Roboboat 2024: SEALS's Technical Design Report

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Abstract* — *After the success of the 2023 season, MHS:SEALS is returning with a focus on improving upon the foundation of the previous year. As the refined successor to the "Aquaholic", "The Meg" is a complete revamp to the hull design, electrical system, propulsion system, vision system, and course approach. Navigation is accomplished via mapping identified objects with waypoints; this way, the vessel has a point to reach or avoid. After the warranted concerns over the prior electrical box, we have corrected the numerous hazards plaguing last year's electrical system. The catamaran design is reused for the new generation, with added modularity to better suit transport and weight distribution. With the principles of upgrades in mind, we believe that "The Meg" is a fully realized, robust, and ready vessel for competition waters.

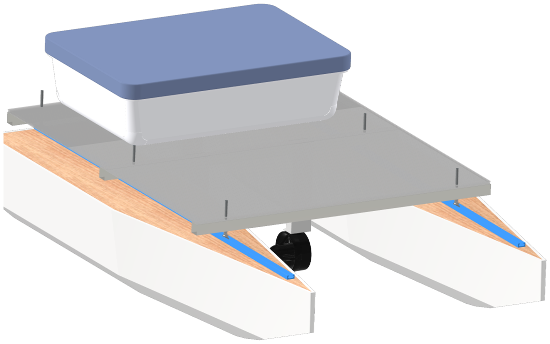

Figure 1 - CAD Render of "The Meg"

I. INTRODUCTION

Driven by newfound confidence, the team decided to attempt all tasks of the competition this season. Acknowledging the technicalities of transporting a fully equipped boat, there was careful consideration of weight, specifically weight distribution across the vessel. However, attempting all tasks also meant significant time would have to be allocated towards developing a solution;with that in mind, time became a primary consideration when finalizing an order of development. For example, the tasks did not arrive until late August, meaning we would have approximately 5 months after competition to design and manufacture the new hulls before the tasks arrived. Additionally, competing in high school means resources are limited compared to universities. We have supplemented some of our deficits through connections with UTA professors and students for equipment and guidance. We recognized the unpredictability of how development will go as more information about the competition specification were revealed, so modularity in software and hardware design was taken into account. In case the team decided later down the road that certain tasks were not worth the cost of development, software and hardware components could be removed to accommodate.

II. COMPETITION STRATEGY

II.A) Delegating Roles

The foundational logic for autonomous movement is synonymous for all navigation tasks. This simplified the designation process with an encompassing navigation team that is further dispersed into three roles: a team for gathering outside input, a team for processing said input, and then a team for transcribing the data into output for the motors. The logic for the other tasks are handled by a separate engineering team to allow parallel development across the entire team, allowing for minimal reliance on the navigation team's system when developing the "robotics" oriented tasks.

II.B) Navigation Tasks

Autonomy is achieved through a waypoint system allowing the boat to follow a point or avoid it. Object and position data is fed into a custom ROS2 node to define the path of the vessel. ROS2 maps dead zones to these objects to create the path; from this point, MAVROS sends the data to the motor.

The “**Navigation Channel**” task demonstrates this waypoint system well. As the boat travels forward, it identifies the buoys adjacent to the vessel. With dead zones on each buoy, the boat does course corrections, as to not collide with the excluded areas, and exits the gate.

The same holds true for “**Follow the Path.**” With multiple buoys at either side of the vessel, ROS2 builds the path from the detected buoys, and the boat carefully executes the path via MAVROS.

The **Speed Challenge** is slightly more complicated. Going through the gates is the same as task 1, but for the autonomy to adapt to the varying position of the blue buoy, it will identify whether the blue buoy is in front or behind the yellow buoy through the waypoints. If in front, circumvent the blue buoy until the boat is past the blue buoy via GPS position. From there circumvent the yellow buoy until position is rotated 180. If behind, circumvent the yellow buoy until the vessel has rotated 180.

Docking is achieved with exclusion zones placed at the perimeter of the docking area, permitting the boat to center itself between these zones with LiDAR data tracking relative position. Once the correct banner has been identified, the vessel will move into position.

Returning home is also a simpler task thanks to waypoints. The vessel repositions itself until it finds the path back to the first waypoint. As it travels, it will identify the black buoys indicating the end of the course.

II.C) Duck Wash

The purpose of this challenge is to evaluate the capability of our boat to remain stable while applying a force. Detection of the duck banner is handled by the Intel Depth Sensor Camera with positioning data collected from LiDAR. Coupled together, the position of the banner relative to the boat is plotted with the ROS2 node. An impeller pump is driven by a 12V motor which consumes water from the lake via vinyl tubing. The tubing is positioned to target the banner at the dock. As the force of the water gun is applied against the boat, ROS2 makes sure that the boat stays within a certain range of the banner and applies course correction via MAVROS.

II.D) Collection Octagon

Taking notes from vessels of similar function, the idea is to implement a conveyor belt that is lowered into the water. Once the camera identifies the banner, ROS2 positions the boat to carefully lower a conveyor belt over the octagon. The conveyor is then turned on and the boat is able to pick up the objects coming towards it

II.E) Delivery Octagon

Items are stored into sorted buckets. Once the depth sensor camera detects the appropriate banner, the boat will position itself port side. A gate is lowered on the correct bucket and the items fall akin to a dump truck mechanism. The same actions are repeated for the other banner and bucket respectively.

III. DESIGN CREATIVITY

III.A) Hull and Frame Design

The basis for the hull’s design was improving upon last year’s vessel, “*Aquaholic"* , to reduce the time needed for R&D. Therefore, we took the basic frame of “*Aquaholic"* and added more curvature to the sides and bow to enhance recovery from listing and trimming. The team concluded other manufacturing methods would require time or equipment we lacked access to. Therefore, we took a cue from traditional marine vessels and constructed a wooden frame. We wrapped a fleece cloth across the wooden frame forming the desired ensemble that was later covered with three layers of fiberglass sealed with polyester resin. To reduce the risk of air bubble formation through a more refined shape, we built the first two layers from huge sheets of fiberglass to provide the strength, with the final layer containing smaller sheets overlapping each other like scales. Overall, the fleece method produced a vessel with significantly higher buoyancy than initially calculated, providing the team ample room for weight distribution.

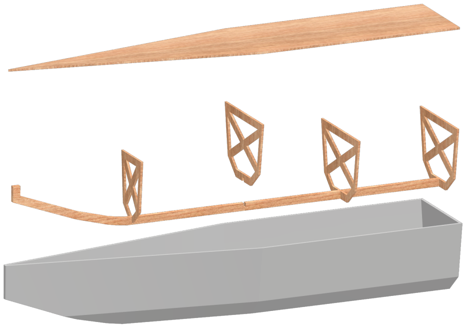

Figure 2 - The Meg's Hull Construction

The platform was designed to be lightweight in order to take advantage of high buoyancies. The base consists of a 3' x 2.5' x 0.25" polycarbonate sheet strengthened with three 2.5' x 1" x 1" aluminum square tubing (Figure-3). The square tubings serve as beams for rigidity against the flexible polycarbonate; as a result, the platform weighs merely 6 pounds, yet it retains the rigidity needed to fasten the other equipment onboard. One big issue last year was the center of gravity contributing to high degrees of listing and trimming. Additionally, a minor issue was the size of the boat causing problems in terms of transportation. To tackle both problems at once, the team designed the platform to slide on a rail system. These rails are fastened to the decks of the hulls allowing the platform to be removed completely or adjusted forward and aft. The boat can be disassembled for transportation and center of gravity can be fine-tuned as need be.

III.B) Propulsion System

Similar to the year previous, we have implemented Blue Robotics's T200 thrusters as the main source of propulsion. Aided by the guarantee that we purchased a surplus of T200 thrusters, the team was able to experiment with different configurations and have spares in case a thruster were to break. Among the different configurations, the team decided on a four thruster arrangement with two thrusters for forward propulsion and two others for side-to-side strafing (Figure-3). This layout provided greater maneuverability while also simplifying the directions of the boat when calculating a path.

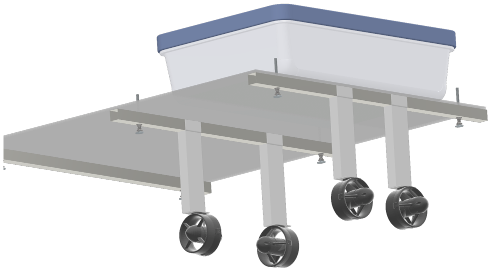

Figure 3 - Thruster Configuration & Frame

III.C) Water Gun

In order to enhance our boat's performance, we devised a simple water-pumping system consisting of an impeller pump driven by a 12V motor and 0.170 in. I.D. x 1/4 in. O.D. clear vinyl tubing in order to create a continuous output using the lake water. The water pump is mounted to the surface of the baseplate and custom 3D-printed mounts are used to position the tubing to the desired height. One half of the vinyl tubing is positioned underwater to provide the necessary ammunition. A custom nozzle was designed to increase the firing distance and accuracy of our pump. With the aforementioned design and components, the boat is able to auto-adjust its position to stay on target.

III.D) Conveyor Belt

Through experimentation, we have found that a scoop or claw would require too many degrees of movement and accuracy for success. In an effort to simplify the mechanism, our team decided upon the employment of a conveyor belt mechanism. A conveyor belt means the boat would just simply drive over the object and it will be caught in the belt. The conveyor is a tank tread design with flaps on every other tread; this way, catching the objects is much more effective. A pair of bike chains is driven via a 12V motor at the front of the boat frame. In between the bike chain is polycarbonate material for a lightweight yet rigid tread. From previously conducted studies, we determined that 30 degrees below horizontal of the frame is ideal for catching objects at angle. Since the PVC octagon surrounds the items, the conveyor belt can be lowered over the PVC via a 12V motor pulley similar to a draw bridge.

III.E) Sorting System

The sorting mechanism is a direct extension of the intake mechanism. Extended conveyors move the collected items toward the two sorting boxes. The collected items, identified by a camera on the intake, are selected to continue on a path determined by a gate. Similar to an airport baggage sorting junction, this gate has two positions. The gate swings between these two positions, which directs the collected objects into their designated drop box when the objects slide along the gate. After the object follows the selected path, they fall into one of the two identical drop boxes. These boxes have a floor angled at -15 degrees, which slides the objects into a hinged wall. When the boat is ready to release the objects, a latch opens, releasing this wall. The wall rotates until it becomes parallel with the floor. This increases the horizontal displacement of where the objects are dropped off of the boat, ensuring the objects are dropped into the scoring octagon. The minimal number of moving parts, low weight, and low power requirement for this step are benefits for this design choice when executing this task.

III.F) Electrical System

Last year's competition allowed our team to see what worked and what didn't for our electrical system. One major flaw observed was that one or two people understood the electrical system which proved problematic since those people were either preoccupied with the computer science team or sleep-deprived. This year put an emphasis on abundance by teaching multiple people how the system works. Other topics of discussion include soldering lessons, electrical hazard safety. In contrast to the inconvenient setup last year, the current system is more organized and easier to follow. Therefore, our renewed electrical system has promoted ease in tracing issues and facilitated teaching others how our boat is powered.

III.F-1) More Robust Remote E-Stop

Last year's competition led us to take less than ideal approaches towards fixing the remote E-stop. Controlled via a cellular device, it was, simply put, very shoddy and lacking in robustness. This year is much more straightforward; the E-stop is tied to a receiver that communicates with a Pixhawk Cube Orange. The Cube Orange receives a signal from a switch on a Taranis QX7 remote controller. With a flick of the switch, the receiver triggers a relay disconnecting the thrusters from the battery.

III.F-2) Better Layout

During the 2023 season, a major source of disruption was troubleshooting, or more specifically the tediousness of troubleshooting. Due to the convoluted layout of the components and wiring, locating the problem in the system became a daunting task. We have rectified this in this season's improved system with properly gauged wire, centralized power terminals, restrained wiring, and a better quick detach system consisting of draw latches and handles to quickly remove the electrical box and the system within.

III.G) Software

Our software infrastructure is designed to support the autonomous functionalities of the boat, comprising two primary systems: the computer vision system and the motor control system. The computer vision system is responsible for constructing models to identify objects in the competition, while the motor control system includes algorithms for autonomous decision-making and control mechanisms for signaling various motors. These systems communicate through a ROS framework, and the Intel Depth Camera D435i is an integral part of the ROS system, providing essential information for localization.

III.G-1) Computer Vision

Working in tandem with the depth camera, our computer vision system enables the boat to detect and localize objects within its field of view. Our workflow involves uploading data, labeling objects, and using the results to enhance the model. Roboflow was employed to create a custom dataset by uploading photos of buoys in different environments and angles. Images were then manually labeled in Roboflow, specifying bounding boxes around target objects, such as various buoy classes. The labeled data was used to train the YOLOv8 computer vision model, precisely testing nano, small, and medium models, with the most effective being YOLOv8s. This model, trained on over 5,000 images, achieves a precision of approximately 90% for object detection, with confidence levels close to 60%. There were initial testings on a less powerful Jetson Nano which could not keep up with the demand of the model. Consequently, a Jetson Xavier NX is powering the machine learning; being an AI oriented machine, this provides better performance in image processing compared to a typical mini-pc on top of handling the model's demands.

Figure 4 - Preparation of "The Meg" For Its Maiden Voyage

III.G-2) Motor Control

The motor control system, crucial for autonomous movement, consists of two subgroups: path planning and path execution. Path planning involves task-specific algorithms to create a list of waypoints defining the boat's optimal path. Waypoints are calculated using a mapping function that considers both local and global frames of reference. We use a combination of specialized selection and calculation for simpler tasks and other algorithms for more complex tasks, handling task transitions with a predefined order.

To execute the waypoint-defined path, we utilize a Cube Orange, equipped with a Here3 GPS, IMU, and compass, enabling seamless communication with the motors to navigate the boat to specific GPS coordinates. Computation of position data provided by the Cube Orange is handled by an Odroid M1. MAVROS, also powered by the Odroid, handles the transition from path data to motor controls for the thrusters. The Cube Orange plays a pivotal role in the execution phase, providing precise location data and orientation information to ensure accurate path following; its integrated capabilities streamline the process, enhancing the boat's navigation efficiency and overall performance during its mission.

However having positional coordinates is useless unless the position relative to the boat is known. This is where the Velodyne LiDAR Puck comes into play. The boat uses the LiDAR sensor to get the exact location and distance a buoy is from the boat. It combines the camera's vision processing system to get the angle the buoy makes with respect to the boat. Subsequently, it looks through the LiDAR point cloud to find the coordinates of the buoy at that angle. Once the exact location relative to the boat is found, the latitude and longitude of the buoy is computed and sent off to the navigation module.

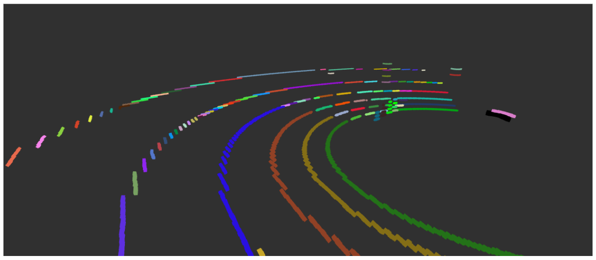

Figure 5 - LiDAR Data With Clusters in Gazebo Simulation

IV. TESTING STRATEGY

Software testing is done through the use of a Gazebo simulation run in a docker container. The boat's design is ported over as a Gazebo model, and from there we are able to program and test to see if the boat can pass the starting gates via software before the physical boat is built. With *Aquaholic* still in functioning order, the computer science team is able to test code and machine learning in a real environment. Hence, the computer science team can work independently of the engineering team while *The Meg* finishes development.

Figure 6 - Testing New Cube Orange Parameters With Aquaholic

After *The Meg*'s completion, testing began at Lake Arlington to simulate the conditions of competition, involving transportation of electronics and buoys over the course of software testing. Performed tests included object recognition, material stress, remote E-stop, fine-tuning positional data, and verifying electrical component connectivity.

Figure 7 - Testing of "The Meg" on open waters

V. ACKNOWLEDGEMENTS

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Appendix A: Component List

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
ASV Hull Form/Platform	Home Depot/Own Design	Plastic Container	link	Purchased	9.98	2022
Waterproof Connectors	Lowes	Silicone Sealant	link	Purchased	10.98	2022
Propulsion	BlueRobotics	T200	link	Purchased	200.00	2022
Power System	HobbyKing	Lithium-polymer battery	link	Purchased	108.97	2022
Motor Controls	BlueRobotics	Basic ESC	link	Purchased	36.00	2022
CPU	Amazon	Jetson Xavier NX	link	Purchased	700.00	2023
CPU	Amazon	Odroid M1	link	Purchased	135.00	2023
Teleoperation	Amazon	Taranis Q X7	link	Purchased	137.99	2022
Compass	CubePilot	Here3	link	Purchased	290.00	2023
Inertial Measurement Unit (IMU	CubePilot	Here3	link	Purchased	290.00	2023
Camera(s)	Intel	Intel RealSense Depth D435	link	Purchased	314.00	2022
Doppler Velocity Logger (DVL)	N/A	N/A	N/A	N/A	N/A	N/A
Hydrophones	N/A	N/A	N/A	N/A	N/A	N/A
Algorithms	N/A	N/A	N/A	N/A	N/A	N/A
Vision	Intel	Intel RealSense Depth D435	link	Purchased	314.00	2022
Localization and Mapping	CubePilot	Cube Orange	link	Purchased	485.00	2022
PyRealsense	Intel	N/A	link	N/A	N/A	2023

MavSDK	DroneCode	N/A	link	N/A	N/A	2023
Gazebo Simulator	Open Robotics	N/A	link	N/A	N/A	2023
ROS	Open Robotics	N/A	link	N/A	N/A	2022
Docker	Docker	N/A	link	N/A	N/A	2022
MicroPython	Raspberry	N/A	link	N/A	N/A	2023
QGroundControl	DroneCode	N/A	link	N/A	N/A	2023
Mission Planner	Ardupilot	N/A	link	N/A	N/A	2022