The Design of Team Inspiration's 2025 RoboBoat Autonomous Surface Vehicle

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Abstract — **Team Inspiration leveraged lessons learned from RoboBoat 2024, RoboSub 2024, and RobotX 2024 to upgrade our Autonomous Surface Vehicle (ASV), Barco Polo, to version 2.0. We improved the performance and reliability of Barco Polo by significantly improving our software and installing a new racquetball launcher and water gun, resulting in the ability to attempt all missions. The team plans to complete all tasks utilizing Simultaneous Localization and Mapping (SLAM) by fusing Differential Global Navigation Satellite System (GNSS) and a stereoscopic camera with depth perception for up to 30 meters. We also organized the electrical systems to address instability of electrical connections observed during testing. A methodical testing strategy, including unit testing, test plans, and status meetings streamlined the development process, enabling remote members to work effectively with local teammates. Design review, continuous integration, and iterative feedback via the systems engineering and agile processes allowed the team to fail fast and improve subsystems in a timely manner.**

I. COMPETITION STRATEGY

Team Inspiration's competition strategy involves developing a system to attempt all tasks, especially since this would double the points from Tasks 1-5 after completion of *Return to Home*. We will focus on completing the missions based on proximity to Barco Polo's location.

We deemed it most beneficial to focus not on building a new boat, but on improving software and algorithms developed by the team in the 2024 season, bringing her from version 1.0 to version 2.0. In all development processes, our team prioritized simplicity and ease of implementation over all other factors, allowing us to decrease development time and ease of integration for operation and development of Barco Polo (Fig. 1).

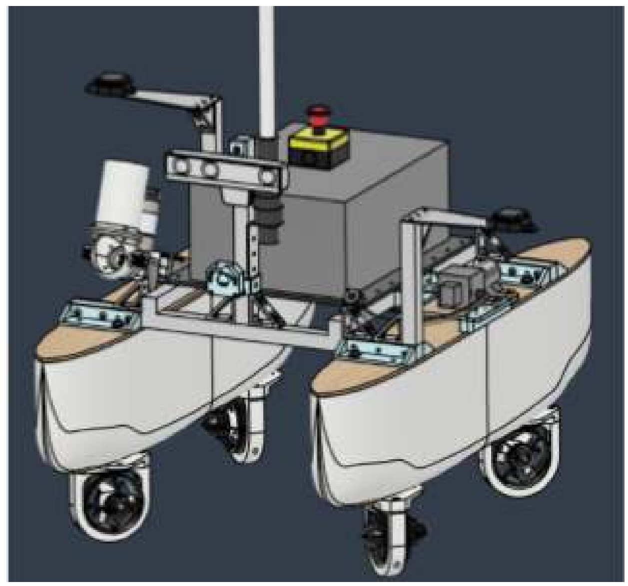

Fig. 1. CAD of Barco Polo 2.0

A. *Overall Mission Strategy/Completion Method*

Our experience in RoboBoat 2024, RoboSub 2024, and RobotX 2024 led us to focus on accurate localization. Object detection localization obtained from perception algorithms is not reliable for larger distances (i.e., 30 meters from the robot) or a large number of obstacles at once. As such, we introduced SLAM [1] in our mission plan. GNSS provides the position of Barco Polo, while a stereo smart camera (OAK-D Long Range) provides perception to enable calculation of the absolute positions of objects on the course. These positions are recorded in an internal map as they are collected, which will be utilized to guide Barco Polo's mission plan and movement throughout the course (Fig. 2).

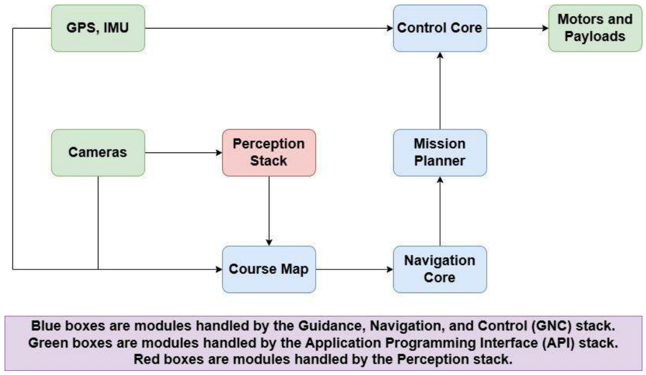

Fig. 2. High-level software function. See Section II.C for specific information on the GNC, API, and Perception stacks for Barco Polo.

Barco Polo utilizes a differential GNSS for high level localization and navigation since it provides translational position and a heading. We will utilize these capabilities to turn the course into a map of coordinates.

While moving through the course, Barco Polo will continuously run a course-generalized YOLO (You Only Look Once) detection model on real-time camera footage to continuously obtain object identification. This data will include both what the object is and the distance of the object from the boat up to 30 meters. This, combined with the data from our GNSS system, allows us to map the course in real-time as Barco Polo continues through the course and detects new objects (visual SLAM).

B. *Detailed Mission Plan*

In developing a mission plan, the team will focus on the *Navigation Channel, Mapping Migration Patterns, and Return to Home*. Once those mission capabilities are reliable, we add in *Race Against Pollution*, *Treacherous Waters*, and finally, *Rescue Deliveries.* Our full competition run is structured in the following order: *Navigation Channel*, *Mapping Migration Patterns*, *Race Against Pollution, Treacherous Waters*, *Rescue Deliveries,* and finally, *Return to Home*. The mission plan prioritizes tasks by proximity (Fig. 3) [2]. For *Mapping Migration Patterns*, we plan to report via a visual display provided by the ASV operator's control system. Barco Polo will keep an updated map of objects on the course as it moves through its tasks.

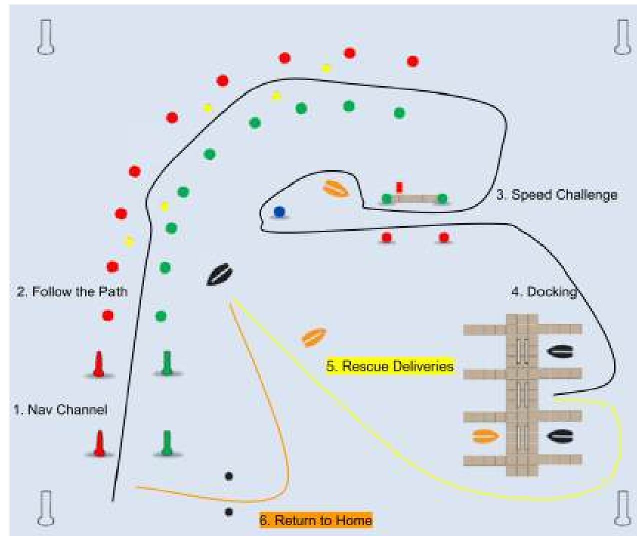

Fig. 3. Barco Polo's anticipated trajectory through a sample course. The black trajectory is for the missions 1-4 as listed below; the yellow trajectory is for the Rescue Deliveries mission; the orange trajectory is for the Return to Home mission.

Below is the Barco Polo's high-level completion logic for each mission:

1) Navigation Channel: Barco Polo will save the initial GNSS position and heading to aid the Return to Home mission, and then surge forward through the buoy gates.

2) Mapping Migration Patterns (Follow the Path): Barco Polo will find the two closest buoys of red and green colors. Barco Polo will then calculate GNSS coordinates for the buoys and the midpoint between them. If there is a yellow buoy nearby, then Barco will check which side of the path it is closer to – if the buoy is closer to the left side, Barco Polo will adjust the waypoint 2 feet to the right, and if the buoy is closer to the right side, Barco Polo will adjust the waypoint 2 feet left. This process will be repeated until there are no more buoys in sight of the camera. Barco Polo will keep track of the yellow buoys on its map as it navigates the path, reporting their number to the judges at the end.

3) Race Against Pollution (Speed Challenge): Barco Polo will localize GNSS coordinates estimated from survey and align heading to the light panel. When Barco Polo detects a green light with the OAK-D LR camera, Barco Polo will rotate to align with the gate, and then continuously surge forward in a trajectory that maintains the ASV on the right side of all obstacles, by ensuring that obstacles stay on the left side of the camera's field of view (FOV), correcting its view leftward if there are no obstacles in sight. This will ensure that Barco Polo circles all obstacles (including the blue buoy). Once the red and green gate buoys are sighted, Barco Polo will align and surge through them.

4) Treacherous Waters (Docking): Barco Polo will begin at one of the corners of the dock, facing the dock. Barco Polo will first check if there is a vessel in the dock. If so, Barco Polo will strafe to the next dock (or around the dock if there aren't any more in front). If the dock is empty, Barco Polo will check if the banner matches the color and shape of the day. If not, Barco Polo will move to the next dock. If the banner matches, then Barco Polo will surge forward to dock, then surge backward.

5) Rescue Deliveries (Object & Water Delivery): Once *Treacherous Waters* is completed, Barco Polo will consult its map to find any boats that were detected throughout its mission run. Barco Polo will return to each boat. Barco Polo will launch racquetballs to strike the plus-shaped icons and shoot water at the triangular icons.

6) Return to Home: Barco Polo will localize by navigating to a GNSS waypoint found via a survey of the course. Any obstacles will be passed on the right by keeping them on the left side of the camera's FOV. Unlike *Race Against Pollution*, Barco Polo will continue moving forward upon obstacles leaving the FOV. Upon localizing to the waypoint, Barco Polo will search based on a general heading until she sights the two black buoys, after which she will surge forward through the gate, which marks the end of the run.

II. DESIGN STRATEGY

In order for Barco Polo to achieve our team's competition strategy, we added a racquetball launcher and water gun to perform the *Rescue Deliveries* task, organized our electrical box to prevent movement of components, integrated an OAK-D Long Range stereoscopic camera to enable perception, as well as more accurate localization data. The team additionally overhauled Barco Polo's software package, reorganizing the code to more easily implement sensor fusion to navigate effectively, and a mission planner which tolerates greater environment variability.

A. Mechanical Subsystem

Barco Polo utilizes catamaran-style pontoons to resist rolling from waves. The pontoons have in their internal structure sheets of wood at the top and bottom to provide structural stability. Between the sheets of wood are 5 layers of high-density foam for buoyancy. The wood and foam are coated in resin, fiberglass, and paint for waterproofing.

We developed a new racquetball launcher for the completion of this year's *Rescue Deliveries* task (Fig. 4). The launcher utilizes a DC motor that turns a gear with three teeth. The teeth engage with a plunger rod to move it backwards, which compresses a spring allowing a racquetball to drop from a magazine. When the gear teeth disengage with the rod, the spring forces the plunger rod forward again, launching the racquetball.

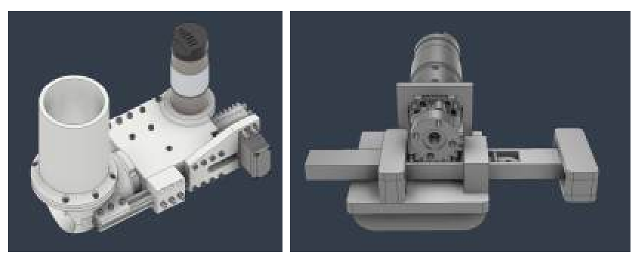

Fig. 4. CAD of racquetball launcher (left) and view of gear system for racquetball launcher prototype (right).

We also developed a water gun for the *Rescue Deliveries* task (Fig. 5). The pump utilizes a tube that takes water from the lake. The water is routed through a nozzle that tapers inward to increase the velocity of the water exiting the pump. This is done to increase the speed of the water exiting the nozzle, increasing the range of the water gun.

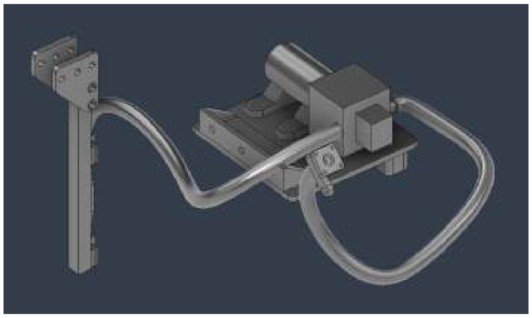

Fig. 5. CAD of Barco Polo's water gun.

We found during the previous competition season that the pontoons were soaking up water from the holes for screws mounting the T200 thrusters. To prevent further impacts on Barco Polo's buoyancy, we sealed these holes with marine glue.

B. Electrical Subsystem

Power to the electrical components comes from one 15.6 Ah 4S LiPo battery. An anti-spark switch is utilized to control power delivery to the system. The electrical subsystem uses two power distribution boards: a higher powered one services the Electronic Speed Controllers (ESCs) and motors, while the other services the rest of the components. This allows the kill switch to cut off power only for the thrusters, ensuring it does not pose a risk for the main computer, the Jetson Xavier NX, to become corrupted.

One of Barco Polo's key sensors are differential GNSS antennas connected to a Beitian GNSS Module. This system allows Barco Polo to know its geographic position and heading anywhere in the course, allowing for waypoint navigation. This system becomes especially powerful in conjunction with the new OAK-D LR PoE camera, where the camera's stereo capabilities provide the ability to calculate distance of nearby objects from Barco Polo. Refer to Appendix C (Fig. C.1) for a graphical representation of our electrical subsystem.

In the previous competition season, the rushed development timeline resulted in a disorganized electrical box where components and wires were not secured properly. Electrical connection problems observed during testing are attributable to movement of electrical components and wires. To prevent these problems and ease the interaction with the components, we secured the components and wires to the sides of the box and 3D printed a battery mount (Fig. 6).

Fig. 6. Barco Polo's electronics box before (left) and after (right) organization.

C. Software Subsystem

Barco Polo's software stack consists of three main substacks – an API (Application Programming Interface) stack, a perception stack, and a GNC (Guidance, Navigation, Control) stack. This architecture merges Team Inspiration's software from RoboSub 2024 [3] and RobotX 2024 [4], combining the modular, mission specific structure from RoboSub with the more advanced navigation and guidance capabilities which were developed for the RobotX competition.

We utilize Python threading to facilitate communication between Barco Polo's software modules. This switch from Robotic Operating System 2 (ROS2) in RoboBoat 2024 [5] enabled us to exert more low-level control on our system, helping us customize and modify components while decreasing onboarding time. Accessing data from our GNSS module and OAK-D LR camera simultaneously allows us to use SLAM in our GNC stack (section C.3).

1) API Substack: The goal of the API stack is to access information from all sensors on Barco Polo, and to actuate motors and launchers when necessary. To increase modularity and scalability, each sensor has its own set of core files, which accesses and parses sensor data into a usable format for the perception and GNC stack (see sections C.2 and C.3). Refer to Appendix C (*Fig. C.3)* for a diagram of the API stack structure.

2) Perception Substack: The perception stack takes data from onboard cameras, and runs real-time inference on camera frames to achieve accurate detection results. As YOLOv8 inference detection methods have given the team advanced detection capabilities in the past, we have decided to continue to use that as our Machine Learning (ML) model architecture. The team uses RoboFlow to obtain high quality labeled datasets which can be inputted into the YOLO models for training.

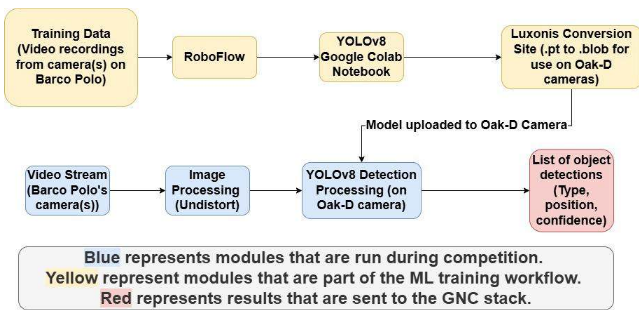

Fig. 7. Perception Workflow Stack. It trains ML models and runs them on real-time camera streams.

3) GNC Substack: The GNC stack consists of algorithms which consider data processed from the API and perception stacks. The GNC stack is split into three further substacks: the control, navigation, and guidance stacks. Refer to Appendix C (*Fig. C.5*) for a diagram of the GNC Substack.

a) Control Stack: The control stack parses data from Barco Polo's GNSS coordinates, heading, and Inertial Measurement Unit (IMU) to calculate Pulse Width Modulation (PWM) values to send to each thruster. These calculations use a Kalman filter to enable accurate stationkeeping and waypoint navigation.

b) Navigation Stack: The navigation stack considers detection data generated from ML models, depth data from the Oak-D LR camera, and the latitude, longitude, and heading from Barco Polo's GNSS. From this data, a mapping algorithm calculates the coordinates of detected objects and stores this data, along with the object's type and confidence level, in Barco Polo's course map. The module also includes calculations for waypoints and conversions between distance and degrees.

c) Guidance Stack: The guidance stack represents Barco Polo's mission planner, weighing several variables such as time spent already on a mission and the importance of each mission, which is stored in Barco Polo's memory. Using the map from Barco Polo's navigation stack, Barco Polo will calculate a path through each mission. If there is not enough information to fully map out a single mission, Barco Polo will calculate the best waypoint to move to next, and depend on her mapping capabilities to update her course knowledge, to inform her next decisions. In either case, Barco Polo will send a waypoint to the control stack, which will handle all low-level commands and calculations to localize to the desired position. For the missions where reporting to judges is relevant, the guidance stack will also handle printing Barco Polo's report on the operator's computer screen.

III. TESTING STRATEGY

It was critical that the team's testing strategy limited logistical overhead and ensured quality control. As such, we employed an agile method which emphasized quick development and testing to fail fast and apply lessons in the next iteration. To this end, the team utilized a systems engineering approach, conducting unit tests on a single part of a system before conducting large scale tests involving multiple systems, since cause of problems can more easily be deduced in smaller tests.

To further streamline our testing process, we utilized test plans (Appendix B). These plans ensured that all team members understood their roles, the equipment required to conduct the test, what kinds of tests would be conducted, and indicators of success and failure. The test plans also provide room for discussion of the results and causes for any failed tests, making way for quick troubleshooting.

A. Land Testing

Land testing was utilized for unit tests that did not require movement of the boat via the thrusters. This increased efficiency by cutting the overhead associated with water testing. One test involved mounting Barco Polo on a cart and finding the range where a base station connection could be maintained via the Bullet antenna, in order to troubleshoot connectivity issues encountered at far ranges during the 2024 competition. We also performed unit tests of the racquetball launcher and the water gun. For detailed test results, see Appendix B.

B. *Remote Testing*

Since the software team members were based in Florida, a remote testing system was required. The team utilized a Tailnet-to-base station setup where members could use Secure Shell (SSH) over a Virtual Private Network (VPN) to connect with a Raspberry Pi model 3B+ (Fig. 8). This increased the ease of software development, integration and testing.

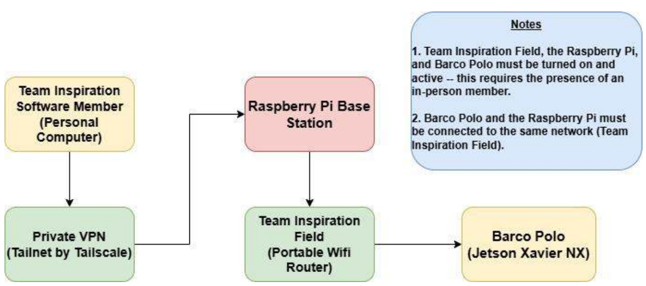

Fig. 8. Visual setup of the private network to base station setup which allows Team Inspiration to test software.

C. *Water Testing*

Water testing was conducted via an in-lab pool to conduct tests which require movement of Barco Polo (Fig. 9). The pool is a controlled, small-scale environment allowing testing of movement logic and individual missions. Due to our limited time and members, we were pushed to develop a systematic method of water testing priority to efficiently produce and develop results.

Water testing is crucial since it more closely simulates the competition environment. This helped us discover electrical connection problems during a pool test when the thrusters failed. Our troubleshooting indicated that increased movement in a maritime environment and loose electrical components led to physical wiring disconnects. We organized the electrical box to minimize component movement during water time, but troubleshooting is still ongoing (see Appendix B).

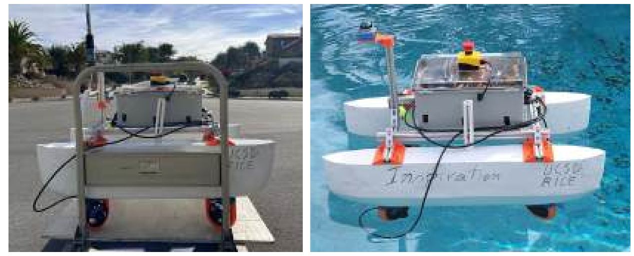

Fig. 9. Barco Polo during a land connectivity test (left) and water motor test (right).

IV. ACKNOWLEDGEMENTS

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Diamond: Advancing Science Technology and Art, the Chen family, Gilman Charitable Fund, and HP.

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Finally, we would like to thank our parents for their support, without which none of our accomplishments would have been possible.

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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
	Home Depot	Maple Plywood, ⅛ in. series	Thickness: ⅛"	Purchased	$23.99	2024
	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
	McMaster-Carr	1016N215 Cable Entry Panels	Supported cable diameter: 0.22"	Purchased	$25.95	2023
	MAKERELE	Cord Grip Cable Glands Kit	1/4", 3/8", 1/2", 3/4", 1", 1-1/4" https://www.amazon.com/gp/product/B08R86BHBC	Purchased	$24.99	2023

			/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&th=1			
Water Cannon	Bayite	12V DC Fresh Water Pressure Diaphragm Pump	https://www.amazon.com/gp/product/B01N75ZIXF/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1	Purchased	$20.99	2024
	Eastrans	3/8" ID x 10 Ft High Pressure Braided Clear PVC Vinyl Tubing	https://www.amazon.com/gp/product/B07MTYMW13/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1	Purchased	$12.99	2024
	Everbilt	1/2 - 1-1/4 in. Stainless Steel Hose Clamp	https://www.homedepot.com/p/Everbilt-1-2-1-1-4-in-Stainless-Steel-Hose-Clamp-6712595/202309385	Purchased	$2.18	2024
Racquetball Launcher	AndyMark	NeveRest Classic 60 Gearmotor	https://www.andymark.com/products/neverest-classic-60-gearmotor	Purchased	$34	2024
	HUAREW	PCA9685 16 Channel PWM Servo Driver Board	https://www.amazon.com/HUAREW-PCA9685-Interface-Compatible-Raspberry/dp/B0CRV3MK14	Purchased	$12.99	2024
Propulsion	Blue Robotics	T200 thrusters	Full Throttle FWD/REV Thrust @ Maximum (20 V): 6.7/5.05 kg f https://bluerobotics.com/store/thrusters/t100-t200-th	Legacy	$200 apiece	2019

			rusters/t200-thruster-r2-rp/			
	Blue Robotics	T200 propellers	Max thrust: 49.82 N	Legacy	Included with thrusters	2019
Motor Control	Blue Robotics	Basic ESC	30A brushless ESC https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/	Legacy	$36 apiece	2019
	Arduino	Arduino Uno Rev 3	https://store-usa.arduino.cc/collections/boards-modules/products/arduino-uno-rev3?_pos=4&_fid=de47b83a5&_ss=c	Purchased	$27.60	2024
	DFRobot	IO Expansion Shield for Arduino V7.1	https://www.amazon.com/DFROBOT-Gravity-Expansion-Shield-Arduino/dp/B00G3IKO68	Purchased	$6.90	2024
Power System (Battery, Converter, Regulator)	Blue Robotics	Lithium-Ion Battery	4S 14.8V 18 Ah	Legacy	Legacy	2019
	Blue Robotics	5V, 6A power supply	5V, 6A	Legacy	Came with BlueROV setup; Legacy	2019
	Boundmotor	Smart Anti-Spark Switch for Boundmotor VESC	https://boundmotor.com/products/power-switch	Purchased	$49.90	2023
	ElecDirect	200A Manual Reset Type 3 Surface Mount	https://www.elecdirect.com/fuse-holders-circuit-breakers/circuit-break	Purchased	$29.95	2023

			ers/200a-high-amp-manual-reset-type-3-surface-mount-12-42-volts			
	Pololu	RC Switch with Omron Relay	https://www.pololu.com/product/2804/specs	Purchased	$12.95	2023
	iRhapsody	4 Pin High Current Relay	120A, 12V	Purchased	$11.99	2023
	McMaster-Carr	7060K16 Insulated Quick-Disconnect Terminals	https://www.mcmaster.com/7060K16/	Purchased	$16.36 per 100 pieces	2024
	McMaster-Carr	7113K612 Ring Terminals	https://www.mcmaster.com/7113K612/	Purchased	$13.74 per 50 pieces	2024
	McMaster-Carr	69145K218 Spade Terminals	https://www.mcmaster.com/69145k218/	Purchased	$14.74 per 50 pieces	2024
Actuator Control	HUAREW	PCA9685 16 Channel PWM Servo Driver Board 12 bit IIC Interface Module Compatible with Arduino and Raspberry Pi	https://www.amazon.com/HUAREW-PCA9685-Interface-Compatible-Raspberry/dp/B0CRV3MK14/ref=sr_1_1_sspa?crid=2ZVIRTROX49XI&dib=eyJ2IjoiMSJ9.wssrvYzmPxMlauJhvIFpcEGvvvZXQJH4pna_yQBXQIxQDzyWO0q4ZODq3vClK8AhqtJKRlGzpwy_1c-mpfH2TiOMzDyqAi9Dgi9suTm87qbuWjTFKZLYEYwCwS_L7DK4WfAy	Purchased	$12.95 per 2 pieces	2025

			W_Wc3tVBnLHlnDcAK7_CkeRDbufhymcKo_3fOR5j99ZLUfa9ehYyWGH3oUNOA6mJFX_yg_Y_1jxl_755cjhqTKe2invmsiHOv2Bb-wuZKGcBsgTaLptCdpWU-BMjYF-wl9JKG9Fxr8S-l47Qq4sQW8AeTkrUBsjbnMoad6k.xymjlKcKjzJHKv79h8nX7UVAx03-kq1ov6tJzvjfBm8&dib_tag=se&keywords=servo+board&qid=1737841489&sprefix=servo+boar%2Caps%2C166&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1			
DC-DC Converter	Cllena Matek Systems	Buck/Boost Converter	DC 8V-40V to 12V 10A 4A/5-12V and 4A/5V	Purchased Legacy	$29.99 Legacy	2023 2021
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

CPU	Nvidia	Nvidia Jetson Xavier NX	https://developer.nvidia.com/embedded/learn/get-started-jetson-xavier-nx-devkit	Legacy	Legacy	2021
Teleoperation	Ubiquiti	airMAX Bullet AC IP67	Communication: GbE, PoE UISP airMAX Bullet AC Dual-Band IP67 Radio - Ubiquiti Store United States	Purchased	$129.00 apiece	2023
	Alfa	AOA-2458-79AF Antenna	https://www.alfa.com.tw/products/aoa-2458-79af?variant=36473962332232	Purchased	$24.46 apiece	2023
	Ubiquiti	Instant Outdoor PoE Converter	https://store.ui.com/us/en/category/all-accessory-tech/products/instant-802-3af-outdoor-gigabit-poe-converter	Purchased	$21.00	2023
	RadioMaster	ER6 ExpressLRS PWM receiver	https://www.tekrc.eu/shop/receivers/expresslrs/radiomaster-er6-expresslrs-pwm-receiver-6-channels/	Purchased	$31.60	2023
	Flysky	FS-iA6B Receiver	https://www.amazon.com/FS-iA6B-Receiver-6-Channel-Compatible-Transmitter/dp/B09STCQCCF/	Purchased	$18.49	2023
	Pololu	4-Channel RC Servo Multiplexer	https://www.pololu.com/product/2806	Purchased	$12.95	2023
Perception	Livox	Mid-360	Specs - Mid-360	Purchased	$749	2023

			LiDAR Sensor - Livox (livoxtech.com)			
Inertial Measurement Unit (IMU)	Adafruit	BNO085	https://www.ceva-ip.com/wp-content/uploads/BNO080_085-Product-Brief.pdf	Purchased	$24.95	2024
Camera	Luxonis	OAK-D LR PoE	Resolution: 2.3MP (1920x1200) Frame Rate: 60 FPS max rate Focus: M12 FF (45cm - ∞) https://shop.luxonis.com/products/oak-d-lr	Purchased	$350.00 (50% discount)	2024
Localization and Mapping	Beitian	UM982 GNSS Module Model BT-982K1	https://store.beitian.com/products/beitian-built-in-zed-f9p-navigation-surveying-positioning-precision-agriculture-centimeter-level-rtk-gnss-module	Purchased	$200.88	2023
	U-blox	ANN-MB series L1/L2 GNSS antennae (2x)	https://content.u-blox.com/sites/default/files/documents/ANN-MB_DataSheet_UBX-18049862.pdf	Purchased	$60.00 apiece	2023
Vision	Custom	Open Computer Vision	Color isolation, binary thresholding, contour		Free/ Open Source	2019

			approximation, erosion and dilation, area thresholding, and Contrast Limited Adaptive Histogram Equalization (CLAHE)			
	Ultralytics	YOLOv8	Real-time object detection and inference https://docs.ultralytics.com/models/yolov8/		Free/Open Source	2022
Autonomy	In-house	Custom (Python)	Object detection integration, mission planning, waypoint navigation		Free	2024
Open-Source Software	Open-Source (N/A)	OpenCV, Python, C++, Linux	Computer Vision, Inter-process communication, programming, computer operating system	Custom	Free	2024

Appendix B: Test Plan & Results

I. TEST PLAN

Testing included unit tests, ground tests, water tests, and mission tests. We built off the competition proven platform of Barco Polo and component tested each individual payload during ground tests before final integration and water test.

We have test plans and procedures, which allow us to assign roles and make a timeline for tasks. Before each test, we wrote up procedures for conducting the tests, including expected behaviour and pass/file criteria. We document the actual results. This ensured that during the test, everyone was in agreement about roles and courses of action. At the bottom of the testing plan, there is room provided for post-test reflections about the results and analysis of any failures.

II. UNIT TESTS

Due to our limited time and roster, it was imperative to test in the most efficient manner possible. Conducting unit tests was prudent since it is easier to troubleshoot at component level. We conducted unit tests of various sensors and payloads before their integration into Barco Polo's system.

We unit tested our relays before installation and determined the procurement of the relay board was incorrect. The boards purchased expected a 12V trigger (which would have been achievable without additional complexity) instead of a 5V trigger (which could be achieved via a microcontroller or receiver).

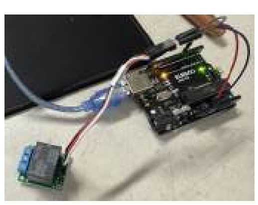

Fig. B.1. Pololu relay module unit test

The relays served as the foundation of actuating the water gun and racquetball launcher. An initial test of the water gun revealed that 1 Gallon Per Minute (GPM) would spray water a distance of 1 foot. Testing after installation of a nozzle increased the range to 8 feet (Fig. B.2). Maintaining mass flow rate, the nozzle increases the water's velocity at exit by a factor of 2.5, increasing the range of the pump by a factor of 3 (Fig. B.3).

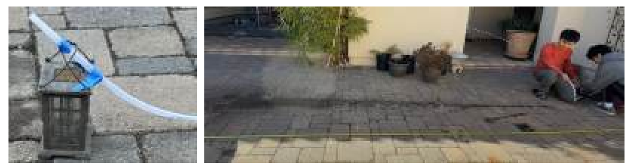

Fig. B.2. First test of water gun without a nozzle (left) and second test with nozzle installed on water gun (right)

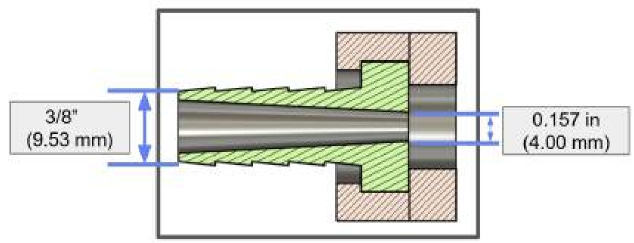

Fig. B.3. Cross section of the nozzle

The team conducted load testing on the ground by running computer vision scripts and simulating other high intensity processing for more than 30 minutes, which is sufficient for multiple competition runs.

Hand-held unit testing of the racquetball launcher showed significant frictional forces in design. The motor was stalling and unable to retract and slip the punching rod. This informed adjustment to the design of reducing the slip gear from 9 teeth to 3 teeth (Fig. B.4). This reduced the draw force from 42 lbs to 30.7 lbs. We added a magazine extender to increase the magazine capacity of the launcher from 3 racquetballs to 6 racquetballs. We later removed the extender during the final installation to ensure the design met the competition sizing requirement.

Fig. B.4. Hand-held racquetball launcher (left). There were nine gear teeth in the original configuration (middle), which was revised to three teeth after testing (right).

We conducted a unit test of our differential GNSS system (Fig. B.5.) by placing the GNSS antennas on a cart and moving them outside the lab (Fig. B.6). This enabled us to verify the system's accuracy and reliability while aiding the utilization of APIs.

Fig. B.5. Differential GNSS unit test setup

Fig. B.6. GNSS waypoint visualization in front of the lab

During RoboBoat 2024, we experienced problems with maintaining the wireless connection to Barco Polo during competition runs. We therefore tested the range of our Bullet antennas on land by setting up a base station, placing Barco Polo on a cart, and moving it down the roads outside of our lab (Fig. B.7). We then tracked via ping command the distance where a connection was maintained. We found the connection range was 300-450 feet, which would be insufficient for the competition venue. There were obstructions blocking the line of sight between the antennas (such as houses and the ground - the testing area had Barco Polo go down a significant slope). Will replicate this test in an environment more like the competition venue in a local lake.

Fig. B.7. Barco Polo during a wireless range test

III. WATER TESTS

This year, we decided to transition our thruster control system from a flight controller to an Arduino. Since we had written new movement scripts, we conducted a water test to verify the functionality of remote control and the correctness of our autonomous movement (Fig. B.8). Although we verified remote control functionality, we found that sudden movements would cause the ESCs to restart, after which the thrusters would not produce any thrust. This exposed problems associated with the disorganization of our electronics box − since many of the components were not secured, they would move and interrupt electrical connections during testing. We have since organized the electronics box, but electrical troubleshooting is still underway.

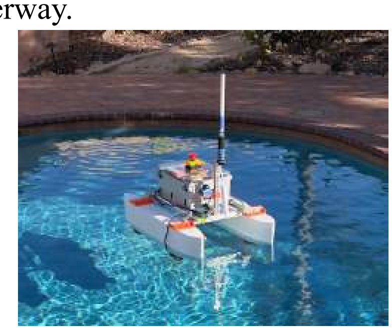

Fig. B.8. Barco Polo during a movement test

Base Station Range Test	Approval Authority	
	Brandon Tran	Tester
	Leonard Wright	Software Team Co-Lead

Date: 12/23/2024	**Mission Title: Base Station Range Test**	
Test #: Bullet 1	**Location:** Abby Wood Court and Stockwood Cove	**Risk:** Low
Software Version: Preliminary 1.0	**Hardware Sensors Mounted:** Bullet Antenna	**Hardware Sensors Used:** Bullet Antenna
Scope: **Primary:** **Secondary:** **Tertiary:**		

Roles		Walkie Talkies/ Cell Phones		Times		
				Event	**Time**	**Actual**
Test Conductor	Leonard	**Ground**	N/A	**Packup**	11:15	11:10
Boat Launcher	Brandon	**Pool Deck**	N/A	**Go to location**	11:16	11:11
Ground Control	Leonard	**Lifeguard**	N/A	**Test**	11:20	11:12
Data Collector	Brandon	**Tether**	N/A	**Cleanup**	12:00	12:25
Photographer	Brandon			**Leave**	12:10	12:30

				Location		
Safety Checker/QA	Leonard			**Put Away**	12:15	12:32
Person in water	N/A					
Status						
Boat		GO				
Ground		GO				
Pool Deck		NO GO				
Attendance	**Test Notes**					
Brandon Tran **Leonard Wright**	**Resources Needed:** Bullet A/C Barco Polo Battery Computers Phone Tripod WiFi router Outlet Power cord/strip Robosub Cart **Environment:** Abby Wood Court (street) **Expected Results:** ● Ping commands to the Jetson will succeed at distances less than a set distance, and fail for distances greater than that distance. The goal of this test is to find out what this set distance (the antenna range) is. **Prerequisites:** Connecting the hardware and power correctly Connecting to WiFi router					

<table>
<tr><td></td><td colspan="4">Test procedure:
1. Confirm that the connections on Barco Polo are correct
2. Connect the charged battery to Barco Polo
3. Connect the hardware together (router, ethernet, PoE injector, wall power, Bullet A/C). Base station antenna is currently just outside the garage, may need to evaluate if it should be further out
4. Cart out Barco Polo to the driveway
5. Try moving it to a location so Colin’s car (parked) obstructs the line of sight. See if a connection is lost. If so, move the antenna further out to the driveway and note the results (antenna should maintain line of sight during competition week)
6. Brandon and Leonard get on a phone call. Brandon takes the boat down the cul-de-sac and Leonard tells him when the pings start to fail
Risk Management:
Having a safety observer</td></tr>
<tr><td>#</td><td>Validation Step Description</td><td>Expected Result</td><td>Reference to Data</td><td>Pass/Fail</td></tr>
<tr><td>1</td><td>Brandon takes Barco Polo out to the driveway</td><td>Successful ping</td><td>64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms</td><td>Pass</td></tr>
<tr><td>2</td><td>Brandon takes Barco Polo to location obscured by Colin’s car (right of the driveway)</td><td>Successful</td><td>64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms
● Time should be greater than other tests</td><td>Fail; Colin’s car did not pose a significant obstruction to the ping signal</td></tr>
<tr><td>3</td><td>Brandon takes Barco Polo to the left of the driveway</td><td>Successful ping</td><td>64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms</td><td>Pass</td></tr>
<tr><td>4</td><td>Brandon takes Barco Polo to the neighbor’s driveway across the street</td><td>Successful ping</td><td>64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms</td><td>Pass. The distance was 93.5 feet</td></tr>
</table>

5	Brandon takes Barco Polo down the cul-de-sac	Pings succeed until an unknown distance is reached (record the distance)	Successful ping: 64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms Failed ping: From 192.168.8.102 icmp_seq=1 Destination Host Unreachable OR <no output>	Fail: We got successful pings the whole way, the pings didn’t fail. The distance was 200-230 feet
6	If a connection is maintained for the whole of Test 5, Brandon takes Barco Polo down Stockwood Cove	Pings succeed until an unknown distance is reached (record the distance)	Successful ping: 64 bytes from 192.168.8.202: icmp_seq=1 ttl=64 time=<time> ms Failed ping: From 192.168.8.102 icmp_seq=1 Destination Host Unreachable OR <no output>	The distance is 473.9 feet Fail: Results are indecisive - need to conduct the test again ● Pings were fairly reliable most of the way there. As Brandon started getting further away, some pings were being dropped, and the pings after that came in after more than 100 ms. ● When Brandon reached the end of the cul-de-sac (473.9 ft), we lost connection to the Jetson ● When Brandon reached the house on the right before the cul-de-sac (~300 ft), the pings were regained for a short while before they were lost again ● Brandon then returned, pings were regained when Brandon was close to Abby Wood Ct
7	Same as Test 6	Same as Test 6	Same as Test 6	The maximum distance is 473.9 feet. This test was a higher quality than Test 6 and is therefore considered a

				success. ● Same location of gained connection ● Got a farther connection at the middle of the cul-de-sac ● Location of disconnection and connection fluctuates. Generally the distance to lose connection is greater than that of regaining connection. ● In one test iteration, we disconnected and were able to connect back in a smaller distance ● Range on the right side of the road was shorter than the left, which was shorter than the center. We may have to consider the houses and trees which may provide obstruction of the signal ● There were some light clouds in the sky and no wind - it was pretty sunny ● **See Table 1**

Table 1: Test 7 Locations of Lost Connection and Gained Connection

Description	**Distance**	**Side of Stockwood Cove (facing down the hill)**	**Was connection lost or connection regained at this point?**
⅔ of the way between the monument porthole (triangular) and far side of	450 ft	Center	Connection Lost

cul-de-sac			
Midline of driveway for the first house on the left of the cul-de-sac	423 ft	Left	Connection Lost
Last bush before the large bush on right-side of cul-de-sac	387 ft	Right	Connection Lost
Further manhole cover in the cul-de-sac	413 ft	Center	Connection Regained
Left side of the road across from the fire hydrant	350 ft	Left	Connection Regained
In the driveway of the house to the right of the cul-de-sac approach	288-295 ft	Right	Connection Regained

Results and Reflections: The optimal range (from the base station) is 300 ft, maximum range 450 ft - I wouldn't go further than 350 ft

- Brandon stated that whenever he moves the boat, the thrusters chirp (might be a problem with loose ESCs)
- We got our predicted results–although, there wasn't too much interference from Colin's car as there was with the trees at the left cul-de-sac.
- Both Brandon and Leonard got on the on-field test and the ground station
- The connection is relatively stable
- The tripod worked well for the antenna, need to have someone design a clamp or a holder
- Used google maps to measure distance from two points
- The time frame was well-followed, considering that we had an interfering call in between.

Some considerations:

- The houses and trees which may provide interference for the signal
- The route down Stockwood Cove has a downward slope, is it possible the ground's slope provides some interference?
- Normally, the RC controller is the master and the Arduino is the slave. In a competition run we would use the RC controller to activate the multiplexer (hand over control to the Arduino). If Barco Polo goes out of range, we could lose remote kill capability during a mission run, which would be a safety problem.
- The lake at Nathan Benderson Park is ~600 ft across, during the finals round they had the boundaries approximately 400-450 ft. -> Brandon

estimated the length of the course to be 700-900 ft, so that the dimensions would range from 700 ft x 400 ft to 900 ft x 400 ft. This means that unless we are willing to move the base station as the boat moves, <u>our current range isn't going to cut it</u>. I would heavily consider an upgrade to our antenna system.

Appendix C: System Diagrams

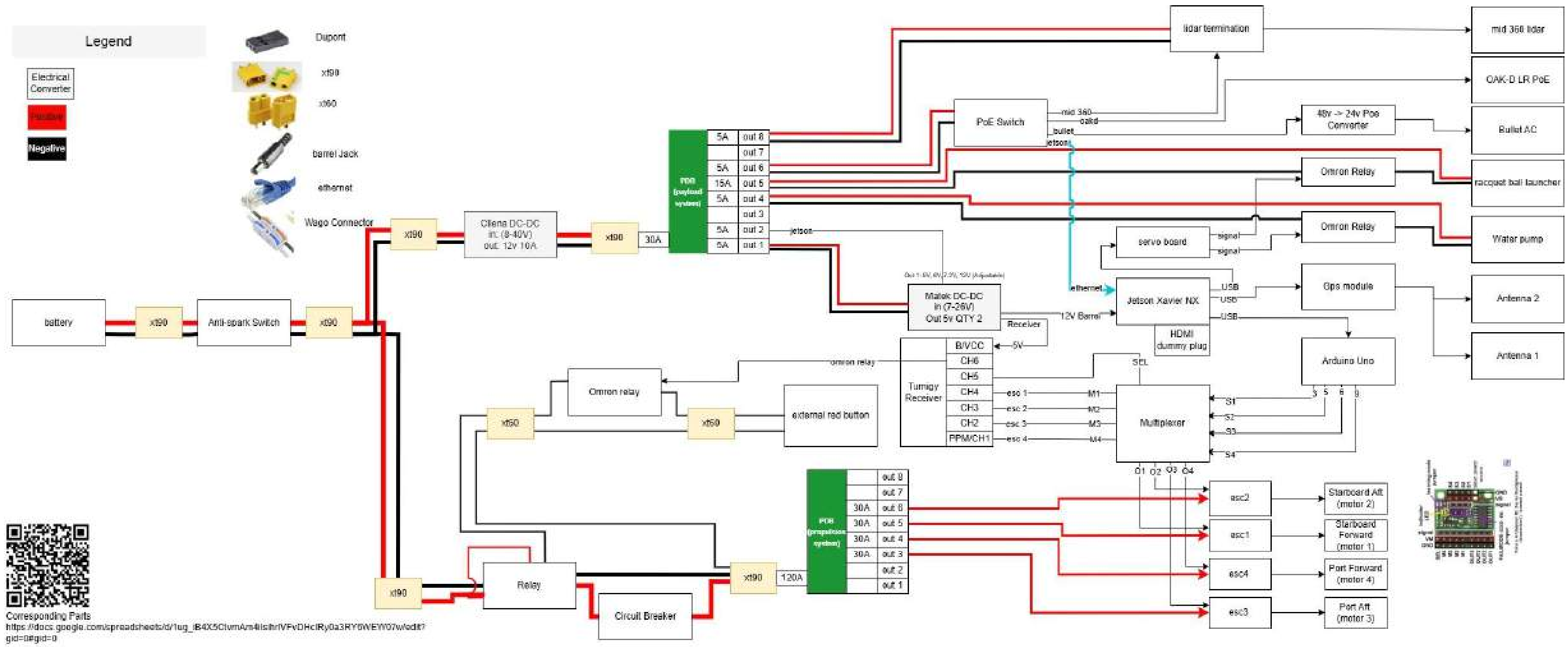

Fig. C.1: Full electrical schematic for Barco Polo.

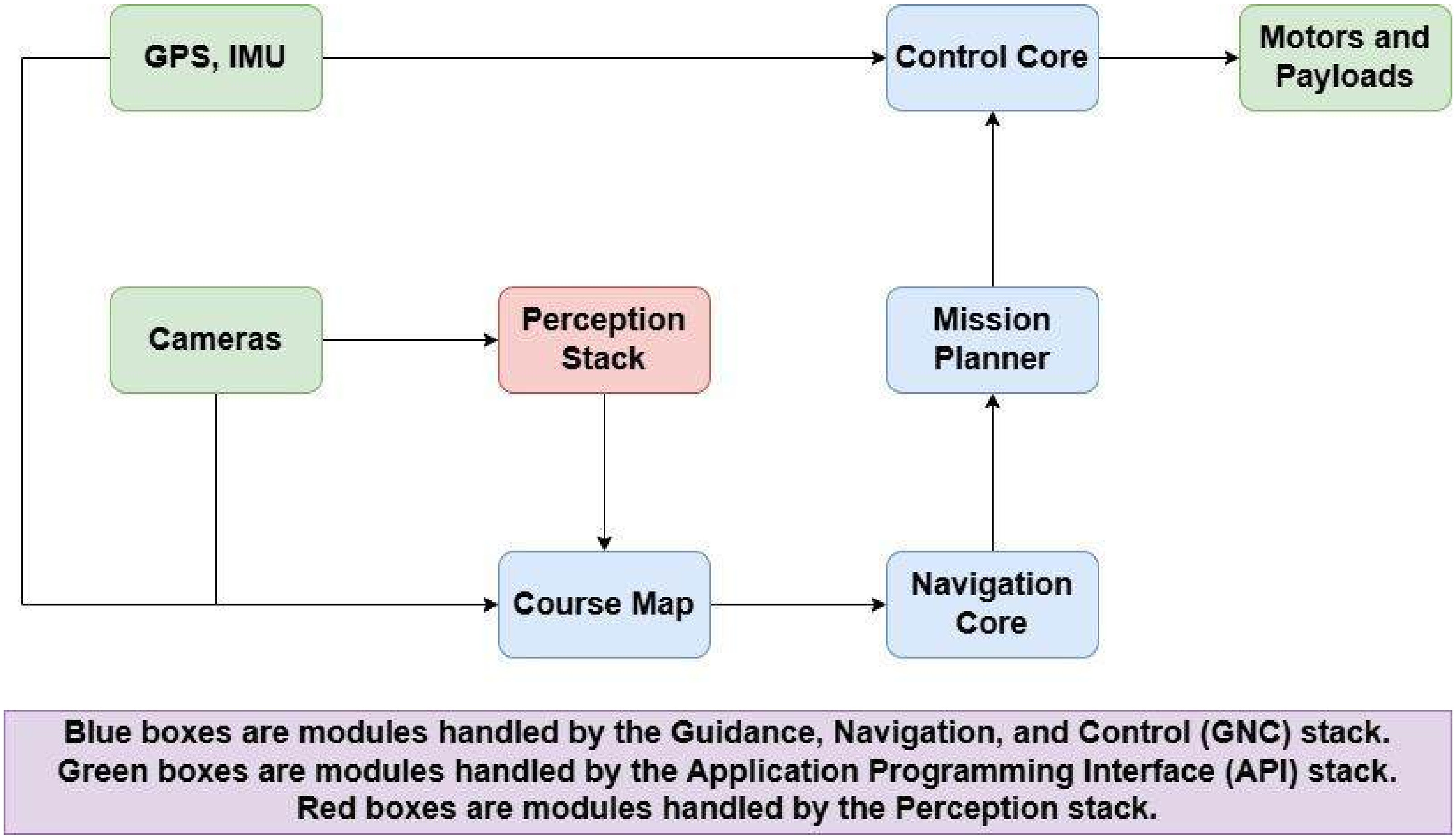

Fig. C.2: High-level software execution stack of Barco Polo for RoboBoat 2025.

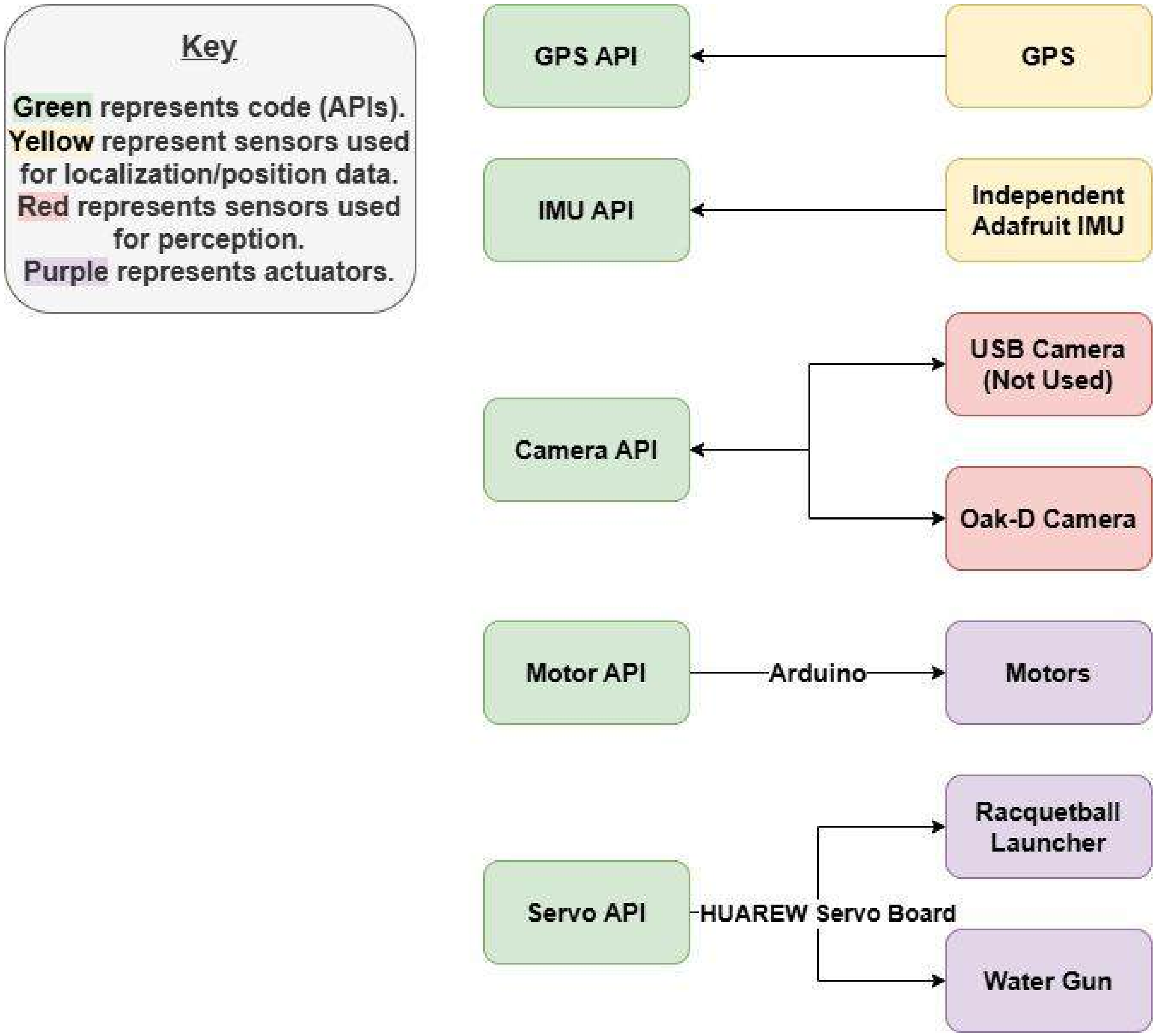

Fig. C.3: API stack diagram. Note that each API is specialized for a specific device or group of devices.

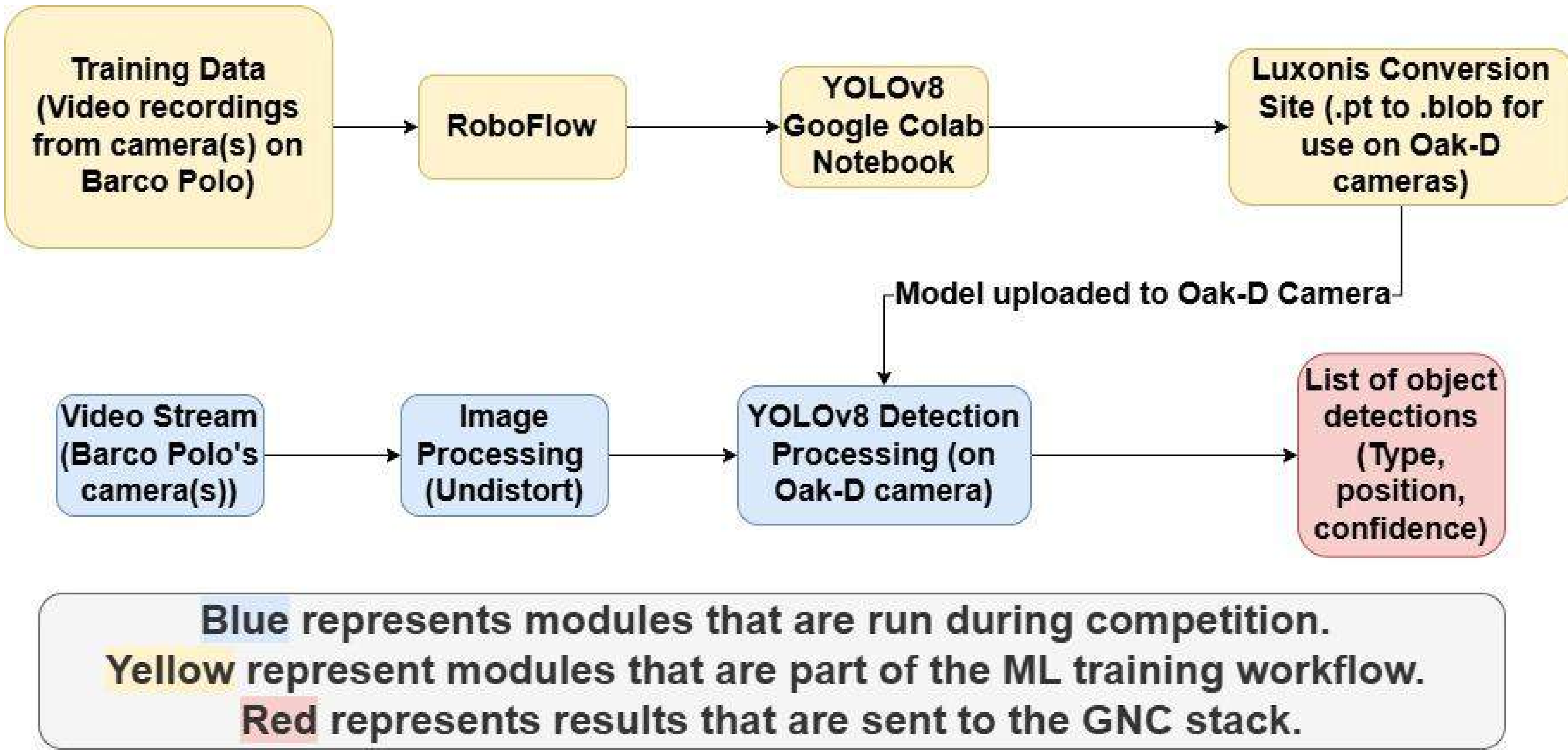

Fig. C.4: Team Inspiration's perception workflow for the RoboBoat 2025 competition.

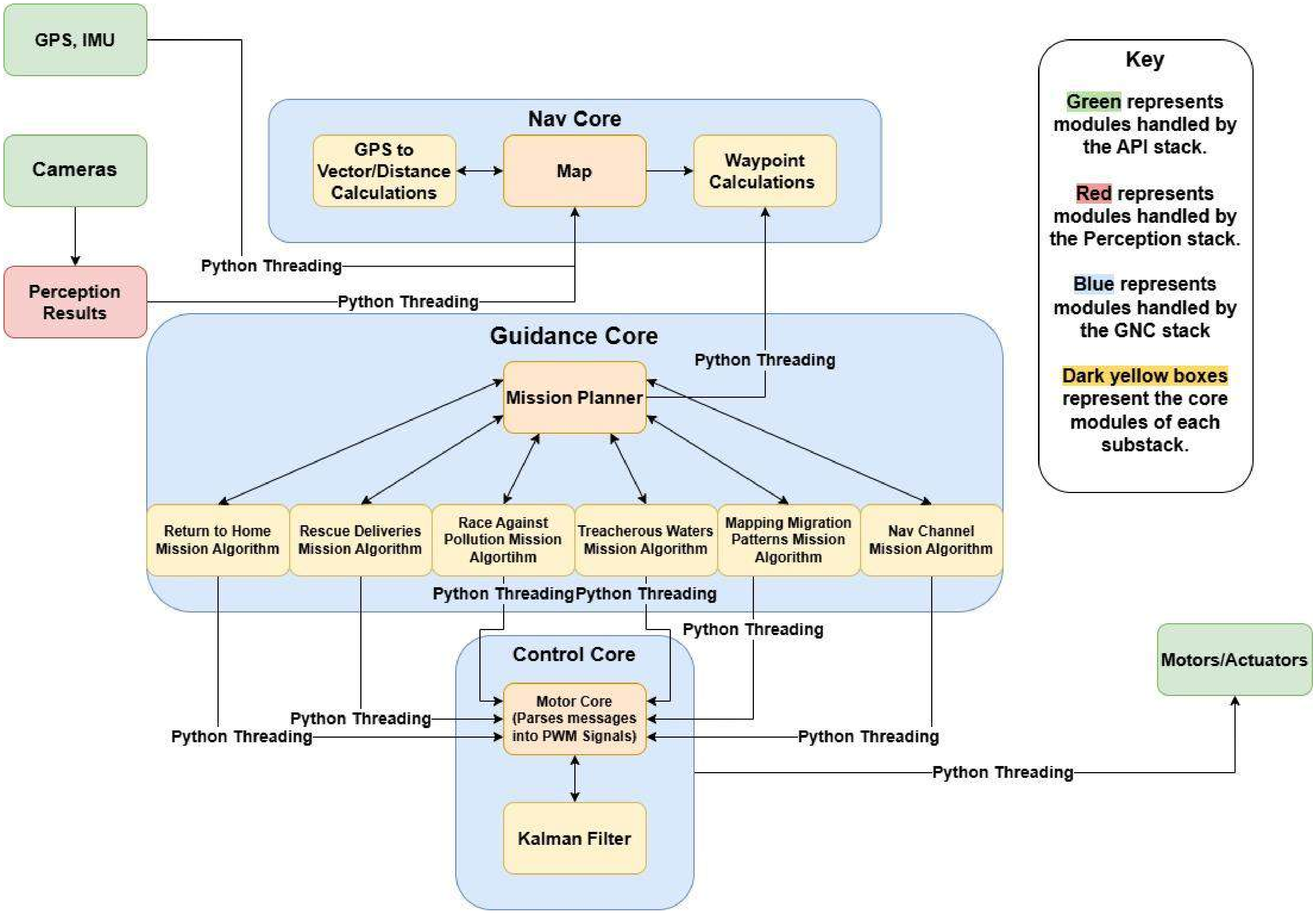

Fig. C.5: Diagram of the interconnections of the GNC substacks and how they integrate with the rest of the software system. Note the task separations for the navigation, guidance, and control stacks.

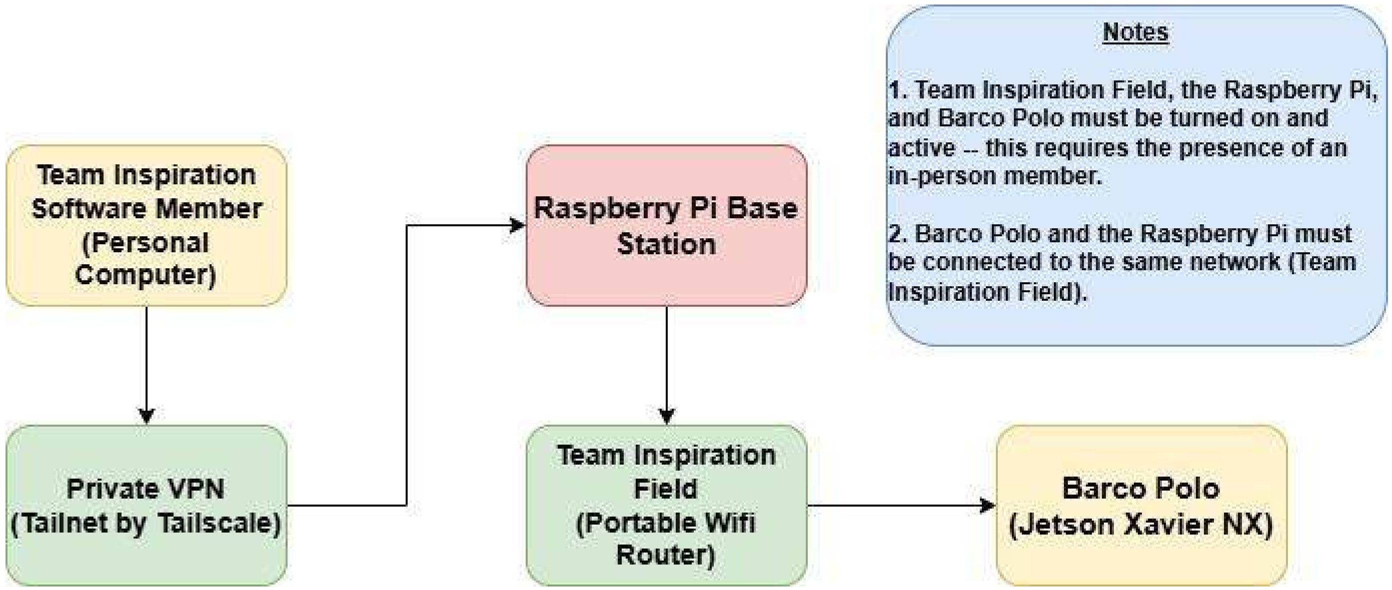

Fig. C.6: Team Inspiration's Virtual Private Network (VPN) setup supporting remote software development