Sonny's Dream - Iceberg ASV

Roboboat 2024: Technical Design Report

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Submitted: December 17, 2023

Abstract - This Technical Design Report outlines Iceberg ASV's approach to designing Sonny's Dream for the 2024 Roboboat Competition. Sonny's Dream was designed to improve reliability, functionality, and safety for the 2024 Roboboat Competition. Improvements from Iceberg ASV's previous ASV, included increased hull size and deck space, improved remote kill switch control, and improved autonomous capabilities of the ASV with object detection and navigation. The team thoroughly tested all iterations through simulation and physical tests in open water to achieve competition-like environments.

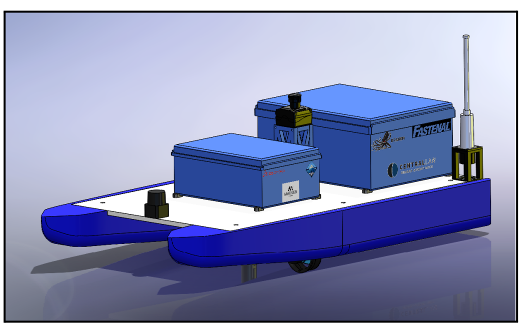

Fig. 1. Sonny's Dream Render

1.0 Competition Strategy

Iceberg Autonomous Surface Vessel (ASV) focused on completing the Navigation Channel, Follow the Path, the Docking Challenge, and the Speed Challenge for the 2024 Roboboat Competition [1]. To complete the tasks at the competition, Iceberg ASV focused on improvements to the vessel's design, electrical systems, and software capabilities.

1.1 Hull Design Strategy

The Roboboat competition is heavily software-focused, therefore the team prioritized design choices and modifications that benefited software implementations. Modifications were made in collaboration with the software team, to determine optimal sensor placement, ensuring a stable platform for accurate data collection. Iterating on last year's design was a priority - maintaining the dual-hull catamaran with a detachable bridge [2], the design team continued to emphasize the importance of stability, modularity, and reliability.

Although the overall design concept remained the same, significant changes were implemented, including scaling the vessel dimensions by a factor of 1.75.

1.2 Electrical Design Strategy

The design strategy for the electrical system was to maximize the amount of in-water time at the competition to allow for continual iteration on the autonomous challenges during the 2024 Roboboat Competition.

During the 2023 Roboboat competition, several flaws in the electrical housing design and layout became apparent, such as spacing, cable management, and component position. The culmination of flaws led to a delayed start for Iceberg ASV as the focus of the first two days of the competition was on passing the safety test. To maximize in-water time at the competition and improve the electrical system's reliability, the Electrical team focused on producing a system with improved cable management, documentation, and component layout.

1.3 Software Design Strategy

Iceberg ASV decided to focus on the four navigation tasks as this is the first time the ASV will complete the tasks dynamically without preset waypoint routes.

The team also aimed to configure wireless communication between the ASV's computer and the shore. During RoboBoat 2023, there was no communication with the ASV's computer while it was on the water, making debugging and controlling the boat difficult. Wireless communication will allow the team to quickly diagnose issues and run tests efficiently.

The final goal was to develop an object detection system to run in real-time and detect each of the competition props.

2.0 Design Choices

2.1 Vessel Size

The hull was increased for the ASV to mitigate issues raised at RoboBoat 2023. One issue during last year's competition was limited deck space. Making both the bridge and hulls larger eliminated this issue. Tables 1 and 2 show the 2023 ASV dimensions compared to the 2024 ASV dimensions.

Table 1. ASV Hull Dimensions

	2023	2024
Hull		
Length	32.5 in	48 in
Total Beam (*two hulls + bridge*)	25 in	26.5 in
Beam (*of one hull*)	6.5 in	7.5 in
Depth	4 in	5 in

Table 2. ASV Bridge Dimensions

	2023	2024
Bridge		
Length	24 in	40 in
Width	20 in	24 in
Thickness	¼ in – ½ in	½ in

2.2 Hull

During the design of the ASV, three primary areas were considered: the hulls, the bridge, and the electrical integration. There were three primary changes made to the hulls this year:

- The hull size was increased to accommodate the larger, heavier electrical boxes and components used.
- The hull CAD models were designed in Maxsurf, a software used for hull modeling, stability, and resistance prediction, allowing for precise curvature in the models.
- The hulls were finished using fiberglass rather than Flex Seal, increasing long-term durability.

2.3 Bridge

High-density polyethylene (HDPE) plastic was used to construct the bridge for its machinability. Aluminum bracing was added to the underside of the bridge to mitigate the risk of bowing due to increased bridge length.

A notable design improvement was the bridge-to-hull mounting system. The mounting system in the last iteration consisted of 3D-printed inserts that were glued into the foam hulls. This was unreliable, as the inserts detached from the foam during the competition. To remedy this problem, a new system was designed where threaded rods were fixed within the foam hulls. The bridge was mounted on the rods with a nut. This system maintained modularity for travel and improved the reliability of the assembly during operation.

Thruster mounts, an emergency stop mount, a camera mount, and a WiFi bullet mount were each redesigned. All mounts to support the electrical components were 3D printed using PET-G filament, which was selected due to its durability and resistance to water and sun exposure.

2.4 Remote-Controlled E-Stop

The remote-controlled emergency stop system implemented on Sonny's Dream employed a 12V-DC relay to control the power to the thrusters and a PWM signal sent from the Remote Control. The remote controller produces a varying Pulse Width Modulation (PWM) signal that controls a DC voltage to trigger the relays.

In the 2023 Roboboat competition, the remote-controlled emergency stop used an Arduino microcontroller to interpret the PWM signal from the receiver and then controlled a MOSFET-based circuit to enable or disable the relays.

This year, the remote-controlled emergency stop has been improved to a reliable hardware-based solution. The PWM signal is averaged and compared against a reference voltage using a series of operational amplifiers and comparators to activate or deactivate the relay [3]. This circuit is implemented on a PCB to ensure stable connections and consistent performance.

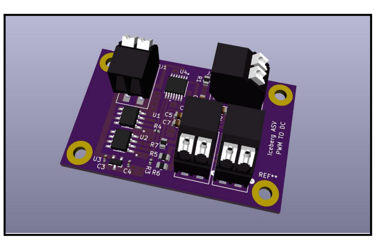

Fig. 2. PWM to DC PCBA

2.5 Electronic Layout

Iceberg ASV implemented DIN Rails within the electrical housing to optimize the component layout and cable management. Previously, Iceberg ASV used velcro to secure the electronics within the housing as it was affordable and straightforward to implement. During the 2023 Roboboat competition, the electronics were reconfigured multiple times, which led to the velcro strips wearing out.

Using DIN rail clips to mount the electronics also allowed for future adjustment as the components could be shifted within the housing as needed.

For Sonny's Dream, the electrical enclosures have increased in volume by a scaling factor of two. The increase in volume allowed the electronics to be spaced apart to avoid physical and magnetic interference with the relays. The larger space also ensures that the positional dependent components, such as the Pixhawk and GPS, can be secured in the correct locations.

2.6 System Overview

The software suite displayed in Figure 3 consists of seven core packages used for object detection, object mapping, control and navigation, and task execution. In addition to packages developed by the team, the software also interacts with a MAVROS package that allows for communication via MAVLink to the Pixhawk flight controller and packages that provide access to data from the LiDAR and camera.

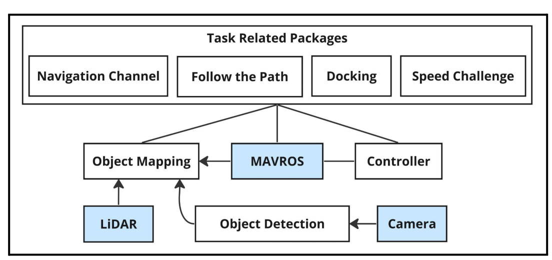

Fig. 3. Packages in the Software Suite

2.7 Object Detection

Object detection was implemented using the Intel Realsense D435 camera within a

ROS framework on Sonny's Dream. The team used Roboflow to annotate and label images to create a custom dataset for identifying objects and used YOLOv5 for the object detection algorithm. YOLOv5 was selected because it is optimized for efficiency, enabling fast and reliable detection.

The trained YOLOv5 model, integrated into the ROS-based system, efficiently identified and located competition objects. The results of this object detection process, including the class, confidence score, and bounding box coordinates of each detected object, are published and made available to the rest of the system. This integration ensures that the robotic system can access and utilize this vital information in real-time, greatly enhancing its ability to interact intelligently with its surroundings.

2.8 Object Mapping

The object mapping package uses LiDAR, camera, and GPS to locate objects and assign local coordinates to them. Bounding box information from the object detection package is used to calculate an angle range where an object could lie based on where a bounding box appears in the camera frame. The distance node extracts the LiDAR data for this angle range and uses clustering to determine the object's relative distance to the ASV. The coordinate node uses the object's relative position and the ASV's position from the GPS to calculate the object's position. Finally, new objects are added to the mapping node. The Object Mapping package runs continuously during a run and provides updated lists of all the detected objects to the other packages in the system.

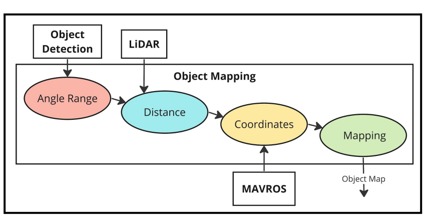

Fig. 4. Object Mapping Package

2.9 Controls and Navigation

The controller package provides three functions to the ASV. It controls the execution order of the tasks, provides a user interface to start and stop runs, and contains global configurations for the ASV.

2.10 Task Packages

Navigation Channel

The Navigation Channel package listens to the object mapping node and drives the ASV forward until it detects a red and green marker to the left and right of the ASV in the object map. Once the markers are detected, it calculates the midpoint between them and sends the midpoint to the waypoint sender. The package uses GPS to detect when the ASV reaches the midpoint and repeats the process for the second gate. It notifies the task controller upon completion.

Follow the Path

The Follow the Path package uses the camera to identify the general direction of the path, then listens to the object map for the buoys that mark the path. Similar to the Navigation Channel, it calculates the midpoint of the buoy pairs and sends the midpoint to the waypoint sender. When the camera detects yellow or black buoys, the package steers the boat away from the obstacle and then returns to the original waypoint after the obstacle has been cleared.

Docking

The Docking package will trigger the object detection package to detect the shapes and colors on the docking bays. Bounding boxes on images of the docking bays are used to determine the bay's location, and the package sends the ASV in that direction. The package uses LiDAR data to determine when the ASV is approaching the dock and can slow down.

Speed Challenge

The Speed Challenge package functions similarly to the Navigation Channel. It listens to the object map for the location of the starting gate and heads toward it once detected. It stores the position of the gate for the return. After passing through the gate, it heads forward until it detects the marker buoy on the map. It avoids the obstacle buoy by making a tight circle around the marker buoy before heading back to the stored location of the start gate.

2.11 Hardware Implementation

The ASV's hardware included an NVIDIA Jetson Tx2 for the onboard computer and a Pixhawk flight controller. The Jetson runs the object detection and ROS packages that control the ASV.

The Pixhawk allowed the ASV to move to the desired position and velocity setpoints. The flight controller simplified the motor mixing process and integrated the GPS and an inertial measurement unit (IMU) to provide positional data so that the team could focus on the autonomous control of the ASV.

The team tested using two GPS receivers to replace a compass. Two low-cost GPS modules on the bow and stern of the ASV can be combined with an Extended Kalman filter to produce a vessel heading [4]. This is useful because the compass inside the Pixhawk is extremely sensitive to electrical noise. The GPS receivers are not affected by noise as much as the compass, so that the heading would be more accurate, and the team would not have to constantly re-calibrate the compass while testing.

Another hardware update was the Ubiquiti airMAX Bullet. The bullet enabled wireless communication between the ASV and the shore by creating a local area network between two bullets, one on the shore and one on the boat. The bullet allowed the team to remotely access the Jetson to control and debug the ASV.

Additional hardware on the ASV included the Hokuyo UST-20LX LiDAR, an Intel RealSense D435 camera, and an RC receiver.

3.0 Testing

3.1 In-Water Testing of Hulls

During in-water testing of the first iteration of new hulls, the team found that excess buoyancy and poor weight distribution led to the boat sitting deeper in the aft – this can be seen in Figure 5. Furthermore, thruster cavitation occurred due to the excess buoyancy and caused a higher-than-expected draft.

Fig. 5. In-Water Test of Boat

A follow-up test consisted of altering the buoyancy of the hulls. This was achieved by conducting weight distribution tests in the MUN Engineering Building Fluid Dynamics laboratory facility. By placing a series of weights on the bridge in various configurations, the design team determined the areas where buoyancy should be removed to reduce the draft to the desired level. Additionally, the team decided that the curvature of the bow should be increased for better hydrodynamics.

3.2 PWM-DC Perf Board

The bench testing of the prototype board included a step-by-step procedure to ensure that each phase of the board was working as anticipated. This enabled a detail-oriented testing strategy, ensuring each node corresponded with the correct output. This allowed for very quick debugging, which was an element that needed to be improved upon from the previous year's competition.

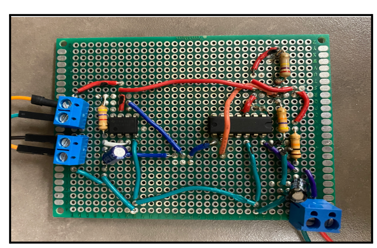

Fig. 6. Perf Board for Testing

3.3 Remote Controlled Emergency Stop

Before performing in-water tests, the following progression will be implemented to ensure the Emergency Stop functionality is working as expected:

Table 3. E-Stop Testing Strategy

Action	Check
Thrusters Forward	
Thrusters Backwards	
Physical E-Stop	
Remote E-Stop	
Fail Safe (Controller Off)	

3.4 Software Testing

Simulation

This year, the team developed a Gazebo simulation to test the software. The simulation sped up development time as it became quicker to test new features, and the team could test new software when it became too cold to test in ponds. The team utilized a Gazebo ArduPilot plugin to model the ArduPilot firmware on the Pixhawk and set up communication between Gazebo and the MAVProxy ground control station, as shown in Figure 7. The simulation modeled the communication between the ground control station and the Pixhawk, which allowed the team to send waypoints to MAVROS to move the boat in the simulation.

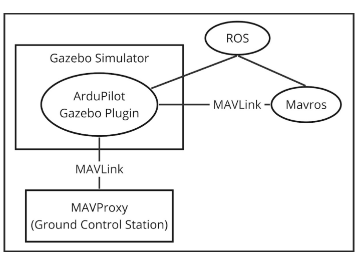

Fig. 7. Gazebo Simulation Package

Dry Testing

The team conducted dry testing for the object detection and mapping packages. This involved placing objects at known distances from the ASV and comparing the calculated and actual positions. Dry testing allowed the team to quickly test mapping, clustering, and detection algorithms.

Waypoint Navigation Testing

The team conducted several waypoint missions using the Pixhawk and GPS to tune PID settings in the Pixhawk and adjust configuration settings so the ASV could more accurately follow the target path.

3.5 Object Detection System Testing

Testing the object detection system included testing its accuracy, performance, and integration with the ROS framework. The team tested accuracy, real-time performance, environmental robustness, ROS integration, and stress.

Results and Analysis

The outcomes of these tests provide insight into the robustness and reliability of the object detection system. Analyzing the results allowed the team to identify improvements that could be made. This comprehensive testing approach ensured that the object detection system was not only accurate but also robust and reliable for the dynamic and challenging conditions of aquatic environments.

4.0 Acknowledgements

Iceberg ASV would like to thank the many people who helped support the team's endeavors. John Walsh encouraged the development of Iceberg ASV and continued to support the team through mentorship, support, and resources from Memorial University's Student Design Hub. Dr. Oscar DeSilva and his graduate students provided significant support for the team's hardware and software development. The team would also like to thank our sponsors: Memorial University of Newfoundland, Genoa Design International, Verafin, Kraken Robotics, Madsen Group, Colab Design, City of St. John's, Fastenal, O'Dea Earle Injury Lawyers, Gander Law, and Ray Creative Agency.

5.0 References

[1] RoboNation, Ducks overboard - robonation.org, https://robonation.org/app/uploads/sites/3/2023/10/Team-Handbook_RoboBoat-2024_v1.0.pdf (accessed Dec. 17, 2023).

[2]W. -Y. Dzan, S. -Y. Chang and K. -C. Hsu, "Designing and Building of a Catamaran and Its Stability Analysis," 2013 Second International Conference on Robot, Vision and Signal Processing, Kitakyushu, Japan, 2013, pp. 148-152, doi: 10.1109/RVSP.2013.41. (accessed Dec. 17, 2023).

[3] K. Burgess, PWM to DC Voltage Conversion - Michigan State University, https://www.egr.msu.edu/classes/ece480/capstone/spring15/group10/Application%20Notes/Kyle.pdf (accessed Dec. 17, 2023).

[4] G. Trigo, “Vehicle heading estimation using a two low-cost GPS ... - IEEE xplore,” IEEE Explore, https://ieeexplore.ieee.org/document/5956715/ (accessed Dec. 17, 2023).

Appendix A: Component List

Table 4. Sonny's Dream Component List

Component	Vendor	Model/Type	Qty	Specs	Custom/Purchased	Cost (CAD)	Year of Purchase
Flight Controller	Holybro	Pixhawk 6C	1	Pixhawk 6C	Purchased	$ 445.80	2022
Stereo Camera	Intel	RealSense D435	1	D435 Specs	Purchased	$ 454.00	2022
RC Controller	FlySky	FS - iA6B	1	FS-iA6B Specs	Purchased	$ 240.74	2022
Telemetry Radios	Holybro	SiK Telemetry V3	1	SiK Specs	Purchased	$ 115.00	2022
GPS Antenna	Ardusimple	APAMP-128	1	GPS Antenna	Purchased	$ 34.29	2022
Thrusters	BlueRobotics	T200	2	T200 Thruster	Purchased	$ 596.30	2022
Speed Controllers	BlueRobotics	Basic ESC	2	Basic ESC	Purchased	$ 163.00	2022
Breaker	Walfront	40A DC Single Pole Circuit Breaker	1	40 Amp Single Pole Circuit Breaker Specs	Purchased	$ 12.29	2023
Relays	Electronics-Salon	10A, 5VDC Power Relay Interface Module	2	2 SPDT 10A Power Relays Specs	Purchased	$ 36.41	2023
Ethernet plug	VCELink	Waterproof RJ45 Coupler	1	Cat5e Water Proof Connectors Specs	Purchased	$ 39.99	2023
DIN clips	Phoenix Contact	BKI TB0109		General Specs	Purchased	$ 11.30	2023
Junction Box Connector	Allaounin	4 Pin Waterproof Connector	2	Basic Info	Purchased	$ 25.99	2023
Tackle Box	Zulkit	IP67 Waterproof Electrical Box	1	Tackle Box Specs	Purchased	$ 28.24	2023
Junction Box	Zulkit	IP67 Waterproof Electrical Box	1	Junction Box Specs	Purchased	$ 41.39	2023
GPS	Ardusimple	simpleRTK2B	1	simpleRTK2B	Purchased	$ 362.56	2023
Power Distribution Board	Holybro	PM07	1	PM07 Specs	Purchased	$ 21.99	2023
Battery	Youme	4S Lipo Battery, 14.8V	2	Youme 4S Specs	Purchased	$ 125.99	2023
Emergency Stop Button	McMaster Carr	6785K23	1	Emergency Stop Enclosed Push Button Switch	Purchased	$ 83.74	2023
Waterproof camera enclosure	Amazon	Awclub ABS Plastic Junction Box	1	Water Proof Enclosure Specs	Purchased	$ 20.69	2023

Jetson TX2	Nvidia	TX2 NX	1	[Jetson TX2]	Donated	N/A	2022
LiDAR	Hokuyo	UST-20LX	1	[UST-20LX]	Donated	N/A	2022
Wifi-Bullet	Ubiquity	Bullet M2	2	[Bullet M2]	Donated	N/A	2023
PWM-DC Converter	N/A	N/A	1	12-15Vdc Input Power, 3 DC Outputs	Custom	$ 50.20	N/A
ASV Bridge	N/A	N/A	1	40" x 24" x 0.5"	Custom	$ 92.30	N/A
ASV Hull	N/A	N/A	2	48" x 7.5"	Custom	$ 299.99	N/A

Appendix B: Testing and Test Plans

Structural Design Test Plan

Table 5. Design Test Plan Checklist

No.	Task	How will we test?	Goal	Achieved?
1	Evaluate weight distribution, buoyancy, and free board	Try various weight distributions while boat is in the water; record results from each weight	Boat sits level in the water; determine the draft for each weight	☐
2	Evaluate stability in head winds, tailwinds, and crosswinds	Observe behavior of boat in the water under windy conditions	The boat rolls/pitches minimally in wind; maintains level sitting	☐
3	Evaluate stability while changing heading and direction of travel	Make sudden changes in direction, acceleration and deceleration, and observe how the boat reacts	Boat maintains level draft under sudden changes	☑
4	Evaluate thruster placement (amount submerged, position on bridge)	Observe thruster placement while boat is in the water; check for cavitation	Have enough clearance from hulls and thrusters to prevent cavitation	☐
5	Test structural integrity of all assembled parts (check fasteners, printed parts, adhesives, sealant)	Visual inspection at beginning and end of regular operation, stress test	Maintain structural integrity during operation	☑
6	Evaluate directional stability	Apply even thrust and observe change in heading	Stay straight	☐

LTSpice Simulation - PWM to DC Converter

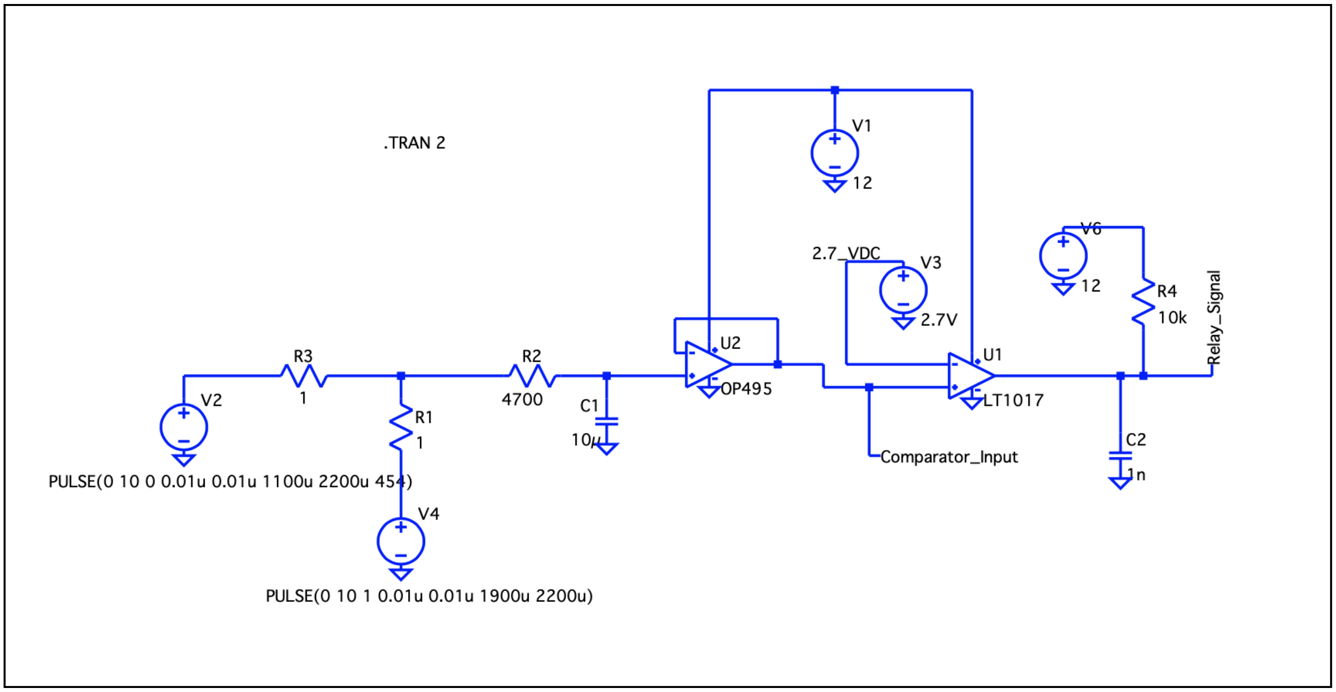

Fig. 7. PWM-DC LTSpice Circuit

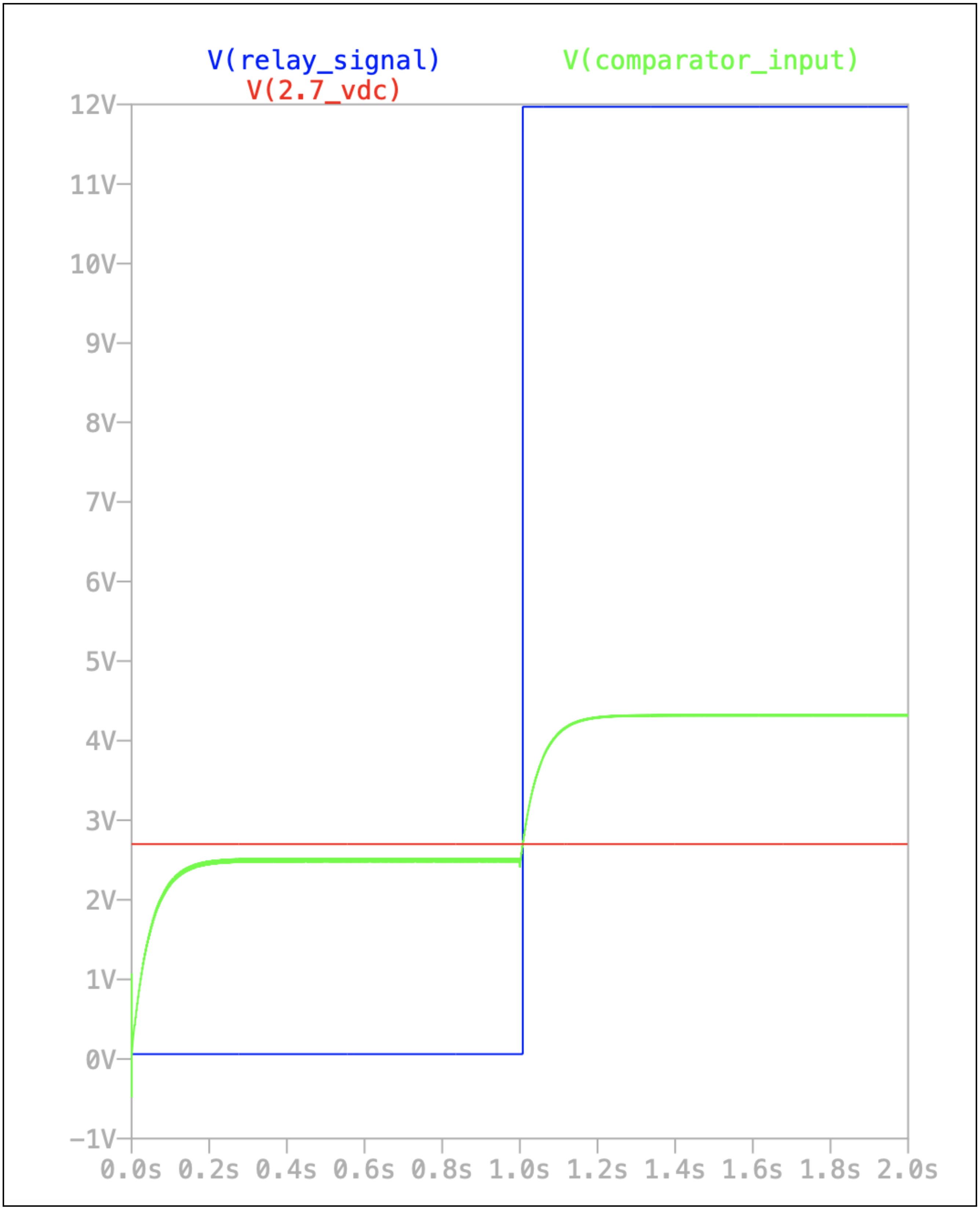

Fig. 8. Remote Operated Emergency Stop Switch Simulation

PWM Converter Perf Board Test Log

1. Turn on all supplies
    a. ENSURE THAT RX GETS MINIMUM 100mA TO TURN ON
    b. Check reference voltage
        i. Should be ~2.1
    c. Check voltage connections at all inputs
        i. Check 12V at top of voltage divider
        ii. Check 12V op-amp input
        iii. Check 12V comparator input
        iv. Check 12V at top of relay
2. PWM Low
    a. Check op-amp output: should be <2.10V
        i. Measured at ~2.6
    b. Comparator output should be HIGH (12)
3. PWM High
    a. Check op-amp output: should be >2.10V
        i. Measure at ~1.90
    b. Comparator output should be LOW (0.00)
4. Connect relays and test full functionality

Figure 9. PWM to DC Converter Test Log

Communication and Controls Test Plan

Table 6. Communications and Controls Test Plan

Test Case	Expected Observation	Debugging
TX and RX ON	TX is able to connect to RX	Ensure RX connections are wired appropriately
TX to Motor Port/Starboard	If working, take note of which channel controls Port/Starboard motor	If motors are not working at all, ensure connections to ESC are appropriate and that power connections are appropriate If orientation P/S or back/forward are messed up, ensure that connections to RX correspond to the desired TX channel
TX to Motor Back/Forward	If working, ensure forwards and backwards correspond to their appropriate direction on the controller.	
Pixhawk Working	Status LED is ON..	Ensure correct power connections
Camera Working	Delivering an accurate picture.	If not working, ensure that power connection is good
Lidar Working	Can hear the LiDAR if its ON and also status LED	If not working, ensure that power connection is good

In-water Electrical Test Plan

Table 7. In-Water Electrical Test Plan

Test	Description	Expected	Actual	Comments
Continuity	Connection between Kill-Switch to motor	Connection	Connection	
	Connection between Battery and Power rails	Connection	Connection	
Controls	Ensuring RX and TX Connections	Responding correctly to L,R, Max Thrust etc…	Controls are correct and agree with assumed directions	RX and TX momentarily lost connection ~ 50m away. Regained connection immediately.
	Remote Kill-Switch	Boat stops when remote KS is activated	Thrusters stopped	Slight delay upon first test, following tests saw no delay

Navigation Testing Results

Table 8. In Water Navigation Results

set_destination(-vector_msg->x, -vector_msg->y, 0, 0);		
	x	y
Actual marker	9.46618	-2.84551
Detected Marker	8.16861	1.89556
Destination set to	-1.89556	8.1686
boat went to	10.888778	-1.047
Actual marker	20.522	11.5198
Detected Marker	17.3552	-13.6267
Destination set to	13.6267	17.3552
boat went to	20.869	-12.071854
Actual marker	12.751	-5.40668
Detected Marker	8.01084	-10.3
Destination set to	10.3	8.01084
boat went to	6.817236	-12.6916

Training losses and Performance Metrics of YOLOv5 Trained Model

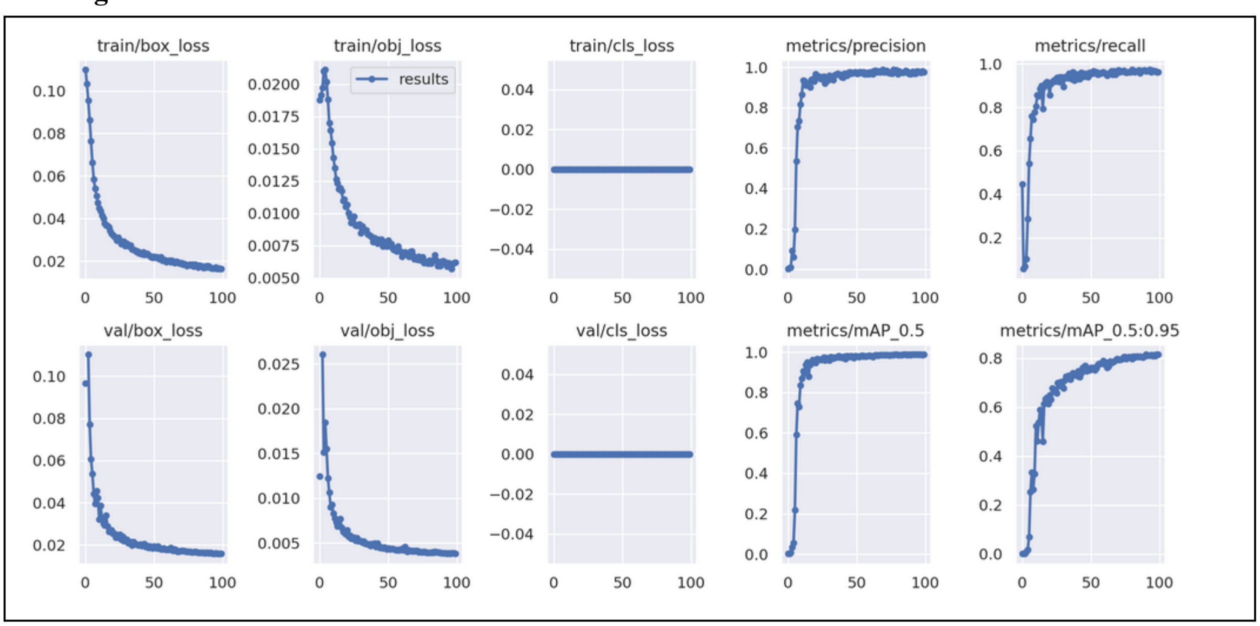

Fig. 9. Results of Yolov5 Trained Model

Example of Object Detection using the YOLOv5 Trained Model

Fig. 10. Example of Object Detection with Yolov5 Trained Model