The Design of Team Inspiration & Triton-AI's 2024 RoboBoat ASV

Jerry Hsieh (Team Captain), Aditya Chandra, Yen-Ru "Rebecca" Chen, Khushee Goel, Brandon Lopez, Matthew Pope, Woojin Rho, Colin Szeto, Mabel Szeto, Lindsay Wright

***Abstract* — Team Inspiration and University of California San Diego (UCSD) Triton-AI are joining forces to design an autonomous surface vessel (ASV) capable of all the RoboBoat 2024 missions in less than 3 months. We are accomplishing this by leveraging experience from other robotics competitions that we participate such as FIRST, RoboSub, RobotX, VRX, and Autonomous Karting Series, in which we use similar concepts for perception, navigation, and control. We utilize systems engineering and systems thinking to enable rapid prototyping for quick incremental results and parallel development of mechanical, electrical, and software systems (agile development). This paper will detail how the engineering process we normally use is allowing us to develop our ASV in a short time span.**

I. Competition Goals

Team Inspiration and Triton-AI are designing an architecture and capabilities to enable us to attempt to complete every mission in RoboBoat, but will prioritize completing certain tasks with higher reliability.

Team Inspiration has previously been successful in competing at other RoboNation's complex missions involving robotics perception and navigation, and machine control: RobotX and RoboSub [1]. We continued using systems engineering and systems thinking to create an architecture and software framework for all missions while emphasizing localization, perception, navigation and position hold. Our first goal is to achieve reliable performance on the Navigation Channel, Follow the Path, Docking, Duck Wash, and Return Home.

We first identified requirements including system capabilities, hardware, and software requirements and associated interfaces. We then performed rapid prototyping and parallel development to enable the software team to have a platform to work with as soon as feasible and mitigate risk. Historically, our software subteam faced limited test time, especially on a brand new competition where we don't have a previous robot to build on. Lessons learned from rapid prototyping serve as feedback to iterate the hardware and software.

Individual missions were broken down into individual steps the software and hardware must take to complete them. Then, we ranked these requirements by priority, with basic safety requirements listed on the team handbooks, including the kill switch, being highest, followed by obstacle avoidance and the Navigation Channel, as these are prerequisites to completing the other RoboBoat missions. In particular, we aim to perform reliably on Follow the Path, Docking, Duck Wash, and Return Home while also attempting the Speed Challenge, Collection Octagon, and Delivery Octagon missions.

Given time constraints due to finishing VRX in November and having university finals from December 1-15, the only way to remain true to our design approach was through rapid prototyping and parallel development. We fast prototyped our power system and distribution, low power electronics including Power over Ethernet switch, machine controller with associated telemetry radios, on-board embedded linux GPU accelerated computer, RGB-D camera, and 3D LIDAR. Then we will incorporate our wireless broadband link already proven on RobotX. We called our first prototype Alpha. In parallel we are designing our competition boat, Barco Polo, and improving our existing perception and mapping code. Alpha doubles as our backup vessel in the event that manufacturing lead times run over competition time for Barco Polo.

We implemented a simplified mission planner in the style that served us well in RoboSub: a predetermined order to attempt each task. We ordered our missions such that our boat would move in an overall clockwise direction on the course per the schematic in Appendix C.

Our recent experience in RoboSub and VRX allowed us to create documentation on our perception system for rapid development and training of future robotics students. This documentation also served us well in transferring our computer vision capabilities from our submarines to Barco Polo.

II. Design Strategy

With the condensed timeline, the team understood it was imperative to get as much water time as possible. We elected to develop our baseline control system on a prototype test bench deployed on a boogie board for rapid deployment and quick iteration of the electrical and control system. In parallel, the mechanical team pushed hard to perform competitor research and learn best practices from other pre-existing competition teams.

We selected a holonomic drive base to enable maximum maneuverability with the ability to strafe the boat in the swaying direction without changing the vehicle's heading. These maneuvers enable eyes-on-target perception as mission models (e.g., targets and buoys) can move.

A. *Mechanical*

Fig. 1. Alpha Design with Holonomic Thrusters

1) Alpha. Utilizing the boat we developed for the UCSD COSMOS High School Summer program —during one of our summer outreach programs to cultivate high school students' interests in math and science— we were able to design an easy to implement rapid-prototype ASV that could be built in 2 weeks. This served as our test bench for software and electronics development while the mechanical team developed our final boat.

2) Barco Polo. We elected to use a catamaran over single-hull designs due to higher stability in water combined with lower drag. We will be using the same thrusters and configuration, the same electronics, control system, and perception system as in Alpha. We based our hull design off the Institut Teknologi Sepuluh Nopember's *Nala Proteus* while employing our own manufacturing techniques with fiberglass, a durable material used by several teams [2][3][4].

The main boat is being constructed from multiple positive polystyrene molds that were hand-shaped to the contours of 2-D profiles pulled from the CAD. We are going to lay a layer of fiberglass sheet and utilize fiberglass mesh to assist with the compressive strength of the boat. We selected UV-curing polyester vinyl from our sponsors, Sunrez, for maximum working time and flexibility before dragging the pontoons out into the sun for the final cure. The positive molds were left within the pontoons to impede water pooling in the hulls in the event of a water incursion.

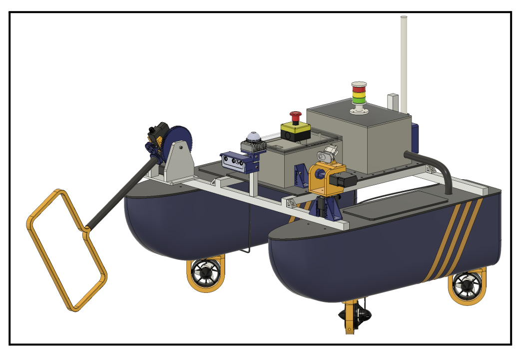

Fig. 2. Barco Polo Hull Design

3) Water Cannon. We explored a commercial off-the-shelf (COTS) water gun to understand its operating mechanism and limitations. The COTS water gun relied on gravity and a motor to flush water out, but unfortunately failed to produce the steady stream required by the RoboBoat rules.

As such, we are designing a water squirter with a pump to suck water from the competition venue and two motors on the pitch and yaw axes. Separate movement of the water cannon relative to the boat enables computer vision close loop control independently of the boat. Additionally, this capability allows us to complete the Duck Wash task quicker as Barco Polo can leave the Docking task without having to park in front of the yellow duck banner.

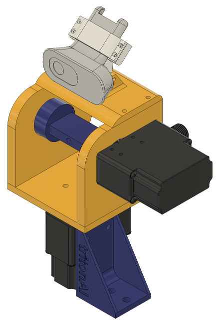

Fig. 3. Water Cannon Isometric View

4) Octagon Delivery Mechanism. We prioritized limiting mechanical complexity. After careful consideration, consensus was reached to use a shoulder and wrist mechanism to indiscriminately pick up task objects, which would then be delivered to any collection site (as teams are not penalized for depositing into incorrect sites). We determined that nets would significantly reduce boat drag and tilt out only when the collection task is being attempted. Once acquiring the ducks, we can rotate the net to a horizontal position to ensure retention of ducks. Shoulder enables us to stow the net to reduce the inertia during regular operations. In prioritizing vision, our plan is for our boat to detect the collection octagon via the marker cube, extend the net over the first octagon, sink the net via the shoulder and wrist system and then traverse the perimeter of the outer octagon.

B. *Electrical*

We built our electronics based on our experience with other robots such as RobotX. We are using Li-ion batteries, our custom power distribution board (PDB), and an embedded computer Jetson Xavier NX from our RoboSub.

Max power draws of all devices were recorded to help determine if two of the batteries we use at our RoboSub would be sufficient with a running time of approximately 35 min to enable us development time and, assuming 20 minute running slots in competition, to have a safer margin.

Electrical diagrams and mechanical CAD helped with planning the electrical box selection.

1) Alpha. For rapid prototyping, pre-existing parts from RoboSub were used alongside materials from UCSD's COSMOS program. From RoboSub, this included four Blue Robotics T200 thrusters, ESCs, and a 14.8 V, 230 Wh Li-Ion battery. From COSMOS, we utilized a Mateksys H743-Wing V3 flight controller, SiK telemetry radios, a GPS/compass module, and a radio receiver and transmitter for RC control. In addition, we plan to use Nvidia Jetson Xavier NX, a PoE injector, a Ubiquiti Bullet AC Dual-Band WiFi Radio, and a multiplexer to switch between RC and autonomous control. We also intend to use DC-to-DC converters to provide constant clean voltage to the PoE injector and the RC receiver, using 12 V and 5 V respectively. Two electrical boxes were used to separate the ESCs and power supply from the sensors and flight controller to prevent noise from the high-frequency PWM signals of the ESCs from disrupting the magnetometer, housed in the compass module. A similar system will be used in Barco Polo, with margin for growth.

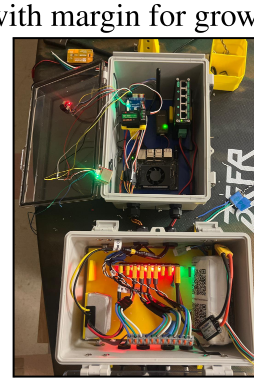

Fig. 4. Alpha Electronics Layout

To protect the Jetson Nano and other delicate electronics from water, the electronics boxes are sealed with O-rings, and all cables are inserted through the boxes with cable glands and sealed with silicone putty and rubber heat shrink.

2) Barco Polo. An issue was found on the SiK Telemetry Radio used to communicate with a companion computer for vehicle arming, collecting data, and testing waypoint navigation on Mission Planner. To support higher data transfer rates we plan to install an Ubiquiti Bullet AC Dual-Band wireless broadband radio. An improvement was made to the power supply as well. The initial 4.5 Ah 4S LiPo battery wasn't able to keep the boat running for a sufficient amount of time: tests with Alpha suggest the average run-time of the boat was 10-15 min. After recording the power specifications of each component of the vehicle, the 4.5 Ah 4S LiPo battery was replaced with a Blue Robotics 15.6 Ah 4S Li-Ion battery from RoboSub to prolong the duration. Currently, our ASV runs on one battery. Depending on the power requirements found through testing Alpha with sensors, we are considering adding another battery and a "hot-swapping" battery management system similar to that used in RoboSub. This would give us the advantage of longer water time.

3) Kill Switch. Per safety requirements, both Alpha and Barco Polo will feature a kill switch that cuts power to the thrusters. There is a red button on each boat and a trigger from the remote control, which both disconnect power when triggered.

C. *Control System/Software*

Team Inspiration's perception architecture for RoboSub was successful and well-documented; as such, many of this software's elements were used in our ASV. Additionally, similar to our strategy in RobotX, we interface autonomous capabilities with an external RC propulsion package.

1) Navigation Algorithms

a) Localization, Perception, and Waypoint Navigation: For ASV localization, we use cameras, LiDAR, GPS, and IMU in tandem.

We plan to interface with ArduPilot's firmware for low-level control, while building high-level autonomous capabilities with ROS.

b) Simplified Mission Planning and Execution: Our planner has a set route of specific missions and a timer to ensure it remains on schedule. This route navigates the course clockwise to reach all the missions before returning home. If the amount of time allocated to a mission runs out, the boat will proceed to the next one. If there is a fault in the vehicle, missions will be skipped accordingly, with an extreme case being that the vehicle gets the signal to go home automatically to end its run.

The mission software controls the actions necessary for the robot to get from one mission to another. The appropriate transitory action between missions is determined by the nature of the mission.

2) Perception. Our experience in RobotX and RoboSub allowed us to develop a robust perception system, including stereo-perception, machine-learning (ML), genetic algorithms, context, feature tracking. We modified this perception system to meet our needs for RoboBoat.

Constrained by processing power, we offloaded our ML processing on Barco Polo to a forward-facing OAK-D Wide Pro camera with ML capabilities, considering it contains a dedicated module named Robotics Vision Core 2 optimized to run Neural Network inference

We utilized the DepthAI Python Library to achieve automatic camera detection, enumeration, stream handling and forwarding, algorithm/model selection, and data collection. Using this library directly provided by Luxonis OAK-D provides us with a layer of abstraction for communicating with the OAK-D hardware and an effective framework to enable Computer Vision capabilities.

To identify game elements and implement basic navigation and position tracking, we used OpenCV and a variety of filters to isolate images within certain parameters, such as intensity, as seen in Fig. 5. Additional steps, such as multi-frame context and pattern recognition, were then used for validity detection.

Fig. 5. *The process of OpenCV algorithms detecting targets.*

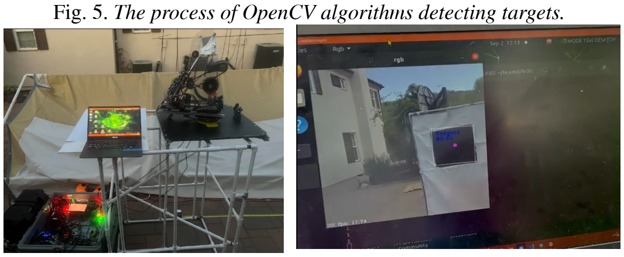

Fig. 6. *YOLOv5 Object Recognition in Dock Targets.*

To further supplement the capabilities OpenCV provides, we decided to build upon the YOLOv5 nano model due to its fast, stable, and lightweight characteristics. On Roboflow, we tailored the model to our competition tasks by training it upon diverse images of buoys, rubber ducks, and various competition props collected and meticulously labeled in our home lab.

III. Testing Strategy

Our test plan includes component, test bench, simulation, subsystem and systems testing. We further develop two platforms: Alpha, the prototype boat, and Barco Polo, the competition boat. The prototype boat will support early testing and risk mitigation. Test environments included local labs, swimming pools, ponds and lakes closely emulating the competition environment in Sarasota, Florida.

We believe quick prototyping and iterative testing are key to effective learning and integration. With a tight schedule, we are designing and testing in tandem, utilizing simulations and prototypes heavily as our team creates the final design for Barco Polo.

One of the most important parts of our testing process was creating detailed test procedures (Appendix B). This not only ensures that the tester knows a test's goals and procedures, but also allows us to support data analysis post-execution. If a test fails, we identify the root cause of the failure, document the problem in our test report and minutes, and work on fixing and preventing it in the future.

We utilize data from our previous experience in RoboSub and RobotX, as well as simulation data to kick-start development. Thanks to rapidly developing Alpha, we have also already completed some subsystem-level testing of our electronics and propulsion. We will continue to update our website on a weekly basis as more tests are completed and more data are collected.

A. *Unit Tests*

To validate our actuators, we conducted unit tests prior to mounting on the vehicle. We also unit-tested individual sensors on competition obstacles to collect data without the time and resource overhead of water testing the entire ASV.

B. *Simulated Tests*

Simulations were run on hardware and software to aid with rapid development.

1) Mechanical Simulations. Our team utilizes Computer-Aided Design (CAD) and reviews each component of our ASV with mentors before ordering materials and beginning construction. Iterating in the virtual environment saves time and resources during the assembly process. Using CAD also allows us to test the durability of each part through Finite Element Analyses (FEA) that identify potential points of failure.

2) Gazebo.

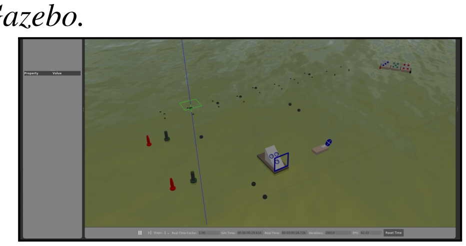

Fig. 7. Gazebo simulation of RoboBoat environment

We set up a virtual RoboBoat competition environment created by SimLE in Gazebo for RoboBoat 2023 [5] to test our software. This allows for parallel development and testing of hardware and software, a necessity given the three-month timeline between our team's registration and the February tournament in Florida.

To further customize the simulation environment for this year's competition tasks, we are developing world files for Tasks 6 to 8.

C. In-Pool Tests

We performed various in-pool tests to verify the functionality of our ASVs as we developed each mechanical and software component.

In-pool tests provide a controlled environment with eased logistics, allowing us to ensure basic capabilities, such as perception, propulsion, position hold, localization, and kill switches, are functional.

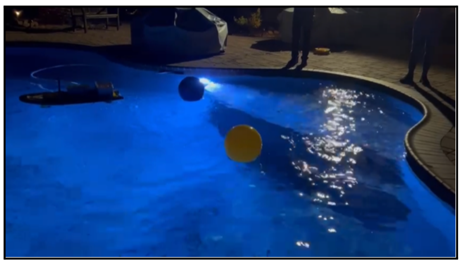

Fig. 8. In-Pool Test for Propulsion (Available 24/7)

D. Lake Tests

Lakes near the Inspiration and Triton-AI labs provide environments closest resembling the actual competition. To ease logistics, a careful catalog of nearby potential testing locations is kept along with their regulations and hours. We emulate the test environment that will appear in competition by securing and fabricating the appropriate props.

IV. Summary

Systems thinking, planning, and testing are all the more important when working on shorter time frames. We utilize proven technology, COTS parts, mentors, and lessons learned from previous RoboBoat teams to bolster rapid development.

V. Acknowledgments

Team Inspiration and Triton-AI would like to thank the sponsors below:

Diamond: Gilman Charitable Fund, Advancing Science Technology and Art.

Platinum level: Qualcomm.

Gold: Northrop Grumman, tinyVision.ai, and Medtronic.

Silver: Blue Trail Engineering, Blue Robotics, Nvidia, Hologic, and HP.

Bronze: ePlastics, Manna's Martial Arts, and Sunrez.

We received engineering support from Blue Trail Engineering [6] and tinyVision.ai. We are grateful to our mentors who helped review our work and provided guidance on team management: Jack Silberman, Alex Szeto, Amit Goel, Venkat Rangan, Teresa To, Cris O'Bryon, and Damon McMillan. We would like to thank Kayla Terry for guiding us in creating our team video. Finally, we appreciate the RoboBoat organizers for putting the competition together to challenge us.

VI. References

[1] Team Inspiration, "The Design of Team Inspiration's 2020 AUVs," Team Inspiration, San Diego, California, 2020. [Online]. Available: https://robonation.org/app/uploads/sites/4/2020/08/RS20_TDR_Team-Inspriation.pdf

[2] Institut Teknologi Sepuluh Nopember, Barunastra ITS, "Roboboat 2023: Nala Proteus' Technical Design Report Barunastra ITS RoboBoat Team," Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia, 2023. [Online]. Available: https://robonation.org/app/uploads/sites/3/2023/02/TDR_Institut-Teknologi-Sepuluh-Nopember_RB2023.pdf

[3] Universitas Sebelas Maret, Bengawan Unmanned Vehicle Roboboat Team, "RoboBoat 2023: Technical Design Report," Universitas Sebelas Maret, Surakarta, Indonesia, 2023 [Online]. Available: https://robonation.org/app/uploads/sites/3/2023/02/TDR_BUVUNS_RB2023.pdf

[4] Cornell University, Autoboat, "RoboBoat 2023: Technical Design Report," Cornell University, Ithaca, New York, 2023 [Online]. Available: https://robonation.org/app/uploads/sites/3/2023/02/TDR_CornellAutoBoat_2023-.pdf

[5] Gdansk University of Technology, Science Club SimLE, "RoboBoat 2023: Technical Design Report SimLE SeaSentinel Team," Gdansk University of Technology, Gdansk, Poland, 2023. [Online]. Available: https://robonation.org/app/uploads/sites/3/2023/02/TDR_GdanskUniverityofTechnology_ScienceClubSimLE_RG2023.pdf

[6] Blue Trail Engineering, https://www.bluetrailengineering.com/ (accessed Apr. 23, 2021).

Appendix A: Component List

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
ASV Hull Form/Platform (Frame, Waterproof Housing)	80/20 Inc.	1010 aluminum extrusion	Weight: 25 oz Size:115 in	Purchased and machined in lab	$234.73	2019
	Lowe's	FOAMULAR NGX F-250 Unfaced Polystyrene Board Insulation	R-10, 2-in x 4-ft x 8-ft	Purchased	$51.98	2023
	ePlastics	Delrin Sheets tube, 8 in. series	Size: 8" diameter	Donated	$343	2019
	Fibre Glast Developments Corp.	1.5 Oz Chopped Strand Mat	Quantity: 2 Length: 5 yards Width: 38 In	Purchased	$93.90	2023
	Sunrez Composites	7315 Polyester Resin	Quantity: 3 gallons	Donated	$320	2023
	Fibre Glast Developments Corp.	2 oz Fiberglass Fabric	Quantity: 2 Length: 3 yards Width: 38 In	Purchased	$49.90	2023
Propulsion	Blue Robotics	T200 thrusters	Full Throttle FWD/REV Thrust @ Maximum (20 V) https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster-r2-rp/	Legacy	$200 apiece	2019
	Blue Robotics	T200 propellers	Max thrust: 49.82 N	Legacy	Included with thrusters	2019

Water Cannon	Blue Trail Engineering	Underwater Servo SER-20XX	https://www.bluetrailengineering.com/product-page/underwater-servo-ser-20xx	Custom	$215	2023
	goBILDA	1309 Series Sonic Hub (6mm D-Bore)	https://www.gobilda.com/1309-series-sonic-hub-6mm-d-bore/	Purchased	$27.96	2023
	Logitech	C270 HD WEBCAM	https://www.logitech.com/en-us/products/webcams/c270-hd-webcam.960-000694.html	Legacy	$29.99	2019
Duck Net	Blue Trail Engineering	Underwater Servo SER-20XX	https://www.bluetrailengineering.com/product-page/underwater-servo-ser-20xx	Custom	$215	2023
	goBILDA	1309 Series Sonic Hub (6mm D-Bore)	https://www.gobilda.com/1309-series-sonic-hub-6mm-d-bore/	Purchased	$27.96	2023
Power System (Battery, Converter, Regulator)	Blue Robotics	Lithium-Ion Battery	4S 14.8V 15.6 Ah	Legacy	Legacy	2019
	Blue Robotics	5V, 6A power supply	5V, 6A	Legacy	Came with BlueROV setup; Legacy	2019
Motor Control	Blue Robotics	Basic ESC	30A brushless ESC https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Legacy	$36 apiece	2019
DC-DC Converter	Cllena Matek	Buck/Boost Converter	DC 8V-40V to 12V 10A 4A/5-12V and	Purchased Legacy	$29.99 Legacy	2023 2021

	Systems		4A/5V			
Flight Controller	Mateksys	H743-Wing V3 flight controller	STM32H743VIT6, 480MHz , 1MB RAM, 2MB Flash	Purchased	$149.99	2023
CPU	Nvidia	Nvidia Jetson Xavier NX	https://developer.nvidia.com/embedded/learn/get-started-jetson-xavier-nx-devkit	Legacy	Legacy	2021
Telecommunication	Ubiquiti	airMAX Bullet AC IP67	Communication: GbE, PoE UISP airMAX Bullet AC Dual-Band IP67 Radio - Ubiquiti Store United States	Purchased	$129.00	2023
Perception	Livox	Mid-360	Specs - Mid-360 LiDAR Sensor - Livox (livoxtech.com)	Purchased	$749	2023
Inertial Measurement Unit (IMU)	Mateksys H743-Wing V3 flight controller	MPU6000 (SPI1) & ICM42605 (SPI4)	STM32H743VIT6, 480MHz , 1MB RAM, 2MB Flash	Legacy	Included with Mateksys Flight controller	2023
	Dampener	XTORI Pixhawk dampener	Materials: plastic and rubber Weight: 17 g	Legacy	$7.99	2021
Camera	Luxonis	OAK-D Pro Wide PoE	12 MP Resolution 60 FPS max frame rate Focus: AF 8 cm+	Donated	$309.00	2023

PoE Switch	Linovision	5 Ports DC12-48V Input Full Gigabit with Voltage Booster	5 Ports Full Gigabit POE Switch with DC12V ~ DC48V Input and Voltage Booster,Total IEEE802.3at POE Power Budget 120W | LINOVISION US Store	Purchased	$109	2023
Vision	Custom	Open Computer Vision	Color isolation, binary thresholding, contour approximation, erosion and dilation, area thresholding, and Contrast Limited Adaptive Histogram Equalization (CLAHE)		Free/ Open Source	2019
	PTC Inc.	Vuforia/Vuforia License	Vuforia Engine version 8.6		Free	2019
Mission Planner	In-house	Custom	Mission planner		Free	2021
Open-Source Software	Open-Source (N/A)	OpenCV, Robot Operating System, Python, C++, Linux	Computer Vision, Inter-process communication, programming, computer operating system		Free	2019

Appendix B: Test Plan & Results

I. Test Plan

Testing included component, test bench, simulation, subsystem and systems testing. We further developed two platforms: Alpha, the prototype boat, and Barco Polo, the competition boat. The prototype boat will support early testing and risk mitigation. Test environments included local labs, swimming pools and ponds and lakes closely emulating the competition environment in Sarasota, Florida.

We utilize data from our previous experience in RoboSub and RobotX, as well as simulation data to kick-start development. Thanks to rapidly developing Alpha, we have also already completed some subsystem level testing of our electronics and propulsion. We will continue to update our website on a weekly basis as more tests are completed and more data are collected.

II. Alpha Testing

Initial testing for Alpha confirmed thruster functionality and RC control capability. Further tests were conducted to ensure omnidirectional movement of the thruster configuration and multiplexor switching capabilities between manual and autonomous control. We also plan to test all component and software functionality on Alpha before finalizing our electrical and software designs for Barco Polo.

III. Unit Testing

To validate our actuators, we conducted unit tests prior to mounting on the vehicle. We also unit-tested individual sensors on competition obstacles to collect data without the time and resource overhead of water testing the entire ASV.

A. Camera Test

The OAK-D Lite and OAK-D PoE are initially tested with a provided test script on PC and later on the Jetson Xavier NX. The script helps verify that the cameras are in working condition and can be run with object detection capability. Finally, object detection models are trained and utilize a modified version of the Roboflow OAK-D library to run edge models on the cameras. Underwater tests were performed to ensure the accurate detection of objects such as the dock and the buoys.

B. Water Gun Test

The water gun was held at 8” height at 15 degrees and fired. The water gun squirt zone was from 113” to 220” forward.

Despite these impressive results, the water gun released its ammunition in spurts instead of the steady flow required in competition. This resulted in us designing a custom water squirter that will be unit tested in similar fashion at the Inspiration pool.

Fig. B1. Unit testing water gun for Duck Wash

IV. Pool Test

We performed various in-pool tests to verify the functionality of our ASVs as we developed each mechanical and software component.

In-pool tests provide a controlled environment with eased logistics, allowing us to ensure basic capabilities, such as perception, propulsion, position hold, localization, and kill switches, are functional. However, further testing of capabilities must be completed in a larger space.

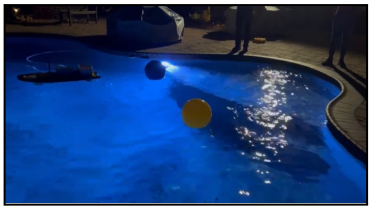

Fig. B2. In-Pool Test for Propulsion

V. Lake Test

Lakes near the Inspiration and Triton-AI labs provide environments closest resembling the actual competition. To ease logistics, a careful catalog of nearby potential testing locations was kept along with their regulations and hours. We emulate the test environment that will appear in competition by securing and fabricating the appropriate props.

VI. Simulations

Simulations were run on hardware and software to aid with rapid development.

A. Mechanical Simulations

Our team utilizes Computer-Aided Design (CAD) and reviews each component of our ASV with mentors before ordering materials and beginning construction. Iterating in the virtual environment saves time and resources during the assembly process. Using CAD also allows us to test the durability of each part through Finite Element Analyses (FEA) that identify potential points of failure. The team also performed a righting arm analysis to compare the mono hull of Alpha to the dual hull catamaran of Barco Polo. We determined that Barco Polo will provide a significantly righting arm.

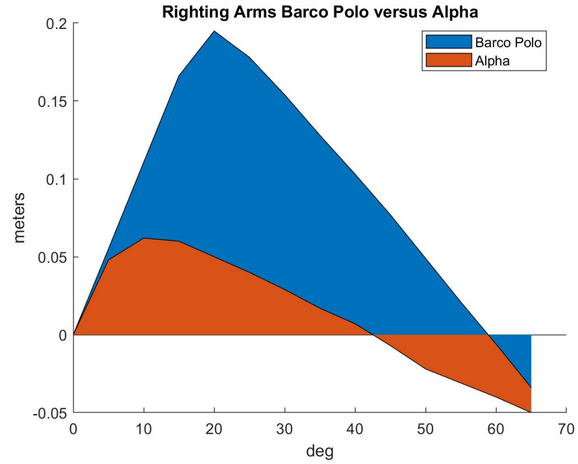

Fig. B3. Righting arms of Barco Polo Vs Alpha

B. Gazebo

We set up a virtual RoboBoat competition environment created by SimLE in Gazebo for RoboBoat 2023 [5] to test our software. This allows for parallel development and testing of hardware and software, a necessity given the three-month timeline between our team's registration and the February tournament in Florida.

We leverage our experience with ROS2, Gazebo, and the WAM-V URDF model from this year's VRX challenge and tested our code for navigation for Tasks 1 to 5 from last year's course.

To further customize the simulation environment for this year's competition tasks, we are developing world files for Tasks 6 to 8. Since we did not have experience with building the Gazebo simulation world, we are still actively learning from the official Gazebo documentation despite the steep learning curve.

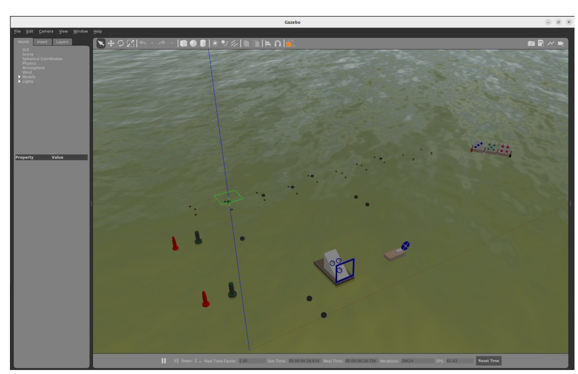

Fig. B4. Gazebo simulation of RoboBoat environment

VI. Integrated Test Procedure

With lessons learned from RobotX and RoboSub, Team Inspiration implemented test plans (example in Table B1) for the various RoboBoat prototypes to plan objectives beforehand, prepare accordingly, record data, and get together afterward for a “hot wash” where team members discuss successes, points that need attention, and lessons learned.

<table>
<tr><td colspan="2" rowspan="2">Table B1 Sample Test Plan
Alpha Lake Test #1</td><td colspan="4">Approval Authority</td></tr>
<tr><td colspan="2">Adi Chandra
(Team Lead)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Date: 2023-11-12</td><td colspan="4">Mission Title: Prototype Boogie Board Water test</td></tr>
<tr><td colspan="2">Test #: 1</td><td colspan="2">Location: Lake Miramar or Poway</td><td colspan="2">Risk: Low</td></tr>
<tr><td colspan="2">Software Version:
Mission Planner</td><td colspan="2">Hardware Sensors Mounted:
Pixhawk 2.4.8, GPS, sik radio, radio receiver/transmitter</td><td colspan="2">Hardware Sensors Used:
Pixhawk 2.4.8, GPS, sik radio, radio receiver/transmitter</td></tr>
<tr><td colspan="6">Scope: <u>Primary:</u> Test thrusters, electrical functionality of boat in the water by RC control
<u>Secondary:</u>
<u>Tertiary:</u>
<u>Quaternary:</u></td></tr>
<tr><td colspan="2" rowspan="2">Roles</td><td colspan="2" rowspan="2">Walkie Talkies/
Cell Phones</td><td colspan="3">Times</td></tr>
<tr><td>Event</td><td>Time</td><td>Actual</td></tr>
<tr><td>Test Conductor</td><td>Adi</td><td>Ground</td><td>N/A</td><td>Packup</td><td>12:45 pm</td><td></td></tr>
<tr><td>Boat Launcher</td><td>Pahan</td><td>Pool Deck</td><td>N/A</td><td>Go to Lake</td><td>1:00 pm</td><td></td></tr>
<tr><td>Ground Control</td><td>Colin, Omar</td><td>Lifeguard</td><td>N/A</td><td>Test</td><td>1:30 pm</td><td></td></tr>
<tr><td>Data Collector</td><td>Jesus</td><td>Tether</td><td>N/A</td><td>Cleanup</td><td>3:30 pm</td><td></td></tr>
<tr><td>Photographer</td><td>Adi, Jesus,</td><td></td><td></td><td>Leave Pool</td><td>4:00 pm</td><td></td></tr>
</table>

	Colin					
Safety Checker/QA	Adi, Pahan, Colin			**Put Away**	4:35 pm	
Person in water	N/A			**Hot Wash**	5:00 pm	

Status			
Boat		GO/NO GO	
		GO/NO GO	
		GO/NO GO	
		GO/NO GO	

Attendance	**Test Notes**
	Resources Needed: Boogie board boat with thrusters, GPS, telemetry, and radio transmitter/receiver. **Environment:** Lake **Expected Results:** Boat is able to move on water using radio transmitter have no malfunctions, GPS can track location. **Prerequisites:** Make sure telemetry and GPS are working on land, thrusters respond to directions of the transmitter. **Test procedure:** Place the boogie board in water. Move around to see test movement capabilities. **Risk Management:** Do not run thrusters on dry land for more than 5-10 seconds.

#	Validation Step Description	Expected Result	Reference to Data	Pass/Fail
1	Boat responds to RC controls			

	at multiple speeds without malfunctioning.			
2				
3				
4				
5				
…				

Results and Reflections

-
-
-
-

Appendix C: Competition Setup and Strategy

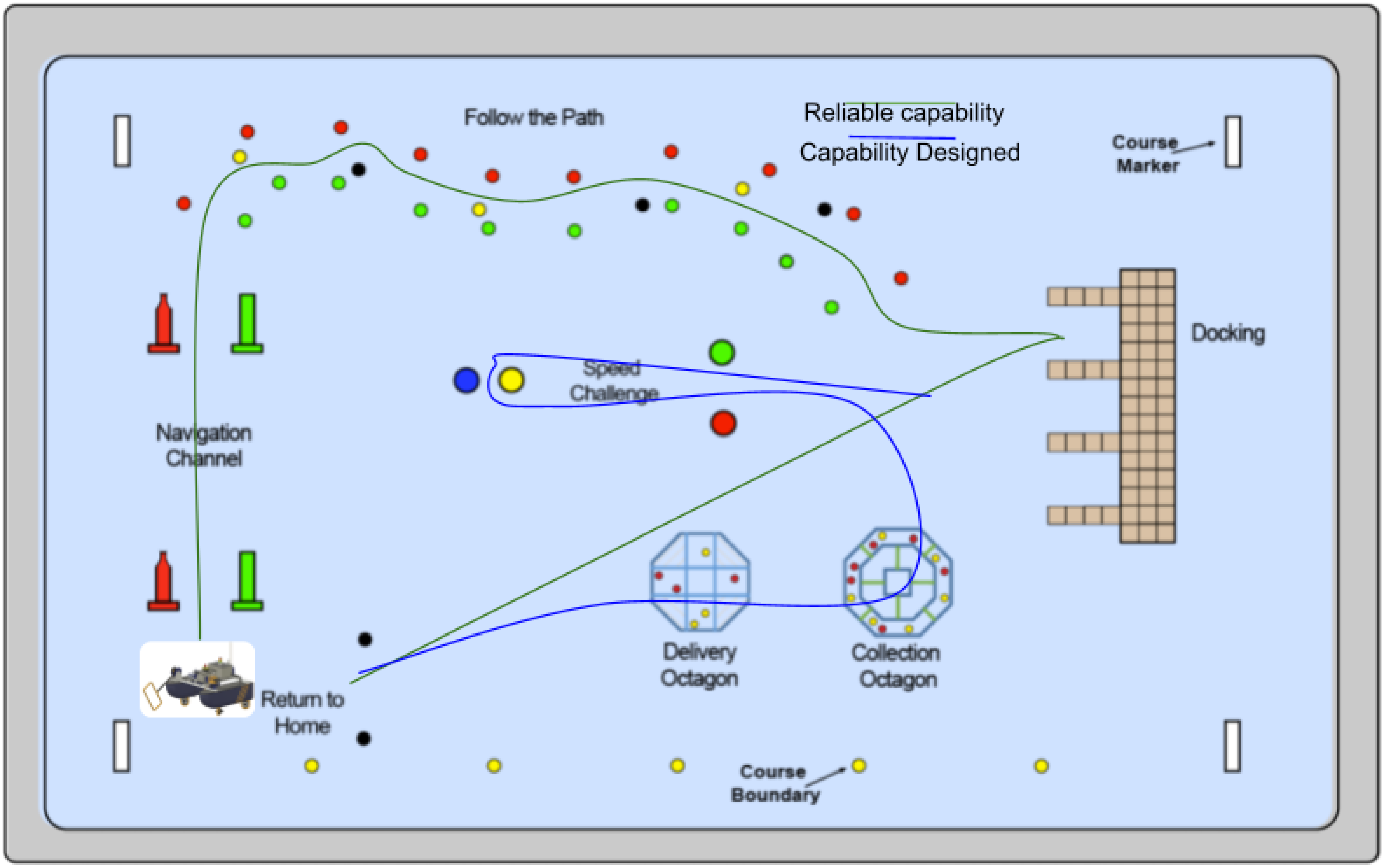

Fig. C1: Competition Strategy