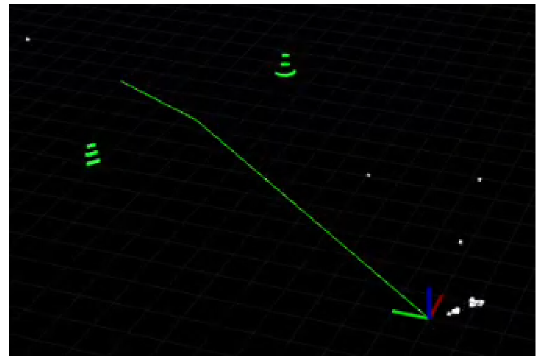

Fig. 12. Buoy Detection and Path Planning Output

C. On-Water Testing

In October 2024, several tests surrounding the control systems and basic mission planning will be tested at US-Intracoastal in Dania Beach, FL. These tests will consist of deploying spheric buoys, and testing the vision system, and path planning algorithms developed based on the simulation environment, and the data shared by other teams on the RoboNation DropBox. Preliminary tests of the PID controllers have been conducted using a figure-eight path, with results shown in Fig. 13. In addition, the UAV launch and recovery testing approach will also be conducted during this month.

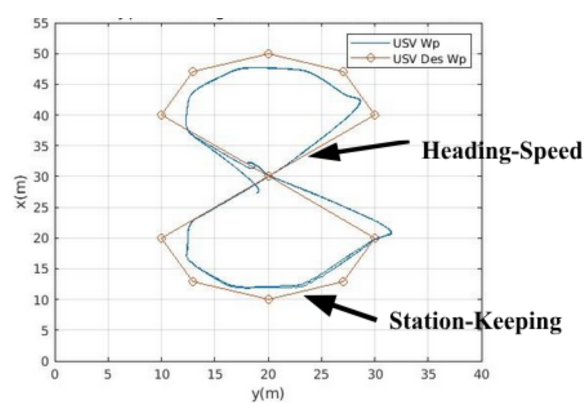

Fig. 13. shows the combined PID controllers approach.

V. Acknowledgments

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VII. Appendix A: List of major components

Component	**Vendor**	**Model/Type**	**Specs**	**Custom/ Purchase**	**Cost**	**Year of Purchase**	**Reasoning**
USV Computer 1	NVIDIA	Jetson Orin AGX	32 GB RAM 2 Tb SSD	Purchased	1999.99	2022	USV Vision Processing
USV Computer 2	NVIDIA	Jetson Xavier	16 GB RAM 2 Tb SSD	Purchased	1499.99	2021	USV Control
USV Custom PCB	FAU E-Lab	USV Main Control Board	6x6in dual Teensy 4.1 Microcontrollers, 8 PWM out, embedded safety, fused outputs, 6 subsystem communications, computer power control	Custom	220.00	2021	USV motor Control, Radio communication, subsystem communication and power distribution, RC monitoring, light stack control, safety system monitoring
USV LiDAR	Velodyne	VLP-16 HighRes	16 Beams, 100 m radius	Purchased	15,000.00	2021	Sensor for autonomous navigation, short and medium ranged performance
USV Camera	Stereolabs	ZED 2i	Stereo Camera, Auto-exposure, waterproof, UV resistant	Purchased	600.00	2021	Object classification and outdoor water resistant sensor
USV RTK GPS/ IMU	Holybro	Pixhawk 6C	RTK and Navigation Sensors	Purchased	124.99	2024	USV Sensors

USV Network Bridge Module	Ubiquiti	RP-5AC-GEN2	5 GHz	Purchased	230.00	2021	USV Communications
USV Light Tower	Banner Engineering Corporation	TL50BLGYRQ	Stack Light Complete Unit Green, Red, Yellow LED Wire Leads	Purchased	263.00	2021	USV Safety and Status
USV Weather Station	AIRMAR	110WX	NMEA2000 Output, wind speed and direction, temperature, humidity.	Purchased	980.00	2021	USV Safety and Control
USV Network Edgerouter	Ubiquiti	ER-X-SFP	5-PORT GIGABIT Router w/POE	Purchased	99.00	2021	USV Communications
USV Main Thrusters	MinnKota	Riptide Fortrex	100lb thrust	Purchased	1149.99	2017	USV Propulsion
USV Bow Thrusters	Flipsky	Inrunner Brushless	160KV, 3000W	Purchased	220.00	2024	USV Propulsion
USV Batteries	Lithium Battery Store	38.4V 40AH LBS Deep Cycle Battery	38.4V 40AH LiFePO4	Purchased	999.00	2017	USV Propulsion
UAV Computer	NVIDIA	Jetson Orin Nano	8 GB RAM 1 Tb SSD	Purchased	499.99	2024	UAV Control and Vision Processing
UAV RTK GPS/ IMU/ Flight Controller	Holybro	Pixhawk 6C Mini	RTK Remote ID Telemetry	Purchased	124.99	2024	UAV Control

UAV RC	Futaba	16 IZS	18 Channel Air Transmitter Only	Purchased	729.99	2024	Mode Switching, RC Control
UAV Battery	Tattuu	Lipo	4s 10000mAh	Purchased	149.99	2024	UAV Power
UAV Frame Kit	Holybro	X500 V2	Kit, Carbon Fiber, motors, ESCs, modified with custom mounts for GNC box	Purchased	149.99	2024	UAVPlatform
UAV Custom PCB	FAU E-Lab	RobotX UAV Motherboard V1	12V 40W, 5V 5W power supplies, lipo cell monitoring, serial sub system communication, temperature sensing and control.	Custom	200.00	2024	Safety and power for electronics and batteries. Small form with specific needs in mind for custom UAV.
UAV LiDAR	LIVOX	Mid-360	360 DEG FOV, 40 m radius range, 16 beams	Purchased	749.99	2024	Aerial Spatial Mapping for Assisted USV navigation, Object classification and localization, UAV landing on USV.
UAV Camera	ELP	16 MP USB Camera	120 DEG FOV, 4K resolution, 30 FPS	Purchased	74.99	2024	UAV Camera for object classification, Aerial mapping and

							landing assistance.

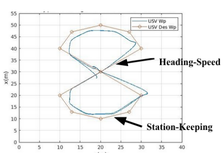
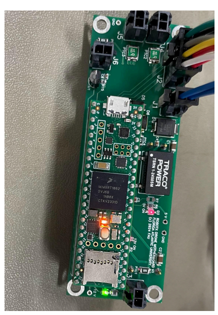
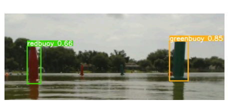
VIII. Appendix B: Testing Plan

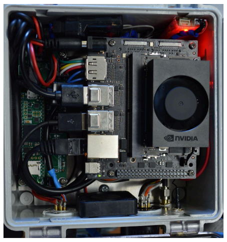
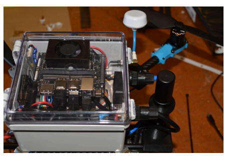
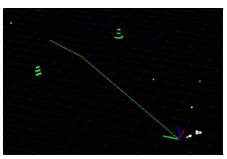
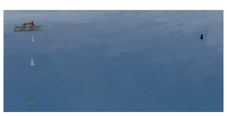
I. Scope

Team Owltonomous designed different testing goals based upon tasks and what equipment was available FAU. The VRX Simulator, and the data shared by other teams is the key in the testing strategy of the AMS.

II. Schedule

The schedule is based on Simulation, rosbags and future on-water tests. Table 1 summarizes the timeline, and results for each of the testings.

Start/End Date	Documentation	Target	Result	Environment	Member Presence
03/01/24 - 05-31-24		Development and test PID Controllers	Accomplished an overall accuracy of 1m (Which it's in the GNSS error interval)	On-Water tests at the US-Intracoastal Waterway in Dania Beach, FL	Software & Controls Team
05/01/24 - 08-01-24		Develop a PCB for the UAV GNC box, battery monitoring, temperature monitoring, fan, 12V, 5V supplies, power switch. PCB V1	PCB tested software written, cells accurate voltage, temperature accurate, power supplies tested. All functioning properly	Electronics Lab	Electronics & Software Team
06/01/24 - 07-31-24		YOLO development with shared data	Average of 0.60 confidence on competition objects	Shared datasets	Artificial Intelligence Team

06/01/24 - 09/30/24		UAV GNC development and waterproof test	Electronics ran for 24 hours, no overheating or issues. Tested in 91 DEG F weather for 3 hours. No leaks in the GNC box, and it floats on the water for at least 30 minutes	FAU-SeaTech Electronics Lab, and wave tank	Electronics Team
08/02/24 - 10/02/24		UAV Hardware assembled with mounts for LiDAR, camera, and GNC box. Weight test under 7kg.	Weight: 6.8 kg.	FAU-SeaTech Electronics Lab	Electronics & Mechanical Team
08/20/24 - 09/15/24		LiDAR clustering and object detection tests with shared data	Ability to detect Light Tower, buoys, and docking bays	Shared rosbags, and use of RViz for visualization of the data	Software & Controls Team
09/01/24 - 09/30/24		Mission and path planning tests of all six USV tasks	Successfully completed all tasks without vision-based navigation	VRX Simulator	Software & Controls Team
09/23/24 - 09/30/24		Bow Thruster Implementation and Testing	Station-Keeping accomplished having a max position error of 1m	On-Water tests at the US-Intracoastal Waterway in Dania Beach, FL	Software & Controls & Mechanical & Electronics Team
10/01/24 - 10/15/24		Path Planning with buoys	N/A	On-Water tests at the US-Intracoastal Waterway in Dania Beach, FL	Software & Controls Team

10/06/24 - 11/01/24		UAV Autonomy testing	N/A	On-Water tests at the US-Intracoastal Waterway in Dania Beach, FL	Software & Controls Team

Table 1. Team Owltonomous' testing schedule and results

III. Resource & Tools

The team required different resources and tools throughout the testing schedule. Electronics lab, and machine shop lab equipment have been utilized for developing the USV and UAV subsystems. VRX Gazebo simulator with the appropriate desktop computer has been used for the Simulation and data sharing tests. A davit for deploying the USV is being used, and anchored buoys will be used for vision-based navigation testing for the on-water tests.

IV. Environment

The software was tested using VRX Gazebo Simulation, and data shared by other teams through the RoboNation Data Sharing DropBox. This was utilized due to the lack of competition objects the team possessed.

The on-the-water testing environment is at FAUs SeaTech Facility on the US-Intracoastal Waterway in Dania Beach. 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

The team realized the need for testing, however through past events of a lithium battery explosion which caused a fire at Lake Superior State University's robotics lab (Previous school for some members of our team), the team recognized the need for safety while testing. As a result, safety protocols have been put in place to manage battery usage and charging.

There is an existing risk of using the Electronics Lab, and machine shop for the development of both vehicles. The team has followed strictly each laboratory safety rule for preventing catastrophic incidents.

The usage of a davit for deploying the USV gives a hazard risk. The team followed safety guidelines provided by FAU, the team always used hard hats when the davit was used.

Additionally, there is great risk in using the US-Intracoastal Waterway due to wildlife access, and constant boat traffic. To manage the risks associated with on-water testing, 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

Between March and October 2024, testing on PID controllers, UAV hardware, vision system, and mission planning was conducted in both simulations and real environments like the US Intracoastal Waterway and FAU-SeaTech labs. Notable results included 1-meter station-keeping accuracy, successful completion of USV tasks without vision-based navigation, and waterproof testing of UAV electronics. The usage of data shared by previous teams on the RoboNation Data Sharing DropBox have been an important key of the results obtained.

IX. Appendix C: Acronyms

Acronym	Definition
AI	Artificial Intelligence
APF	Artificial Potential Field
ENU	East-North-Up (coordinate system)
GNC	Guidance, Navigation, and Control
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
LiPo	Lithium Polymer (battery)
MAVROS	MAVLink ROS (middleware for communication between vehicles)
PID	Proportional-Integral-Derivative (controller)
PX4	Open-source flight control firmware
RC	Remote Control
ROS2	Robot Operating System 2
RTK	Real-Time Kinematic (GPS positioning)
UAV	Unmanned Aerial Vehicle
USV	Unmanned Surface Vehicle
SSE	Sum of Squared Errors
WAM-V	Wave Adaptive Modular Vessel
YOLO	You Only Look Once (object detection algorithm)