Voltage Voyagers Technical Report

H. B. Meisner
Electrical Engineering
U.S. Coast Guard
New London, CT
hannah.b.meisner@uscga.edu

D. L. Rivie
Electrical Engineering
U.S. Coast Guard
New London, CT
dylan.l.rivie@uscga.edu

P. B. Stevens
Electrical Engineering
U.S. Coast Guard
New London, CT
phoebe.b.stevens@uscga.edu

S. J. Rutman
Electrical Engineering
U.S. Coast Guard
New London, CT
sara.j.rutman@uscga.edu

***Abstract*— Our group is part of the United State Coast Guard Academy's Electrical Engineering Department and building the Autonomous Surface Vessel (ASV) serves as our senior capstone project. Our ASV is of a dual catamaran design, battery-powered, has remote control capabilities, and utilizes the Robot Operating System (ROS) for autonomous decision-making. The propulsion system consists of two Blue Robotics T200 thrusters powered by lithium-ion batteries. The center of gravity of the ASV was adjusted by changing our vessel design to accommodate the weight of our new electronics and make the vessel more stable. We are using the SLAM (Simultaneous Localization and Mapping) algorithm which will allow us to navigate the course using sensor inputs from our GPS, IMU, and image-processing camera. Our team's game strategy will focus on the first two tasks of the competition "Navigate the Panama Canal" and "Magellan's Route". This will be accomplished using a Zed 2i camera and our AI algorithm to identify buoys and adjust the direction of thrusters. The YOLO (You Only Look Once) object detection algorithm will be used to train the AI to identify red and green buoys. Our group aims to build a strong base for future teams and ensure a successful competition entry next year.**

I. Technical Content

Based on the competition requirements, we knew our vessel needed to navigate narrow channels, demonstrate collision avoidance, and identify objects used for navigation purposes. Other objectives we must meet are that the vessel is battery powered, autonomous navigate through a channel of buoys, have remote control capabilities, possess stable buoyancy, utilize Robot Operating System (ROS), and have a physical kill switch on its body. In order to accommodate the weight of the new electronics we adjusted the center of gravity of our new vessel. Although it set our progress back, we have a stable longer lasting vessel. As for our strategies behind our design, we are utilizing the SLAM (Simultaneous localization and mapping) algorithm to navigate through the course. This entails using different sensor inputs such as GPS, IMU, and image processing camera.

II. Competition Goals

Due to us being a small, first-year group, we decided to focus on meeting the first two tasks of the competition course: "Navigate the Panama Canal" and "Magellan's Route". Mapping out the full course using a SLAM algorithm and GPS was part of our initial plan, as well, but was dropped due to time constraints and it being unnecessary for the first two tasks. Both tasks can be accomplished using a similar strategy, as the goal in both is to center the vessel between red and green buoys. To accomplish this, we are utilizing a Zed 2i camera placed on the bow of the vessel, which will send image data to our Jetson AGX Orin, where it will be processed using an AI algorithm. The algorithm will identify where buoys are in the water and the boat will adjust the direction and intensity of its thrusters accordingly. Initially, we were planning to use a more traditional image processing algorithm utilizing OpenCV. However, we switched to an AI algorithm because we were given access to an Nvidia Jetson AGX Orin, the most power compact AI accelerator on the market. We also believe the flexibility that AI provides will make it simpler for groups in the future to expand our work. For instance, now that the initial setup is complete, it will be relatively easy to generate a new algorithm to identify the colors and shapes found in later competition tasks.

Another main goal for our group is building a strong base that future teams will be able to build upon. Our team is an electrical engineering senior capstone project, meaning that there will always be a high turnover of people every year. To combat this, we have freshmen and junior electrical engineering students that joined the group second semester. We are keeping them active and involved in the design process so that when they take over the project in future years, they won't need to start from square one. We are confident that by the end of this semester, we will have all the ship's sensors (GPS, IMU, LiDAR, and camera) mounted and the wiring complete so that future groups can focus primarily on coding the ASV. Setting next year's group up for success so they can fully compete in next year's competition is our most central and important goal as a team.

III. Design Strategy

a. Physical Design

Given that this is the first year the Coast Guard Academy's ASV capstone group has entered the RoboBoat competition, we have started building up from the basics. For our vessel body, we have a dual-thruster catamaran that was passed down from previous capstone groups. The advantage of this design is its increased stability and maneuverability. It also offers a wide platform in the center of the two hulls, which provides ample room for mounting sensors. We modified the vessel by refurbishing it, starting with changing the deck from plastic to wood material. This improved buoyancy made installing containers easier. We also refurbished the electronics housing unit so that it is now a waterproof container and has enough room for all our current and potential future groups' electronics.

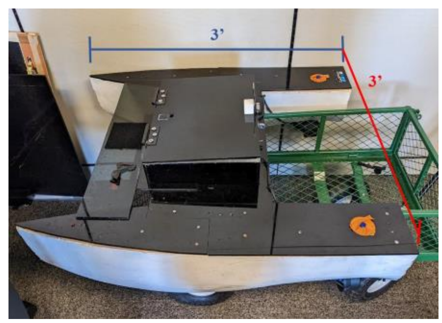

Fig. 1. The autonomous surface vessel's physical design and dimensions.

b. Power System and Propulsion

Over this semester, our group redesigned the power and propulsion systems. The vessel's propulsion is handled by two Blue Robotics T200 thrusters. Each thruster is powered by a 14.8V, 18Ah lithium-ion battery. The thrusters are controlled by an electronic speed controller which recieves a pulse width modulation (PWM) pulse that determines how fast, and in what direction, the thrusters spin. For example, a 1.5 ms width pulse puts the thrusters in neutral and 1.9 ms width pulse puts the thrusters at their maximum forward speed. The batteries are connected to the thrusters through two 25A circuit breakers and a two channel relay module. The relay module allows us to have a switch to disconnect the batteries from the thrusters. The relay recieves 5 volts of power from the Jetson AGX Orin, which will pass through the vessel's emergency stop button before reaching the relay. When the emergency stop button is pressed, it disconnects power from the relay, which opens the switch between the batteries and the thrusters. This switch can also be opened by sending a digital "low" signal from the Jetson to the relay. This will serve as the secondary remote e-stop, which is required by the RoboBoat compeition rules. Fig. 2 shows the ASV's power and emergency stop system.

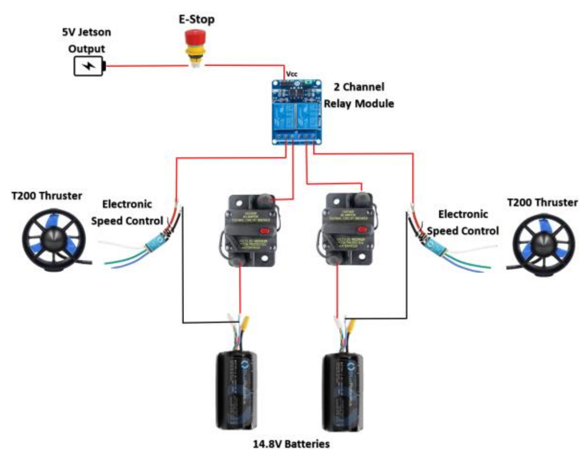

Fig. 2. The ASV's power system with emergency stop.

c. Autonomous and Manual Control

The Jetson AGX Orin has been chosen as the vessel's onboard computing unit, meaning it will control decision making and the vessel's thrusters when it is in autonomous mode. The Jetson will be powered by a 26.8 Ah Anker power bank, which can supply up to 60 watts, as required by the Jetson. The vessel's manual control is being done with a Fly-Sky remote control, operating in the 2.4 GHz frequency band. To switch between the manual and autonomous control inputs, a Pololu 4-channel multiplexer is being used. Flipping the "SWA" switch down on the remote control will allow inputs from the Jetson to pass to the thrusters, while the switch in the up position gives control to the remote control.

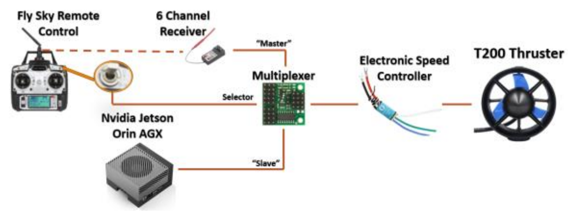

Fig. 3. The ASV's autonomous and manual input switch system.

To meet the objective of the first task in the RoboBoat competition (navigating through a channel of red and green buoys), the group will utilize machine learning to identify red and green buoys in the water. You Only Look Once (YOLO) is the object detection algorithm we will use to train AI to perform this task [2]. This algorithm will then be deployed on the Jetson AGX Orin, which will receive information from the Zed 2i camera placed at the front of the vessel.

The vessel will utilize a Simultaneous Localization and Mapping (SLAM) algorithm to help map the RoboBoat competition course. The primary input feeding this algorithm will also be from the Zed 2i camera and a LiDAR placed at the front of the vessel. To ensure we have an accurate vessel heading, we will utilize our recently purchased GPS-RKT Dead Reckoning kit. It has a built-in GPS and IMU complimentary filter, which allows it to switch between the two headings. For instance, GPS is more accurate when traveling in one direction for a long time, as IMU starts to drift after a while. But the IMU is more accurate when making sharp turns. So, the complimentary filter uses both inputs to output the most accurate heading information.

The Jetson will be running on Ubuntu 20.04 LTS with Robot Operating System 2 installed to manage the sensor inputs from the Zed 2i Camera, GPS, IMU, and LiDAR. ROS is a middleware designed to provide a software framework for robotics development. It allows the user to send action requests and responses between various nodes, representing various parts of the robot [1].

Our vessel's physical design, paired with the inputs from our new sensors, and the processing power of the Jetson AGX Orin, will allow our autonomous surface vessel to autonomously navigate through a channel of buoys. This meets the first requirement of the RoboBoat competition, and will setup future capstone groups to tackle the more advanced competition tasks.

IV. Testing Strategy

Our team is fortunate enough to have access to the Naval Architecture and Marine Engineering laboratory space on campus. This includes various small testing tanks, a 50,000-gallon tow tank, and a 10,000-gallon circulating water channel. Before putting the boat in the water, however, we utilized an oscilloscope to measure PWM pulses being sent to the vessel's thrusters, to ensure they were responding appropriately. We measured the PWM pulses being sent via our remote control, the Fly-Sky remote, and used it to control a thruster on the test bench. The biggest challenge in this process was finding a functioning remote control and receiver pair, but setup was straight forward after that.

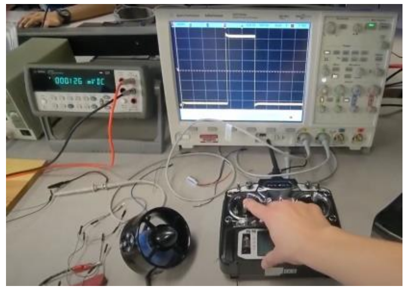

Fig. 4. Controlling a T200 thruster with the remote control and measuring the PWM output.

The vessel's first pool test was conducted on October 17th, 2022. We controlled the vessel with the Fly-Sky remote in the smaller tank located next to Naval Architecture's tow tank. The testing revealed that controlling the vessel with a remote meant for RC planes is a bit difficult, but doable. Around this time, we also replaced much of the power system's cabling, as many of the wires had frayed over the past two years of use.

In late October, we demonstrated successfully outputting a PWM pulse from the Jetson Orin and using the multiplexer to switch between the Fly-Sky remote and Jetson Orin to control the thrusters.

After assessing space availability for the electronics, we felt it was necessary to conduct a weight test. We brought the vessel down to the Naval Architecture lab and tested various weights in different sections of the electronics box. Through our test we discovered that the box could hold 22.1 kg but only at the stern of the electronics box and only 6 kg at the bow. We concluded that we needed to adjust the center of gravity by moving the electronics box and avoiding unnecessary trim.

Fig. 5. Weight testing the ASV with 6 kg placed in the bow.

The new hull design allows for more flexible placement of the electronics. The plywood is lighter than the acrylic and with the addition of stability beams will be just as secure as the last design. The electronics will be placed on top of the hull in waterproof containers to avoid unnecessary drag caused by halfway submerging the original box. This design should greatly reduce trim and strengthen the stability of the vessel.

Fig. 6. New plywood deck design.

The group set out with the intention of using previous groups' image recognition software, which ran off python and utilized OpenCV. We successfully documented and manipulated their code to detect object shapes and colors, but the results were too unreliable. In mid-October the group decided to shift to machine learning for object detection, deciding to use the YOLO algorithm. The reasoning behind this decision was that YOLO is extremely accurate and fast, which is necessary for our ASV to successfully complete RoboBoat challenges.

In order to use YOLO, our group had to collect photos of the competition buoys to feed to our machine learning algorithm. We successfully utilized RHIs to collect data samples at USCGA's waterfront and labeled them using YOLO-Label. Working with Cyber ARP, our capstone group has started setting up their server in order to use the dataset to train the algorithm.

When we are further along with our project, we will set the green and red competition buoys out in the Thames and test our vessel's ability to stay in the center of the channel.

Fig. 7. Thames River testing from the 2022 ASV capstone group.

V. Conclusions

Throughout the four months we have been working on the Autonomous Surface Vessel, we have drawn several conclusions. We learned how critical documentation is for a project. We had bits and pieces of information from last year, but we found there were many temporary solutions patched together rather than lasting ones. We not only improved the documentation, but we have created helpful diagrams for next year's group to understand our work. Another issue we ran into is outdated technology, but the changes we made to the hardware (Jetson, GPS, IMU, and the entire vessel) as well as software (ROS2) should provide more permanent solutions. By making these various changes, as well as taking active steps to prepare for the

RoboBoat Competition, we feel that our vessel will be an incredibly strong competitor in future years.

References

[1] "ROS 2 Documentation," ROS Documenation. https://docs.ros.org/en/rolling/index.html (accessed Dec. 08, 2022)

[2] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You Only Look Once: Unified, Real-Time Object Detection," arXiv.org, Jun. 08, 2015. https://arxiv.org/abs/1506.02640

Acknowledgements

We would like to thank our capstone advisor, CAPT Kelly Seals for guiding us throughout the project. The team has also been immensely supported by the entire USCGA Electrical Engineering and Naval Architecture departments. Finally, we would like to thank one of our professor, Dr. Ali Reza, for deepening our understanding of signal processing and his supportive mentoring.

APPENDIX A: COMPONENT LIST

Component	Vendor	Model/Type	Specs	Custom/Purchased	Cost	Year of Purchase
ASV Hull Form/Platform	Developed	N/A	Plywood and insulation foam	Custom	Unknown	2018
Propulsion	Blue Robotics	T200 Thruster	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Purchased	$200	2018
Power System	Blue Robotics	Lithium-ion Battery (14.8V)	https://bluerobotics.com/store/comm-control-power/powersupplies-batteries/battery-li-4s-18ah-r3/	Purchased	$350	2018
Motor Controls	Blue Robotics	Basic ESC	https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Purchased	$36	2018
CPU	Nvidia	Jetson AGX Orin	https://www.nvidia.com/en-us/autonomous-machines/embedded-systems/jetson-orin/	Purchased	$2,000	2022
Teleoperation	Fly Sky	FS-T6	https://www.flysky-cn.com/fst6	Purchased	Unknown	Unknown
Compass	SparkFun	GPS-RTK	https://www.sparkfun.com/products/18294	Purchased	$350	2022
E-Stop Button	EAO	61-6451.4247	https://www.mouser.com/ProductDetail/EAO/61-6451.4247?qs=wd5RIQLrsJhPopbfUPkaMQ%3D%3D	Purchased	$75	2022
Camera(s)	Stereo Labs	Zed 2i	https://www.stereolabs.com/zed-2i/	Purchased	$500	2022
Algorithms	YOLO	Object Detection	https://github.com/WongKinYiu/yolov7/blob/main/paper/yolov7.pdf	N/A	$0	2022
Open-Source Software	ROS	ROS 2	https://docs.ros.org/en/rolling/index.html	N/A	$0	2022