Technical Design of Vessel for 2024 Maritime RobotX Competition

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***Abstract*—This document covers the systems and methods used by the Bayou Bot Krewe for the RobotX competition. The Bayou Bot Krewe is a team of undergraduate seniors majoring in mechanical engineering from the University of Louisiana. The RobotX competition challenges teams from around the globe to design and develop an autonomous vessel to complete a series of tasks. The autonomous platform used by all teams is the Wave Adaptive Modular-Vessel (WAM-V) by Marine Advanced Research. The vessel must be able to complete challenges ranging from object detection to gate navigation completely autonomous. To complete these challenges the vessel needs to possess systems to assist with navigation, vision, and propulsion.**

I. Introduction

The Bayou Bot Krewe, a team of five undergraduate seniors majoring in Mechanical Engineering at the University of Louisiana at Lafayette, was tasked with developing and configuring a Wave Adaptive Modular-Vessel (WAM-V) system to compete in the 2024 RobotX Maritime Challenge hosted by RoboNation. Teams gain hands-on experience with unmanned, autonomous systems. Teams include undergraduate and graduate students, faculty mentors, and sometimes high school students. Students gain valuable skills and insights in one of the fastest-growing fields, autonomous marine systems.

The Bayou Bot Krewe began work on the system in the Spring of 2024. The team built on the system initially developed by the inaugural 2016 team that was then improved by a team in 2018. The team was tasked with revitalizing and upgrading a system that hadn't been in use for six years. The system consists of commercially available products and custom parts by utilizing rapid production methods, such as 3D printing and water jet cutting.

A 3D model of the UL Lafayette WAM-V can be seen in Figure 1. When generating the model, the idea was to design with the capability to complete all the assigned tasks outlined in the RobotX handbook. The team based the design on this conceptual model while focusing on functionality. The final design of the vessel is equipped with two enclosures for electronic hardware, two battery boxes for power supply, and an LED indicator, which are pictured in the model. Not pictured in the conceptual design is the antenna for wireless communication and the propulsion system, but they have been incorporated into the final design.

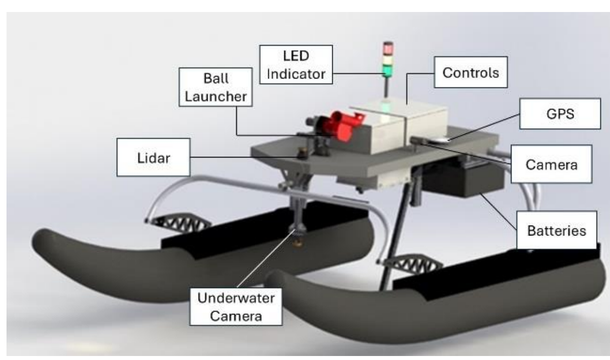


Figure 1: UL Lafayette WAM-V Concept (propulsion system and antenna not pictured)

One feature, illustrated in the conceptual design, is a ball launcher. This subsystem was added with the intention to maximize the team's point potential; however, the ball launcher was excluded from the final design and will be added by future teams.

The support structures that hold the enclosures in place were designed to be modular. For example, the onboard electronics boxes, mounted on the roof, and both battery boxes, positioned under the payload tray, are mounted using extruded aluminum beams (80/20) [3]. This modular design enhances the robustness of the overall system, making it more reliable by allowing for secure repositioning and mounting of components as needed.

The team's design strategy and reasoning will be discussed in section II. In section III, the system testing strategy will be outlined. Section IV will provide the competition preparation strategy. Finally, section V will conclude and section VI will provide acknowledgements.

II. Design Strategy

A. System Layout

The computing of the RobotX USV consists of a Raspberry Pi [4] and NVIDIA Jetson TX1s [5]. The system is powered using four 12V batteries with sets of two being wired in series to increase the voltage to 24V [6]. The batteries have nominal voltages of 12V, but the actual measured voltage after they are connected in series is 25V. One set of batteries is connected directly to one of the motors while the other set of batteries is connected to the other motor along with to the controls/electronics box. The components require 48V, 25V, 12V, and 5V.

The varying voltages are achieved by using DC to DC power converters with appropriate current capacity. Proper gauge wires were used to compensate for the current draw. The Raspberry Pi and NVIDIA Jetsons are run using Robot Operating System (ROS). The connections between the Raspberry Pi, NVIDIA Jetson, the Roboclaw [1], and the Rocket M2 [2] are shown in Figure 2. The Jetson acts as the master while the Raspberry Pi is the slave board. The first step to running the required code to operate the boat is to run the Jetson Master code, which is accessed through an SSH connection that is on shore. After the Jetson master code is run, the Raspberry Pi set of codes is run. To operate properly, the heartbeat from the Raspberry Pi is run along with a Mode Setter code that shows which mode the Raspberry Pi is in, and subsequently the boat. Another voltage monitor code is useful to have on the onshore computer that has the SSH connection to allow the team to monitor the boat in ways other than the heartbeat. The heartbeat refers to the consistent signals or feedback loops within the control system that ensure the continuous monitoring and communication between the onboard sensors and the boat's decision-making algorithms. The motion of objects can be broken down into two main components: linear and angular. Linear

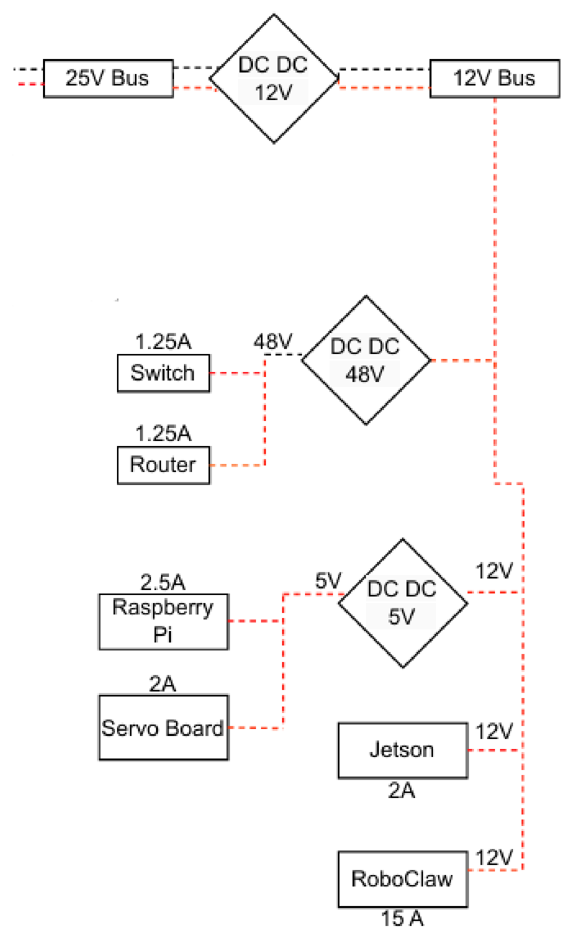


Figure 2: Electronic Control Wiring Diagram

motion refers to the movement of an object in a straight line and is characterized by variables such as velocity, acceleration, and displacement along a specific axis. On the other hand, angular motion deals with rotation around an axis. Angular velocity and angular acceleration are analogous to their linear counterparts but applied to rotational movement. In many cases, both linear and angular components interact, especially in systems like wheels, gears, or any rotating body where a force results in both linear and angular displacement. In the case of the WAM-V, the boat only requires a linear-x component and an angular-z component for remote and autonomous control. The other linear and angular components are included as a standard for ROS.

After running the necessary code to control the boat, the Raspberry Pi controls the throttle and steering. The throttle is controlled through an Adafruit PCA9685 servo board [8] which is connected to two servo motors. The servo motors are connected to the Torqeedo remote throttles [9] that control the starboard and port motors. The servo motors and remote throttles are connected by a 3D printed housing which holds the servo motors in precise locations. This allows for the throttles of each motor to be controlled independently. The Raspberry Pi controls the steering of the two motors through a Roboclaw 2x15A. The Roboclaw is used to output 12V to two Panther T5's, one of which is mounted to the starboard and port side motors [10]. The Panther T5 breaks down to a linear actuator which extends or retracks depending on the configuration of how it receives 12V from the Roboclaw. The Roboclaw gives the ability to not only control when 12V is sent or stopped but to also flip which of the two wires is positive or negative. Since there is no output from the Panther T5 to know the exact angle of the motor, a string potentiometer is mounted to the motor. The string pot has an input of 12V and outputs a voltage that depends on how far the string is extended. The output voltage is sent to a ADS1115 converter board [7] which takes the analog signal and converts to a digital signal which is read by the Raspberry Pi to determine the angle of the two Torqeedo motors.

The WAM-V is a dual pontoon vessel propelled by two Torqeedo motors. The WAM-V body is secured by fixed supports on the aft section of the vessel and a shock-absorbing system toward the bow. This shock-absorbing system protects the electrical equipment from shock in the case of harsh conditions. The Torqeedo motors are located at the aft of the vessel and are programmed to share the same angle of rotation to enhance the vessels efficiency and maneuverability. The four batteries are encased in waterproof battery boxes fixed beneath the platform of the vessel using 80/20 T-Slot extruded aluminum framing. The frame configuration acts as a modular addition to allow for the easy alteration of fixed equipment. Each battery box powers a motor and shares in the effort to power the electrical equipment located on top of the vessel. The electrical equipment is in a watertight container that uses rubber and plastic glands to run wires inside the box. All power delivered to each component is run through a kill-switch that can be toggled to shut off all power. These kill-switches are red buttons on the port and starboard sides of the vessel. The Foscam F19900EP cameras [11] that assist with navigation and task completion are located on the top of the vessel in the forward, aft, port, and starboard positions. Each system described above is described in more detail in the following sections.

B. Enclosures

The WAM-V system possesses three enclosed system environments, shown in Figure 3. The first of these systems are the two battery boxes beneath the vessel's main platform. Each box has two 12.5V marine batteries enclosed within it. These boxes are watertight with plastic glands attached to allow wiring to escape from the box. This battery enclosure is contained by a rigid t-slot aluminum structure, allowing for the easy removal of the battery boxes for maintenance purposes. The battery boxes are each equipped with watertight charging ports to allow for charging without taking apart the structure. The enclosure on the port side has an extra port to power the relay and electronics boxes [12]. The second enclosed system is the box containing all computing equipment used for all functionality aside from steering. The box is on the top center of the platform. This system is fastened via screws to the modular structure on the roof. The system is watertight with multiple gland holes to allow for external wiring to be delivered to the components within the system. The third system is identical to the previous system except it contains the steering components. All system environments are IP-67 compliant with their use of watertight wiring glands to protect the electrical equipment within.

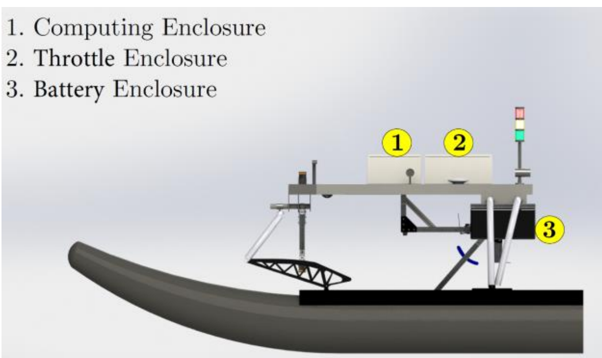


Figure 3: 3D Render of Enclosure Layout

C. Machine Learning Design

The team's selection of You Only Look Once Version 5 (YOLOV5) [13] was based on its prominence in size, deployment, and ease of training. The file size of a fully trained model is only fourteen megabytes and can be stored on a microSD card within an NVIDIA Jetson. YOLOV5 is also easily deployable onto Raspberry Pi's and NVIDIA Jetsons. The team opted to deploy the model onto the Jetson because of its superior computing power. The model can be deployed with a simple download as long as the Jetson is connected to the same internet as the host computer. The model can be trained on hosting platforms such as RoboFlow or Google Colab. These platforms remove the large space requirements of training with large datasets.

The model was trained using a data set of over 500 images. Rotation and a variety of filters were used on the dataset to increase the robustness of the model. These filters helped prepare the model for various lighting conditions and other factors that may force a false identification or a non-identification. The model was trained to identify 6 classes: green, orange, black, red, and white buoys and the WAM-V. Within the dataset green, red, and white buoys were the most common and the model performed with an accuracy of 80%, 79%, and 74%, respectively.

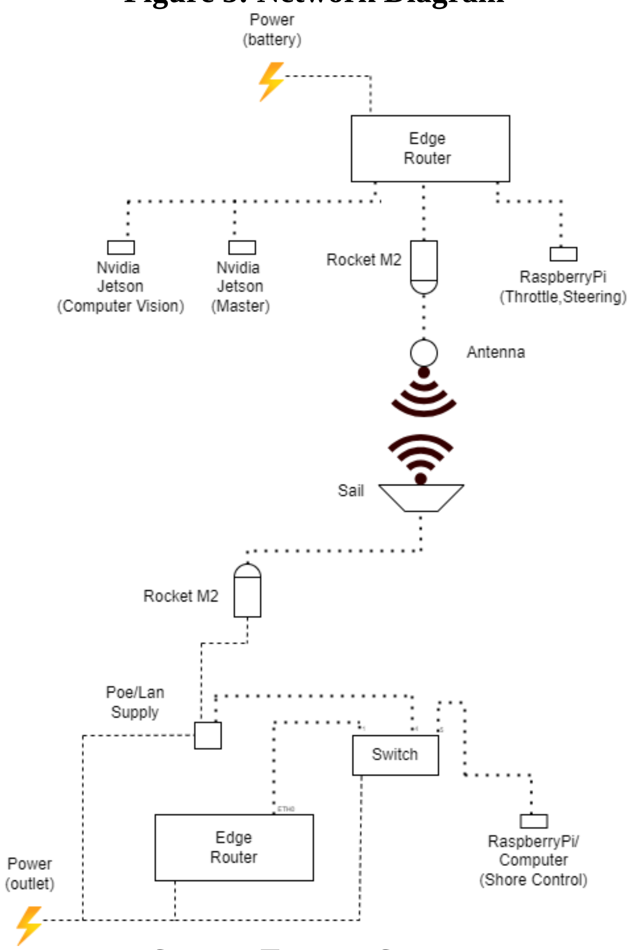
The machine learning model is used for buoy identification and navigation between buoys. The model uses the cameras on the vessel to locate and identify the color of the surrounding buoys. From there, the model will look for a sequence of colored buoys that correspond to the current challenge and locate the centroid between the two buoys. The model counts the pixels between buoys and sends the position to the Raspberry Pi where signals are sent to navigate the vessel toward the centroid point, shown in Figure 4. As the vessel moves, this calculation and sequence of events is repeated until the vessel passes through the correct buoys.

Figure 4: Image Showing Image Output of Machine Learning Model

D. Networking

The Network diagram, shown in Figure 5, is a complete depiction of how the vessel communicates to the shore. The vessel is equipped with two batteries, an Edge Router, two NVIDIA Jetsons, Rocket M2, a Raspberry Pi, and an Ubiquiti AirMax Omni 2x2 Dual Polarity MIMO Antenna [14]. The shore is equipped with an Edge Router [15], a switch, a Raspberry Pi, poe/lan supply, Rocket M2, and Ubiquiti 2.4Ghz AirMax Basestation[16]. The Rocket M2's send and receive signals to communicate information between the vessel and the shore, while the basestation and the antenna amplify the signals.

Figure 5: Network Diagram



III. SYSTEM TESTING STRATEGY

The team's first experimental run occurred on September 28, 2024. The team tested the range of connection between onshore and on boat components, boat orientation in windy conditions, and on boat component workability throughout different weather conditions.

Unfortunately, due to beginning the project in January 2024 as a new team, the amount of on-water-testing of the vessel before the start of the competition was limited. The objective of on-water-testing is to ensure that the USV 's hardware, software, control algorithms, system integration, and safety systems are installed and programmed properly. This is to ensure that the team can be successful for the competition. Although the team was unable to attempt many trials of on-water-testing, the team had set tasks and goals to ensure a successful performance including propulsion system testing, steering and navigation systems testing, sensor functionality testing, remote control and manual test, emergency stop testing, basic autonomy testing, obstacle detection and avoidance testing, full autonomy testing, and power management testing. These are the key testing goals to ensure a successful competition.

IV. COMPETITION PREPARATION STRATEGY

In preparation for the RobotX competition in Sarasota, Florida, the Bayou Bot Krewe conducted thorough testing of the USV, both in the lab and on the water. While most tests were performed as dry bench tests in the University of Louisiana at Lafayette's robotics lab many aquatic tests were performed. The aquatic tests were conducted at Airport Lake in Lafayette, LA to evaluate the vessel's performance in a realistic environment.

The vessel's electronics are set up so that multiple computers can communicate over a ROS network. This approach allows for faster data processing and troubleshooting through system isolation. The Jetson TX1 units and Raspberry Pi's are the key components in this system and were assigned specific roles with the Jetsons currently act as the master and computer vision slaves, while the Raspberry Pi computer acts as the slave in this ROS system. The team plans to have the Jetsons handle critical tasks, such as image processing and recognition for the machine learning algorithm and path planning, while the Raspberry Pi is responsible for managing less computationally intensive functions like the LED mode indicators and other similar components.

To ensure hardware reliability, the team purchased and created more than five complete sets of each major and minor electrical components. The major components include the Jetson TX1s and Raspberry Pi's, while secondary, but still necessary components, include servo controller boards and an analog to digital (ADC) board that converts the string potentiometer data into a useful signal for the Raspberry Pi to read. These redundancies provide room for testing and failure. This project, like many others, had electrical setbacks and had over five microcontrollers fail during testing and deployment. These backup boards allowed the team to test ideas without the worry of being setback waiting for new equipment to arrive. This approach carries over to the competition since the team already identified and addressed potential issues through rapid testing, enabling quick resolve of any problems that arise in the field.

Five microSD cards were also created to store multiple versions of the system's code, which allowed for testing of different ROS packages and internal code.

Network stability was of chief importance throughout the preparation phase. The ROS network was tested extensively to ensure communication between microcontrollers and other peripheral boards was reliable.

Furthermore, a shutoff switch was added to the ground wire going to the relay box to allow for an easy shutdown of the entire system. It can shut off the electronics and motors, while the e-stop switches on either side of the boat only stop the motors. The e-stop switches are beneficial to stop the boat while still maintaining communication with the onboard microcontrollers. Several switches and fuses were incorporated in the computing box to protect components against current overdraws, adding additional layers of safety to the electrical system.

For power management, initial tests utilized benchtop power supplies, but new batteries were purchased and installed for the competition and aquatic tests. This approach saved the team money during early system development, while ensuring new batteries were ready for the event, supplying reliable energy on competition day.

The Bayou Bot Krewe plans to tow its USV from Lafayette, Louisiana to the RobotX competition in Sarasota, Florida on November 2, 2024. As previously mentioned, the team securely fastened the enclosures and hardware to the payload tray and boat structure, and any additional items will be firmly attached to the boat. It is essential to ensure that nothing falls off the boat during transport or operation.

V. Conclusions

The Bayou Bot Krewe's design possesses seven subsystems that are interconnected to achieve functionality. These systems were designed to be built upon by future teams from the University of Louisiana. The use of enclosed environments allows for each system to be watertight and secure during transportation and operation. The design utilizes a network for far range connection and instant data collection for trouble shooting and research purposes. Extensive testing was performed on each subsystem to ensure reliability of each component and to reduce points of weakness.

VI. Acknowledgements

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