RobotX 2024 Technical Design Paper

George Mason University
Team Name: The Strawhats
Boat: Frank S.S. Ocean

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***Abstract*—This paper describes the design and implementation of the Wave Adaptive Modular-Vehicle (WAM-V) belonging to the George Mason University (GMU) RobotX team, The Straw-Hats. The design and function of the WAM-V is focused on completing the goals set forth by the RobotX 2024 competition, such as GPS navigation, image recognition, and situational awareness. The team equipped their WAM-V with a LiDAR sensor and a ZED camera, along with algorithms developed with Robot Operating System (ROS) that specialize in GPS navigation/station keeping and path navigation to accomplish the goals.**

I. Course Approach

This year's RobotX Challenge consists of 8 tasks, in which different equipment and software will have to be developed to complete them. Task one is centered on data transmission between the AMS and the team on the shore. Tasks two, three, four, five, and six focus on navigation of the WAM-V and its environmental detection abilities for beacons and RGB images/signatures. Tasks seven and eight focus on the Unmanned Aerial Vehicle (UAV) aspect and its ability to recognize and process its environment to deliver and transmit position data of objects. The Straw-Hats are initially focused on tasks one, two, and three of the RobotX Challenge. Previous data from Task 1 from the 2022 competition will be utilized. Task 2 involves the detection of beacons and navigating through gates. Task 3 will have the WAMV navigate through a series of gates based off of red and green buoys. The team will then work on perfecting each task in succession, once the initial tasks have been realized through troubleshooting and design iteration.

II. Design Strategy

In terms of operation for the technical design portion of the competition, there are three main categories for team operation: hardware, electrical, and software sub-teams. Hardware oversees the propulsion system and fabrication of components, such as designing and constructing mount assemblies; electrical works on the wiring schematic and maintains safety-checks, such as the emergency stop button operations; software works with ROS, focusing on researching autonomous navigational algorithms, through the ZED camera or LiDAR.

Preliminary goals were to familiarize with ROS to produce a navigation script and test in a simulated environment, essentially producing a digital twin. In terms of the hardware sub-team, a small-scale test model was constructed to efficiently practice autonomous algorithms in a controlled environment, as opposed to working on the WAM-V, serving as a physical twin. This allowed for members to become familiar with RC transmitters and receivers, and brushless motor systems and its associated ESC use. Arduino was a major component in not relying on RC functionality, and instead on programming scripts for the model's movement, with PWM signals to control the brushed motor system. The plan was to eventually scale-up operations and begin work on the WAM-V.

For context, the WAM-V was used for a 2023-2024 George Mason University mechanical design capstone project, team *Maritime Mavericks*, where it was in the Promoting Electric

Propulsion (PEP) competition funded by the Office of Naval Research (ONR). The WAM-V was then passed on to the RobotX team, where members fabricated and modified parts of the old system and re-integrated them into a new plan. Upon further research and development, a new propulsion system was to be used, involving a new motor mount design, in addition to different ESCs, and a completely new navigation/GPS system. Much of the hardware and electrical sub-teams were focused on building upon and improving designs from the previous PEP team.

A. Electrical Sub-system

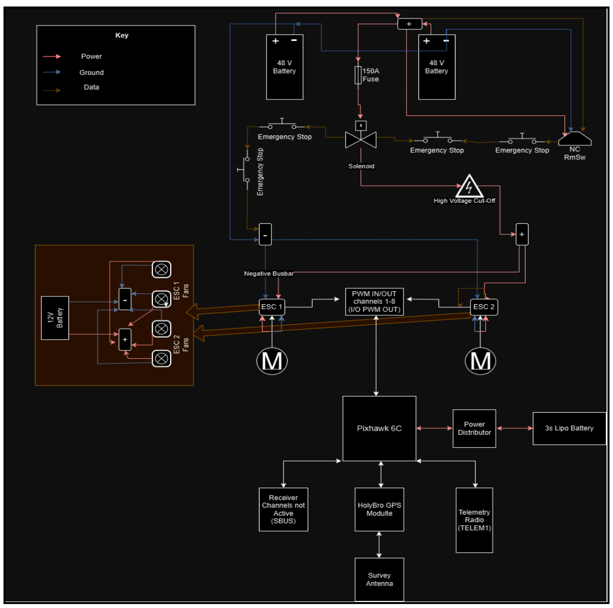

Figure 1: Electrical Schematic using Pixhawk Prototype 1

The preliminary design for the electrical schematics which was used for initial testing can be shown on figure above. The main goal of this setup was to test that all components worked as intended, that supply and cut-off power would work on command, and to achieve basic RC control as well as attempt waypoint navigation with the Pixhawk Prototype 1 setup.

1. Solenoid

Starting from the top of the figure lie two 48V batteries that connect to a positive and a negative busbar with 2.5 ft, 8 AWG wire, and serve as the main power supply for our system. Power is then distributed from the positive busbar (located above the batteries) which then runs down a 150A fuse and connects to a Solenoid, protecting it from any excessive jump in current that may occur. Connecting to the solenoids are two emergency stops on both the left and right side, which run in series. The two on the left connect to ground, while the ones on the right connect to a normally closed remote relay switch, which then connects back to the positive busbar above, as well as ground.

2. Normally Closed Relay Remote Switch

The normally closed relay switch is operated using the main receiver and a transmitter to remotely control the solenoid and determine when it should allow for power to run through and drive the system, or when it should shut off. This allows for control of power distribution from afar. This device is rated to work between 12V-48V, with a max load of 10A. For this particular setup, it was run using the 48V batteries, but moving forward it will be subject to change, possibly to the minimum requirement of 12V. The maximum remote operating distance is 50m, which should provide enough distance to control when navigating in the competition.

3. Kill Switch

If current is not distributed from the solenoid to the emergency stop buttons, it then reaches a high voltage cut off, which is connected in series with it. This is to ensure that the conjoining of current is constant. From here, if everything works properly and as intended, it then travels to another positive bus bar.

4. Electronic Speed Controllers

At this positive busbar, the power then separates into two power wires, traveling into a left ESC and a right ESC. The ESCs are housed inside a 3D-printed casing that also houses 2 small fans for each ESC. These fans are powered with separate positive and negative busbars connected to a 12V battery, as seen on the left side of the schematic, and serve as a cooling/heat exhaustion system for ESC temperature control. The wires in the ESC finally then end at the left and right motors.

Once current reaches the motors, then it returns to the set up for the "Control" or "Brain of the Boat", as seen in Figure 1.

After successful testing of Pixhawk Prototype 1, RC control and waypoint navigation were both achieved. At this point, reviews and alterations were made to the schematic, with the goal of achieving fully autonomous control on command to complete the required tasks in preparation for the competition.

5. *GPS & Navigation Prototype*

For the initial prototype testing regarding GPS and navigation, a Pixhawk 6C model with a HolyBro 59P GPS module, RC receiver (operating on MHz), and telemetry radio was used to communicate with the home station via mission planner.

This setup allowed for an evaluation of the WAM-V capabilities to switch between RC control and GPS waypoint navigation. It uses a three-cell, 11.1V battery to operate. The Pixhawk Prototype 1 serves as a secondary option for the competition if ROS2 navigation deems unsuccessful.

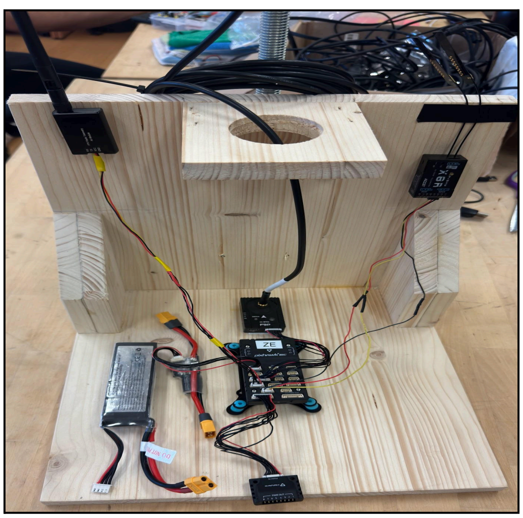

Figure 2: Pixhawk Prototype 1

6. *Hydrophone*

The hydrophone, essentially an underwater microphone, is mainly directed to complete task 2 and gain signals from the underwater beacon. Three main sub-components include the hydrophone itself, Ambient ASF-2 MKII, and an XLR cable allowing it to connect to the Focusrite Scarlett 2i2 4th Gen, which is a USB audio interface interacting with a Jetson Nano.

It will serve to pick up a minimum of 2kHz frequency, while blocking excessive noise through a fast fourier transform noise filter, resulting in a clearer signal. The hydrophone will be housed centered on the front arch, where it is able to be raised and released via a pulley system.

7. *Electrical Hardware Placement*

Many of the main components of the electrical and control system are integrated within the top platform of the WAM-V. As seen in Figure 1: Pixhawk Prototype 1, consists of a Pixhawk 6C model, HolyBro F9P GPS module, an RC receiver, telemetry radio, and survey antenna. Also included are two 48V batteries to supply power to the motors and one 12V battery for the ESC fans, along with solenoids and fuses.

From the platform tray housing on the WAM-V, are Pixhawk 6C PWM Breakout Boards. On the rear arches are tightly twisted and looped servo signal wires that connect to ESCs on both sides and ground wires connected to a ground busbar. This was to avoid any interference coming from motor or AC power lines, in addition to organized cable management purposes. The length of the 22 AWG servo signal wires is 2.5m.

8. *Updated Electrical Schematic*

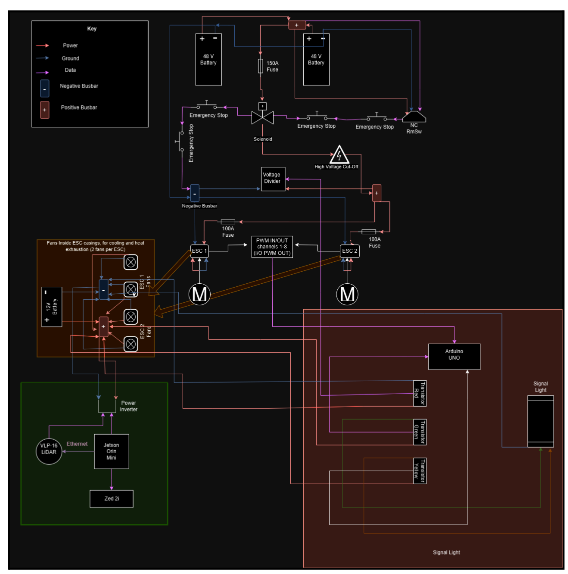

Figure 3: Jetson Orin Mini Electrical Schematic

Figure 3 above showcases the new and updated schematic. Most of the system remained the same, but some changes such as implementing 100A fuses before each ESC. Though there is no plan on using the motors at full power, these fuses were added for safety measures in case any abnormal surges in current occur.

The Pixhawk Prototype 1 is now removed, and in place is the new Jetson Orin Mini setup, which can be seen on the bottom left corner of the Schematic on Figure 3. The Jetson Orin Mini is rated for 12V DC and 5A of power. With this in mind, the same 12V battery as the ESC fans can provide power. However, since the power connector from the Jetson cannot be connected directly to the battery, a power inverter, rated to convert 12V DC to 110V AC, would provide up to 600W of power. This would allow for an AC power source to operate the Jetson with no issues.

A VLP-16 LiDAR rated 9-32V DC would also connect to the power inverter and to the Jetson via Ethernet. Along with the LiDAR, a ZED 2i connects to the Jetson and serves as the 'eyes' for operating.

The signal light for the WAM-V has three different colors, red, yellow, and green, signifying no power/stopped WAM-V, RC Control Mode, and Autonomous Mode, respectively. An Arduino UNO works in conjunction with a HolyBro PWM output module, along with the transmitter. Some transistors will also be used, as seen on the bottom right of the schematic, and serve as current regulators for the light to change color depending on specified WAM-V modes. The light is rated for 12V and about 1A of current. With this in mind, it will run on the same 12V battery as the rest of the devices. Since multiple devices are powered by this 12V battery, seen on the left side of the schematic on Figure 3, if needed, another 12V battery can be in parallel. This would increase current capacity and battery life.

9. Power Distribution

Power is strongest at the platform tray where each 48V battery pack is located. Due to the long battery and ESC wires, there may be a slight drop. However 48V is a strong enough range to supply power, and therefore wire length is not significant enough to cause interference.

The only occurrence as to where there may be a significant disturbance to power distribution would be found at the solenoid. As seen in Figure: 3, the solenoid is placed between a 150A fuse and four emergency stop buttons. The purpose of the solenoid is to allow or block current towards the main line where the motors are connected. As these buttons are required, they are programmed to shut off power to the motors, physically and remotely.

B. Software Architecture

For the software architecture, the team discussed using ROS2 or Python scripts along with libraries provided on the internet.

While ROS2 offers the advantage of connecting multiple systems and facilitating fast, efficient communication between them, the challenge lies in the time remaining before the competition to fully learn and integrate ROS2 with all components. Given the team's familiarity with Python, it was decided to prioritize using Python for system integration. This allows for focus on leveraging existing libraries and ensuring smooth functionality without the steep learning curve that ROS2 would require at this stage.

The team wanted to include libraries from the ZED 2i and implement Simultaneous Localization and Mapping (SLAM) with the VLP-16 Velodyne LiDAR and have the GPS and propulsion control for the Pixhawk 6C all work together using the Jetson Orin Mini.

The 2D localization and mapping were developed by Team Athena from the previous GMU RobotX team in 2022. Team Athena used the SLAM algorithm in ROS to generate a 2D point cloud that will show on a map where objects are located.

The object detection for buoys was developed using associated StereoLabs libraries from the ZED 2i camera. The team modified the code from the library to train a model that would only detect buoys or cones and give a proximity distance from the detected obstacles.

The Pixhawk flight controller will use Python Mavlink libraries to communicate with the motors and receive compass and GPS data. The software, Qgroundcontrol, will also be utilized to see vessel position and orientation.

If components fail to work together, the team will try using two components such as the ZED camera and Pixhawk together and so on. ROS2 will be downloaded on the main computer for simulations and future work.

1. Control System

The control system will receive data from the LiDAR and the ZED camera to understand the position of the boat and send the appropriate propulsion commands through the Pixhawk.

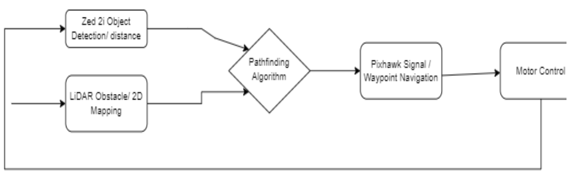

Figure 4: Control Logic

Using the data from the LiDAR and ZED 2i, the control system continuously computes the vessel's position relative to detected obstacles. It achieves this by combining information from the sensors with GPS data received from the Pixhawk 6C. The fusion of sensor data allows the system to maintain accurate localization.

The system uses this fused data to maintain a situational awareness of the vessel's position and orientation. By understanding its precise location in the environment and the distance to obstacles, the system can determine the safest path forward.

C. Mechanical Hardware

1. Propulsion System

The motors being used for propelling the WAM-V are brushless waterproof APISQUEEN 70167 7.5kW internal rotor motors. Initially ESC wires did not reach the motors, so extension wires were fabricated and spliced to extend reach to the ESCs, along with soldering XT60 connectors.

2. Motor Mounts

The motor mounts were designed in AutoDesk Inventor and calculations were done by hand to determine a 255 MPa yield strength, with a safety factor greater than 2. Two 12 x 12 x ½ inch flat plates of 6061 aluminum metal were purchased, in addition to two pipes with an outer diameter of 1.9 inches and an inner diameter of 1.5 inches. Stainless steel lock nuts with zinc washers and hex bolts were used to secure the motor mounts to the rear engine pods, which ended up being drilled to account for the hole positioning in the mounts. It should be noted that materials of zinc were not preferred, as opposed to using galvanized steel material due to its better anti-rust properties, but the team was constrained with their budget.

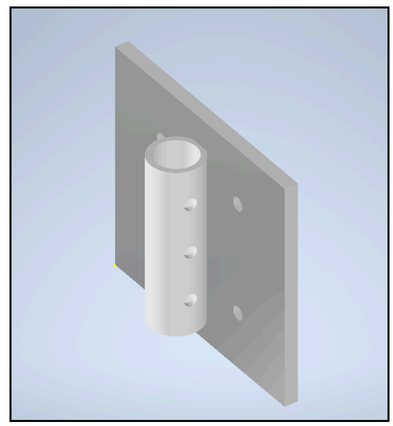

Figure 5: Motor Mount Design in CAD

3. Motor Casings

Designs to the motor casings were modified from the previous cases done by the *Maritime Mavericks* capstone team. Modifications included adding more screw holes and making aspects of the new model hydrodynamic by adding gussets. Bambu Lab PETG Basic filament was used to 3D print, due to its high durability.

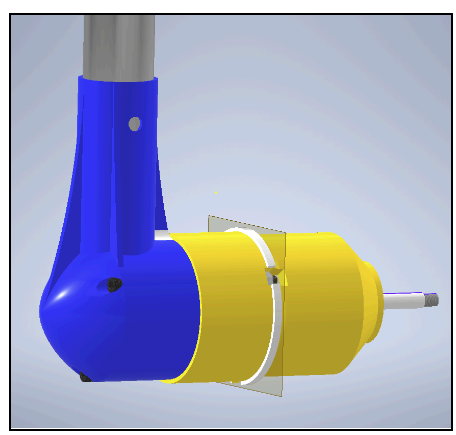

Figure 6: Front and Rear Assembly of Motor Casing

4. *Electronic Speed Controller Cases*

Autodesk Inventor was used to construct a design for mounting/encasing ESCs. This was to ensure protection from the elements, as well as provide adequate cooling to reduce rising temperatures and avoid the possibility of a thermal cutoff point.

The design of the cases went through multiple drafts, ensuring that motor wires could successfully connect to the ESC through the cases, along with the battery, and signal wires. Finalized designs included a mesh around the lid, where the fans were placed to ensure enough ambient air could reach the ESCs and aid in cooling. In addition, fillets were placed along hard ridges all around the design, to decrease stress concentrators and increase aerodynamic properties.

III. Experimental Results

A. *In-water Testing of Motors*

After splicing and soldering battery wires that served to extend the wires connecting from the ESCs to the battery, the motor and ESC assembly was tested at the dock to ensure proper connectivity. At this point in time, the ESCs were paired to a FrSky Taranis Digital transmitter.

B. *Pixhawk Prototype 1 Functionality Testing*

For convenience and time, fully integrating and testing with the WAM-V in the water and the Pixhawk Prototype was avoided in the preliminary stages of testing. To address this, a cart holding needed items, including brushless motors, were hauled outside of the laboratory to initially test output from the RC transmitter.

Once outside, traffic cones were placed out in the parking lot to simulate the waypoints on Mission Planner and the cart was rolled around with the GPS on for the most accurate testing. Then basic functions such as switching from RC, automated, and return to home modes were tested, along with RC output from the transmitter to the motor.

A “mission” was planned out, and the cart was to navigate to those specified waypoints, while observations were recorded, monitoring the brushless motor outputs. For scenario testing, the cart was intentionally veered off course to see if the motors would automatically correct. After this testing, the Pixhawk Prototype 1 was ready to be integrated to the WAM-V for full-scale testing, without any adjustments being made to the design.

C. *WAM-V Waypoint Navigation*

Within the Occoquan Harbor Marina, the Pixhawk Prototype 1, along with all systems integrated on the WAM-V were tested, with the goal of ensuring proper component set-up and a fully operational system testing on the water. The boat was able to run on autonomous waypoint navigation and also by remote control. According to data, the WAM-V was moving faster than the previous propulsion system the team had modified, only running at 20-25% power from the 4hp motors. The motor mounts fabricated by the hardware team proved to be secure, without any notice of deformation along the pipes. In addition the electrical team had satisfactory emergency stop button operations. Likewise, ESC cases did not reach concerning temperatures.

Some issues that arose included faulty/deteriorating motor casings, which only allowed for forward thrust. In addition, compass calibrations for the Pixhawk were not accurate in Mission Planner, resulting in it being manually shifted and taped down for correct positioning. Further work was noted to be done on better wire organization throughout the WAM-V, along with a new motor casing design.

IV. Acknowledgements

Team Straw-hats developments and success would not be possible without our mentors and sponsors (refer to Appendix B), allowing us to compete at an international level and foster our student-led organization. We are truly thankful to the ’22 George Mason University RobotX team, as well as the ’23-’24 Maritime Mavericks capstone team for being fundamental to our progress. We extend our deepest gratitude to Dr. Leigh McCue, Dr. Van Jones, Vanessa Barth, Damion & Orion Colgrove, and Valerie Blaemire for their unwavering confidence and support in us.

V. References

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VI. Appendix A

Sponsors

A. Sailboat Sponsors
Dominion Energy.

B. Canoe Sponsors
Maggie O'Brien.

C. Raft Sponsors
McDonough Bolyard Peck: MBP, Carter Machinery, Joe Boucher, and Chris Eastman.