Maritime Robotics - Autonomous, Unmanned, Multi-Domain Vehicles Challenge

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Abstract – **Team Inspiration collaborated with University of California San Diego's Triton-AI engaged seven capstone teams and high school students to prepare for the multi-domain RobotX challenge sponsored by RoboNation and Office of Naval Research. The team utilized RoboNation hosted International Aerial Robotics Competition (IARC), RoboBoat, RoboSub, platforms as training and prototype test beds to mature the RobotX system.**

The team focused on lessons learned from their first 2022 competition, enhancing the WAM-V software, firmware, electrical, and mechanical components to be an easy-to-maintain, more modular and reliable platform to build upon. The drone system enables autonomous navigation and mission performance using sensors, ROS-2 flight control and communication with the WAM-V.

After developing the basic foundations and new improvements, the team improved efficiency of bench and water testing to the point that the RobotX WAM-V and ground station testing can be deployed with a two person team with over 21 hours water time in addition to 100+ hours perception testing via RoboSub and navigation testing via RoboBoat. This paper describes how competition strategy influenced design strategy and the test methodology to ensure a viable RobotX system ready for competition.

I. Competition Strategy

The team focused on the main variables – the number of members, individual skills, and resources – to develop an actionable and sustainable competition strategy. As previous team members graduated, leadership within Team Inspiration worked with seven capstone teams to improve the system capabilities by making the electrical system modular, drone prototype and navigation with RoboBoat as a mini WAM-V. This enabled the team to focus on system design's knowledge and past competition experience to revamp the team's software architecture and mechanical design.

From the 2024 RoboBoat competition, it gave valuable insights into faults in the electrical and communications systems, and enabled smaller-scale perception testing, which allowed for parallel transfer of the RobotX perception software. The team recruited two capstone teams to focus on electrical subsystem improvement.

The 2024 RoboSub competition acted as a training ground for new Inspiration members to graduate directly into the RobotX competition, as participating members brought insights of computer vision, navigation and systems thinking to the WAM-V and drone. The team learned hydrophone implementation was beyond current schedule and resources. The gate mission will be accomplished without underwater beacon localization.

The 2024 International Aerial Robotics Competition (IARC) highlights the limitation of drone battery power by most teams. The team decided to pursue the UAV Replenishment mission in the future that resulted in a lighter drone design which extended power on time to support the boat missions.

Taking these variables in account, the team set their focus on strengthening the fundamentals: navigation and communication. The team settled on six missions: Entrance/Exit Gate, Follow the Path, Scan The Code, Wildlife Encounter, Dock and Deliver, and UAV Search and Reports missions.

II. Design Strategy

The team emphasized the systems engineering process of establishing clear requirements and collaboration between subteams. This enabled the usage of a crawl, walk, run approach as each system was individually bench tested, tested within sub systems, then fully integrated into the larger system.

A. Test Benches - RoboSub and RoboBoat

The team participated in other RoboNation competitions such as RoboSub and RoboBoat to expose new members to the competition timeline. We utilized these competition vehicles as test benches and trainers for students to learn about system integration and deployment of software.

B. WAM-V

1. Mechanical

a. Undermounted Payload Tray and Electronics Enclosure

Our mounting structure from 2022 featured an electronics enclosure mounted on the top of the payload tray. This required removal of the drone landing platform to make configuration changes, a nuisance during maintenance. The configuration of all electronics and sensors routing to the main enclosure meant extraneous noise from electrical components impacted our sensors, making it difficult to maintain accurate positioning. The driving requirement this year was ease maintenance and to isolate the electrical noise of high power systems from our sensitive electronics as positional awareness and navigation is paramount for autonomy. This is why the undermounted payload tray was the backbone of this year's competition strategy (see Fig. 1).

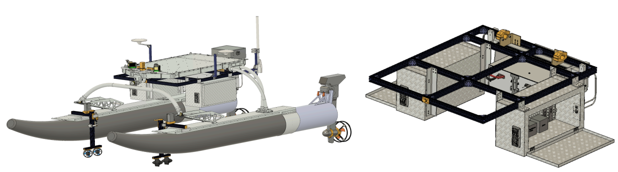

Fig. 1. Full system CAD model of the WAM-V (left), undermounted payload tray (right)

b. Front Vectored Thrusters

The position, hold, and sway maneuvers of the autonomous surface vessel (ASV) are paramount to enable our vehicle with superior maneuverability over a traditional differential thrust configuration when using only the aft thrusters. Our front vectored thrusters consist of four Blue Robotics T500 thrusters mounted towards the stern of the vehicle. By azimuthing the aft Torqeedo Cruise 2.0 thrusters coupled with the T500s the ASV is able to vary the target vector to navigate to waypoints while maintaining a specified heading.

c. Racquet Ball Launcher

The Racquet Ball Launchers use solenoids and custom air canisters made of schedule 40 PVC pipes that are 2 inches in diameter. The custom canisters are rated to ~200 psi, and a range of 20-40 psi would be adequate for launching the racquetballs. As test data shows, 20 psi corresponds to 7 meters in horizontal trajectory distance, which is 2 times greater than the intended horizontal distance of 2~3 meters (minimum distance between launcher exit and target in the horizontal direction). Testing was done to determine the adequate psi range by having the launchers at a 15 degree tilt as shown in Fig. 2. Data of psi and corresponding projectile distance is shown in Fig. 3.

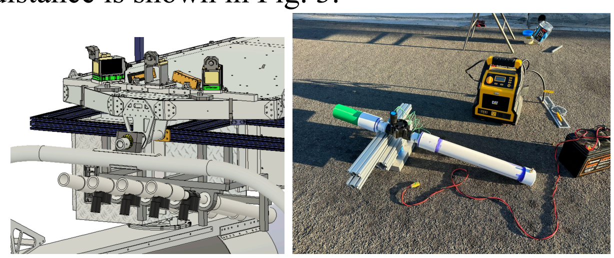

Fig. 2. CAD mockup (left), test setup of the launcher (right)

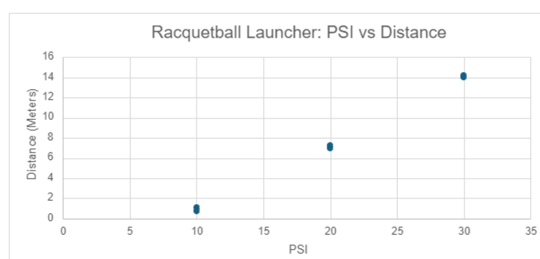

Fig. 3. Plot of PSI and distance of launcher test fixed 15°

d. Sensor Mounting

The team prioritized simplicity and modularity, utilizing the 80/20 extruded aluminum build system, giving the ability to create a bi-stable pivot mechanism for the main base station antenna. The mid differential GPS antennas are able to be installed in under three seconds. The forward perception rail is adhered to the payload tray with rivet nuts and 90° aluminum angle brackets. This construction enables a repeatability of placement of sensors (rail can slide in and out) while maintaining relative position between sensors.

2. *Electrical*

The team reflected on the previous sensitive electrical system and limitations in communication distance in RoboBoat to improve aspects in the WAM-V.

The team used the NVIDIA Jetson Orin AGX as the primary computer for the perception and guidance navigation control (GNC) software stack. It parses three camera streams, two LiDAR streams, and uses local and global path planning algorithms to determine the ideal real-time target vector. These vectors among other commands are sent to our low-level controller, a Jetson Nano which translates the vectors into direct motor control via PWM and serial commands. This approach enables an abstraction layer where the Jetson Orion AGX does not need to use its computer power for low level control, and adds a layer of safety by simplifying the control code that runs at the Jetson Nano.

With a revamped electrical system, the team emphasized safety and endurance. Our 2022 electrical configuration, contained over five separate batteries, the team now uses only two Torqeedo Power 24-3500 batteries in parallel with one central power distribution system. Our system has an endurance of 4 hours.

To isolate our core computational electronics, we developed a custom printed circuit board (PCB) that regulates our ~30V batteries into multiple clean 12V and 5V 10A rails. These rails power the entirety of our port-side electronics box using a single connector.

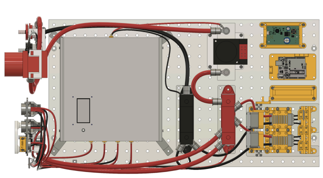

Fig. 4. Starboard side power distribution box

The regulator is housed within the starboard-side box which also features the high-power rails for our thrusters and a solenoid for killing the thruster power. The solenoid is triggered either externally by the push buttons on the corners of the ASV or remotely wirelessly by a custom PCB that uses LoRa to communicate with the ground station. The light status was also designed to be much simpler than 2022 and utilizes a programmable LED strip with an Arduino to detect and display a power-kill or switch between auto and tele modes.

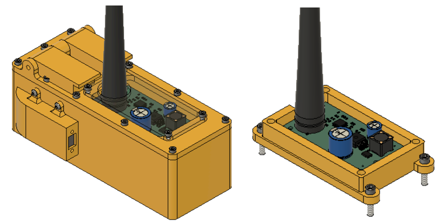

Fig. 5. Lora base station (left), Lora on ASV (right)

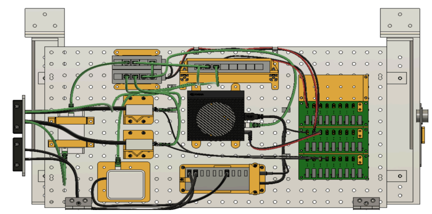

Fig. 6. Port side electronics box

Our port-side box holds a Orin AGX for our main computer and also the connections to 2 LiDARs and 3 cameras, allowing for a full 198.5 degree panoramic view of the front of the boat. There are 3 network switches to support the various devices and enable communication to our ground station as well as to the Jetson Nano housed in our onboard control box (OCB) which is our low-level interface to control the motors.

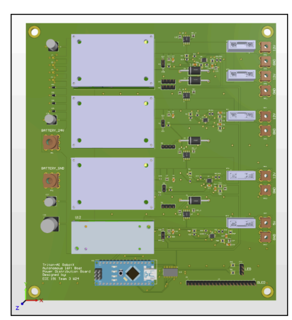

Fig. 7. Main power distribution board

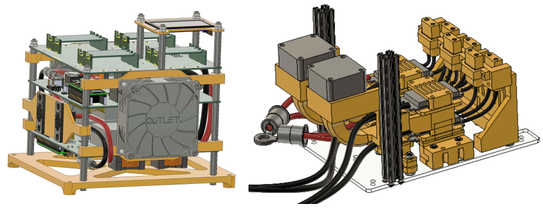

Fig. 8. ESC power distribution board (left), direct ESC mounting included forced convection cooling (right)

The team sought to maintain the life of our forward vector thrusters with a new Electronic Speed Controller (ESC) regulation board. Previous implementations utilized adjusting the PWM and duty cycles of the ESCs to keep the motors within an appropriate voltage range, but this wasn't ideal. So this year we leveraged a capstone team to develop a custom PCB with switching regulators capable of delivering over 100 amps at 25V and other safety monitoring systems. However, due to scheduling, the team was not able to implement the new power distribution board for the ESCs and reverted to the previous configuration in the interest of time.

C. Drone

The drone system integrates multiple sensors: camera, gps, barometer, inertial measurement unit (IMU), communication systems, and control systems to enable autonomy. The drone utilizes a three pronged approach in localization: RoboFlow enables machine learning to localize against missions models of search and report and replenish tasks, april tags to localize to land back on the ASV, and computer visions to localize search and report missions.

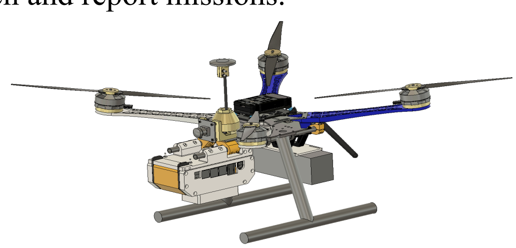

Fig. 9. Simplified drone

The core of the drone control is an API (application programming interface) which is responsible for executing flight commands like arming and powering off as well as switching between the different flight modes (loiter, guided, land). It also is responsible for sending the velocity commands to control the movement of the drone.

In order to accomplish precise and accurate landing, we are using Aruco Markers/ April Tags. Using an open source computer vision library (OpenCV), we can detect the marker and find the drone's relative position and orientation to the target image. The perception node on the onboard computer continuously processes the camera feed and detects for the correct Aruco Marker and calculates the distance and angle from the camera to the marker, from there we compute heading. Using the Drone API commands, the drone then centers itself about the April Tag and is prompted to land.

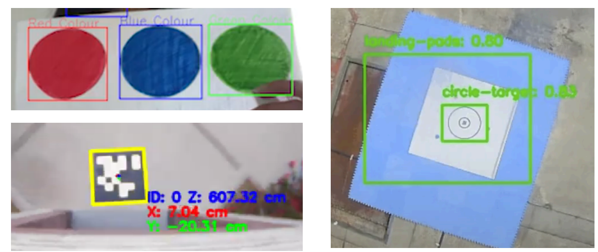

Fig. 10. Computer vision, April Tag, machine learning implementation

In order to communicate with the ASV, the Drone utilizes the RFD900+ modem paired with the Jetson GPIO pins. This modem is capable of line of sight data transceiving and is a proven reliable wireless solution. The Jetson Nano, equipped with GPIO pins, acts as the drone's onboard computer which processes the communication between the ASV and the drone. We adhere to competition safety requirements with an override as well as a switch to enable inter vehicular communication.

D. Software Development across Multiple Domains

1. Perception

We use 3 cameras on the front of the vehicle, each with 120 deg FOV at different angles from each other. One is centered while the other two are pointed 39.25 degrees away from the center. This enables a complete 198.5 degree panoramic view of the front of the ASV since the FOVs overlap. Within the software stack, each camera can run a separate machine learning model and have its own computer vision layered on top of it (based on what the mission needs). Additionally, there is a LiDAR mounted under both the port and the starboard cameras. This arrangement of LiDARs also enables a full panoramic view of the front of the boat. To handle the heavy processing of the LiDARs, we built a C++ stack focused on linear matrix operations that both stitches the lidars, and also builds an occupancy grid of the environment.

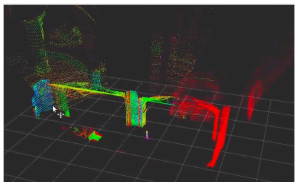

Fig. 11: Port and Starboard LiDAR Output

Using a transformation matrix, we are able to map pixels on the respective camera views to a distance given by the LiDAR data, allowing for accurate object detection and positioning enabling sensor fusion. The overall perception stack is combined into a single Python package which can process and access all the respective data, while providing a clean interface for anyone to program with.

A key aspect of the team's perception system was the necessary LiDAR-camera calibration. Proper calibration is critical to ensure that the 3D point clouds from the LiDAR and the 2D images from the camera are aligned in space, allowing for precise tracking and sensor fusion.

The team's LiDAR data is preprocessed by applying a voxel grid filter to downsample the data and remove outlier points. This preprocessing was crucial for accurate alignment and quick processing by ensuring that only relevant and significant points were considered.

For the team to align the point cloud data, they used the Iterative Closest Point (ICP) algorithm due to its balance between accuracy and computational efficiency. The ICP worked by iteratively finding the alignment between the point cloud and the 2D image that minimizes the distance between the center of mass and the selected points.

2. Low-Level control

The OCB uses a Jetson Nano which houses all of the low-level control code. The control code is designed to be a single program acting as a client that has the capability to translate high-level vector commands from the Orin AGX into direct thruster control. It has a sensor fusion stack using a Kalman filter for combined GPS and IMU data. The low-level control code has many capabilities such as vector command translation, position hold, and waypoint missions. For safety purposes, the controller will time out after 10 seconds without input from the Orin AGX. To enable all this functionality, the control code uses a custom-developed protocol over TCP/IP to talk to the Orin AGX over ethernet. The control code reports its current position and telemetry data to the Orin AGX and receives high-level commands on the same network.

3. Guidance Navigation Control (GNC)

Through the occupancy grid computed using the LiDAR stack, we use the principle of a polarity field to perform our local path planning and obstacle avoidance. This is where detected objects can be marked as obstacles and emit a repulsive force on the ASV while other objects marked as goals emit attractive forces. The sum of these vector forces on the ASV provide the ideal unit vector for the ASV to travel.

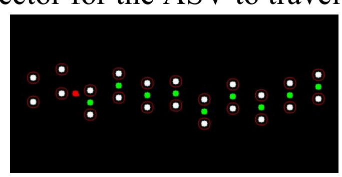

Fig. 12. Polarity field around buoys (red) represents current position (green) represents desired position

The GNC runs on the Orin AGX and inputs the data from the Jetson Nano running in the OCB. A separate ROS node allows for processing of LiDAR and positional data, building an occupancy grid as the ASV travels for quick access to the current surroundings, allowing the ASV to navigate diverse environments.

Fig. 13. Occupancy grid with overhead view and visual noise of data from moving fishing vessel

III. Testing Strategy

It is close to impossible when asking for permission to test autonomous vehicles in public venues like lakes and bay. The team leveraged most testing in bench testing and pool testing with the RoboBoat and RoboSub. In addition to water testing, the team also used simulation software, ROS Gazebo, to gain results for smaller increments of the system testing. These tests allowed for efficiency in system development and improvement, which were conducted in parallel.

The team gains access to Lake Miramar by building community relationships educating visitors, rangers, and local TV media of the benefits of STEM education. The team briefs rangers about test plans, remote shutdown capabilities, and kayakers following the ASV to conduct tests in a safe manner. With many team members working remote and on different calendars, the team was able to transport WAM-V from the lab, set up ground communication and launch the ASV with 2 people including a kayak as an emergency safety and tow vehicle.

Fig. 14. Circular error probable (CEP) navigation is accurate under 0.1 m with no oscillation if waypoints are >2 m apart (left), but oscillates heavily when <2 m (right).

The team placed a large emphasis on weekly constant and efficient water test planning in order to achieve results and rapid development. The team conducts hotwash after each test to capture lessons learned and apply them to the next development and test activities (Refer to Appendix B for the test plan).

IV. Acknowledgements

The team would like to thank the sponsors below especially our primary sponsor, Advancing Science, Technology, and Art:

Funding support -

- *Diamond level*: Advancing Science Technology and Art, Gilman Charitable Fund, HP, Qualcomm, and Qi's family.
- *Platinum level*: Intuit.
- *Gold level*: Tinyvision.ai, and Medtronic.
- *Silver level*: Blue Trail Engineering, Hologic, Chris Freeman, Tang's family, and San Diego Foundation.
- *Bronze level*: UC San Diego.

Resource support - Nvidia, Blue Robotics, Kenautics, Leverett Bezanson, SolidWorks, JetBrains, Vinatech Engineering, MathWorks, RJE International, and ePlastics.

Team Inspiration and Triton-AI members are grateful to their mentors who helped to review their work and provide guidance throughout the competition: Alex Szeto, Jack Silberman Ph.D., Amit Goel, Venkat Rangan, and Teresa To. We would like to thank all of the University of California, San Diego's capstone students. We appreciate RoboNation and the Office of Naval Research for providing a WAM-V for our team in 2021 and believing that we were ready to compete in RobotX. Lastly, we are indebted to our parents for their constant support.

V. References

None.

Appendix A: Component List

Component	Vendor	Model / Type	Specs	Custom / Pur-chased	Cost	Year of Purchase	Reasoning
Water Resistant Connectors	ZBLZGP	WS28 8 Pin Aviation Circular Metal Power Electrical Connector	https://www.amazon.com/gp/product/B0BN19LJB1/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&th=1	Pur-chased	$201.75	2024	Enable quick disconnect of cable from enclosure
Propulsion	Torqeedo	Cruise 2.0	TORQEEDO Cruise 2.0R Electric Outboard, Long Shaft, Remote Steering | West Marine				
	Blue Robotics	T500 thrusters	Max thrust: __ https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t500-thruster/				
Battery, Converter, Regulator	Torqeedo	Power 24-3500	Power 24-3500 Battery - Torqeedo	Purchased		2021	
	ECE 191 SP24 Capstone Team	ESC POWER DISTRIBUTION	https://github.com/InspirationRobotics/RX24-ESC	Custom		2024	
	ECE 191 WI 24 Capstone	Port Side Power Distribution Board	https://drive.google.com/file/d	Custom		2024	

	Team		/1eF3yxodIE5dhTbWAyZee0Z3hr7-Dw6lf/view?usp=drive_link				
CPU	Nvidia	Nvidia Jetson Nano	1.4 GHZ clock speed 4 GB RAM	Purchased	$99.00	2021	
	Nvidia	Nvidia Jetson AGX Xavier	https://developer.nvidia.com/embedded/jetson-agx-xavier-developer-kit	*Donated by a sponsor*		2021	
	Nvidia	Jetson Orin AGX	Jetson AGX Orin for Next-Gen Robotics | NVIDIA				
Tele-operation	WAM-V						
GPS	Beitian	BT-982K1	https://store.beitian.com/products/beitian-built-in-zed-f9p-navigation-surveying-positioning-precision-agriculture-centimeter-level-rtk-gnss-module?variant=44850918097183&srsltid=AfmBOorN7v7z0XQPK2e_LUXybN_KS1rPr2Z0nn2tpdi7iqxNd-jMn_Ox	Purchased	$200.88	2024	

Inertial Measurement Unit (IMU)	Pixhawk	Invensense® MPU 6000 3-axis accelerometer/gyroscope	32-bit ARM Cortex M4 core with FPU 168 MHz/256 KB RAM/2 MB Flash 32-bit failsafe co-processor	Legacy		2019, 2022	
LiDAR	Livox	Horizon LiDAR					
Camera(s)	Arducam	1080P Low Light WDR Ultra Wide Angle USB Camera Module	Arducam 1080P Low Light WDR Ultra Wide Angle USB Camera Module for Computer				
Hydrophones	Custom	Hydrophone Circuit	100kHz sample rate for DTOA analysis. Variable gain control. 1-40kHz frequency lock range. Sub-watt and sub-degree precision under ideal conditions.	Legacy	$314.77	2020	
	Aquarian Audio & Scientific	AS-1 Hydrophone	Linear range: 1Hz to	Legacy		2019	

			100kHz ±2dB Horizontal Directivity (20kHz): ±0.2dB Horizontal Directivity (100kHz): ±1dB Vertical Directivity (20kHz): ±1dB Vertical Directivity (100kHz): +6dB -11dB				
Algorithms (acoustics)	Custom	Fast Fourier Transform (FFT)	Redundant		Free	2020	
Vision	Custom	Open Computer Vision (OpenCV)	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	
Localization and Mapping	In-house	Custom	GPS, LiDAR, Hydrophones, CV		Free	2021	
Autonomy	In-house	Custom	Mission		Free		

			planner				
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	
Drone Frame	Readytosky	Readytosky S500 Quadcopter Frame Stretch X FPV Drone Frame Kit PCB Version with Carbon Fiber Landing Gear	https://www.amazon.com/dp/B01N0AX1MZ?ref_=cm_sw_r_cp_ud_dp_ATSB4VEH9JZ50HC7M2SN	Purchased	$48.99		
Drone Motors	Tarot	Tarot TL68P07 6S 380KV 4108 Multi Rotor Disc Brushless Motor for DIY Quadcopter FPV Drone	https://www.amazon.com/dp/B01G3KIHS2?ref_=cm_sw_r_cp_ud_dp_Y6PFV8K7RSPQTGMZ2RGA	Purchased	$148.88		
Drone Flight Controller	SoloGood	Pixhawk PX4 PIX 2.4.8 Flight Controller NEO-M8N GPS 3DR 915Mhz Radio Telemetry Set OSD Module PPM Module I2C Splitter Expand Module Power Module for FPV	https://www.amazon.com/dp/B07NRMFTXL?_encoding=UTF8&psc=1&ref_=cm_sw_r_cp_ud_dp_RGEHDQQMBX8C6MYTW7YZ	Purchased	$209.99		

		Quadcopter Multirotor					
Drone ESC	Readytosky	Readytosky 35A ESC 2-6S Brushless ESC Lipo BLHeli_S Brushless Electronic Speed Controller Support D-Shot 150/300/600 for FPV Drone RC Helicopter Quadcopter	https://www.amazon.com/dp/B0C77JSR14?ref_=cm_sw_r_cp_ud_dp_X0C95TGGE74YK5MWQAHK&th=1	Purchased	$39.99		
Drone Propellers	KingVal	2 Pair KingVal Replacement T-Series 1255 Carbon Fiber Prop Propeller CW/CCW Compatible with RC Drone Quadcopter	https://www.amazon.com/dp/B096JQPM6J?psc=1&ref=ppx_yo2ov_dt_b_product_details	Purchased	$17.88		
Drone Perception	Arducam	Arducam 1080P Low Light WDR Ultra Wide Angle USB Camera Module for Computer, 2MP CMOS IMX291 160 Degree Fisheye Mini UVC USB2.0 Webcam Board with Microphone	https://www.amazon.com/dp/B07ZS75KZR?ref_=cm_sw_r_cp_ud_dp_GT05N9XQCPJ27PYR72SF&th=1	Purchased	$49.99		
Drone Power	ELNONE	USB Type C Pigtail 2 Wire Left Right Direction,0.3M/1 Ft 22AWG 5V 3A USB C to 2	https://www.amazon.com/dp/B0CL7S9C5G/ref=sspa_dk_detail_1?pd_rd_i=B0CL	Purchased	$7.99		

		Pin Bare Wire Open End Wire Power Pigtail DIY Cable with Quick Wire Cable Connector	7B6GDN&pd_rd_w=4kxh9&content-id=amzn1.sym.f734d1a2-0bf9-4a26-ad34-2e1b969a5a75&pf_rd_p=f734d1a2-0bf9-4a26-ad34-2e1b969a5a75&pf_rd_r=PE1C5ZG78MFZWKAPG6FC&pd_rd_wg=3kOn9&pd_rd_r=d04d7bef-d8e1-41e3-a6ec-6ff77849c38c&s=industrial&sp_csd=d2lkZ2V0TmFtZT1zcF9kZXRhaWw&th=1				
Drone Regulator	Matek Systems	Matek UBEC DUO, 4A/5~12V & 4A/5V	https://www.readymaderc.com/products/details/matek-ubec-duo-esc-4a-12v-5v	Purchased	$19.99		
Drone Remote ID	Holybro	Remote ID	https://holybro.com/products/remote-id?variant=43034167279805		$29.59		
Drone Battery	HRB	HRB 6S 5000mAh Lipo	https://www.amazon.		$55.24		

		Battery XT90 50C-100C 22.2V RC Lipo Battery Compatible with RC Quadcopter Helicopter Airplane Car Boat Truck	com/gp/product/B0719DNTM4/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1				

Appendix B: Test Plan & Result

<table>
<tr><td colspan="4" rowspan="2">WAM-V Test Waypoint Navigation- Legacy</td><td colspan="3">Approval Authority</td></tr>
<tr><td>Eesh Vij
(Team Lead)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Date: 2024-07-06</td><td colspan="5">Mission Title: Autonomous at Fiesta Island</td></tr>
<tr><td colspan="2">Test #: 2</td><td colspan="3">Location:
Ramp 1
S Shores Pkwy, San Diego, CA 92109
yelp</td><td colspan="2">Risk: Medium (will be carrying camera, Jetson, and LiDAR)</td></tr>
<tr><td colspan="2">Software Version: legacy (ROS)</td><td colspan="3">Hardware Sensors Mounted: GPS</td><td colspan="2">Hardware Sensors Used: GPS</td></tr>
<tr><td colspan="7">Scope: <u>Primary:</u> GPS Testing | autonomous waypoint navigation code
<u>Secondary:</u> mounting Antennas + comms - Live stream of the data as it is being collected back to the base station | Testing camera feed and collecting data for model
<u>Tertiary:</u> Testing LiDAR feed and collecting data to analyze
<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></td><td>Ground</td><td></td><td>Packup</td><td>7:00</td><td>8:30</td></tr>
</table>

Boat Launcher		**Pool Deck**		**Go to Lake**	7:50 am	9:47
Ground Control		**Chase Boat**		**Test**	8:30 am	10:23
Data Collector		**Tether**		**Cleanup**	9:00 am	
Photographer				**Leave Lake**	9:30 am	13:23
Safety Checker/QA				**Put Away**	10:00 am	
Remote Control				**Hot Wash**	10:30 am	
Status						
Weather		GO/NO GO				
Boat		GO/NO GO				
Attendance						
	Resources Needed: Life vests for person deploying the boat and people in canoe Canoe to toe the boat back if required 17 mm socket wrench (11/16 imperial is close) O-rings for torqeedo thrusters manual					

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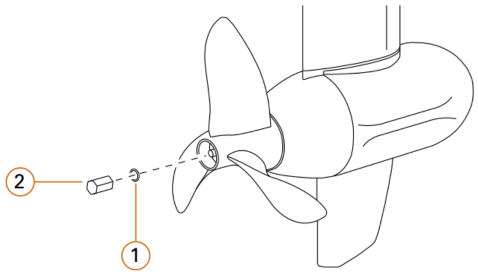
Installation



1. First position a new O-ring (1) on the motor shaft.

NOTE! Component damage due to thread locking varnish. Do not use locking varnishes or additives.

2. Screw the new galvanic anode (2) onto the motor shaft and tighten it.
- Galvanic anode: 7+/- 1 Nm, 62+/- in-lbs

10.4.4 Propeller

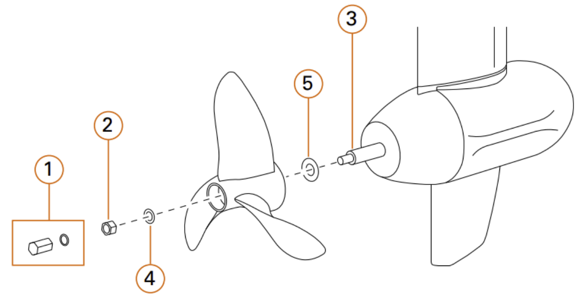
DANGER

Danger of injury or death from rotating propeller. This can result in sever injuries or death.
- Switch off the system at the battery main switch and secure it against being switched on again by pulling off the switch handle to prevent the propeller from starting.

Checking

1. Switch off the system at the battery main switch and secure it against being switched on again by pulling off the switch handle.
2. Check the propeller for damage such as cracks, chipping and deformation.
3. Check the gap between the pylon and the propeller for foreign objects, e.g. fishing lines, seaweed, etc. Wear gloves when doing this to avoid injury.
4. Dismantle the propeller to remove any contamination.

Disassembly



TIP! Remove the propeller when the motor is attached to the boat and the boat is safely on land.

1. Ensure that the motor is securely fastened and secured against falling (e.g. e.g. on the boat or on a workbench).
2. Remove the galvanic anode (1).
3. Loosen the lock nut (2) with a socket wrench SW17 and unscrew it from the motor shaft (3).
4. Remove the washer (4).

NOTE! Component damage due to incorrect tool. Do not use force or tools such as hammers to remove the propeller.

5. Pull the propeller off the motor shaft, move the propeller in different directions to make it easier to pull off.
6. Remove the thrust washer (5).
7. Clean the motor shaft.
8. Clean the thread of the motor shaft.

Water Time RobotX (Water time logging)

Software command lines	**GPS Navigation:**

#	Validation Step Description	Expected Result	Reference to Data	Pass/Fail
1	**Pre-lab departure**			
2	Ensure checklist items completed	pass	Check list below	
3	Power on, motor, remote check	pass		
4	Kill switch safety check	pass		
5	Remote control kill safety check	pass		
6	Check port IDs of GPS and Teensy by unplugging each and typing ls /dev/tty*			

	Ensure that GPS and communication antennas are stowed down (will not crash into the arch of the garage)			
7	Assign roles	pass		
8	Walk around the boat before driving to ensure no loose items	pass		
9	**Launch parking lots check up**			
10	Ensure the boat is ready to go into water. Clean up the trailer	pass		
11	Power on, motor, remote check	pass		
12	Take the boat to ramp with safety personnel	pass		
13	Ensure the boat is tether	pass		
14	Turn On thrusters, power assist getting off of the trailer	pass		
15	Tie the boat down to the dock	pass		
16	Drive the trailer back to the parking lot	pass		
17	Deploy safety kayak	pass		
18	Check the boat one more time on all power system, and the waterline	pass		
19	While tether - drive the boat forward	pass		
20	While tether - drive the boat backward	pass		
21	Ensure the safety kayak is in the water	pass		

22	**Boat launch from the dock**			
23	Test drive the boat with RC control	pass		
24	ssh jetson@ip-or-dns			
25	Verify GPS data is being received python3 nmea_reader.py Ctrl+C to kill the program	pass		
26	Stay in RC mode and pilot the boat to collect 4 waypoints on laptop notepad python3 navigator.py			
27	Hit Ctrl+C to kill the program, please!			
28	Log GPS points in lat_lon.txt as follows: nano lat_lon.txt Format: lat1-space-lon1 lat2-space-lon2 etc. Make sure no extra lines on the bottom	pass		
29	python3 navigator.py	pass		
30	If boat steering too much back and forth, increase angle threshold; if boat steering too little, decrease angle threshold			
31	Back to dock when testing is done	pass		
32	Tether the boat	pass		
31	**Get the boat ready out of the water**			
32	Drive the trailer back to water with safety personnel	pass		
33	RC the boat to the trailer	pass		

34	Tie down the boat	pass		
35	Raise the motors	pass		
36	Park the kayak back on trailer	pass		
37	Drive the boat to parking lot	pass		
38	**Pre-departure from test site**			
37	Ensure all items are load	pass		
38	Tie down the boat and all items - walk around the trailer	pass		
39	Ensure all team members on vehicle	pass		
40	**Back to the lab**			
41	Ensure all items and boats are wash and clean	pass		
42	Back the boat to the garage and ensure the trailer is properly secure	pass		
43	Ensure all things are stored back to proper location	pass		
44	Hotwash - meetings of all team members to reflect on the test events	pass		
…				

Maneuvers

		Start time (24 hr format)	End time (24 hr format)	**Description**
0	**Acceleration data while we are driving the car to the lake**			
1	**Straight line (forward 3 meters)**			
2	**turn cw (differential)**			
3	**Turn ccw (differential)**			
4	**Box cw (steering)**			
5	**Box ccw (steering)**			
6	**U turn cw (differential) 3 meters straight**			
7	**U turn ccw (differential) 3 meters straight**			

WAM-V Checklist

Some Safety-Related Housekeeping

- Do Not stand on the boat
- Do Not get on top of the trailer behind the wheels without two chairs to support
- Don't drag the boat on the ground
- Stay close to one end of the boat ramp
- Someone keep an eyes on the car when moving away from launch area - don't stay in the back
- DO NOT leave the life jackets, first aid kit and AED at the lab

Night before launch

- Note modifications to WAM-V and mounted systems
- Charge FRC batteries (lead acid)
- Note propeller models of the Torqeedo motors
- Use voltmeter to check/record battery voltage
- Assure fasteners tightened, have not sustained damage
- Check the electronics:
    - radio, camera, GPS
    - Batteries
    - Electronics box
    - LiDARs
- Look for damage on both port and starboard sides
    - Hull, skis and can, hinges, foot (lazy susan), suspension, pods
    - Front/rear arches
    - Payload tray
    - Retractable sonar mount (if applicable)
    - Steering system & motors
    - Data & battery cables
    - Onboard Control Box (OCB)
    - 3 safety lanyards, 12 push button Quick Release Pins (QRP)
- Hull pressure b/w 2.0-2.5 psi
- All electronic/mechanical payloads bolted in/attached properly (except for things to be ratchet strapped)

Before leaving

- Systems in good condition
    - WAM-V and pods secured to trailer
    - Ball & hitch secured
    - Trailer safety chains, brake lights, turn signals, pack docking lines & fenders, mast folded

Bring (LIST OF PARTS)

Name	**Quantity**
Inflator Pump with Valve Adapter	1
Wing Hull Repair Kit	1
3 oz. Grease Gun	1
3 oz. Marine Grease Cartridge	4
MAR spring suspension adjustment nut	1
Operator Control Unit (OCU)	1
IP Radio (with antenna)	1
GPS Antenna with Mast Mount Ground Plates	2
Onboard Control Box (OCB)	1
Bi-Color Navigation Lights (port and starboard)	1
All around Navigation Light	1
Torqeedo 2.0 Outboard Motors w/ rudder actuator, wiring harness	2
Torqeedo Propeller, V13	2
Torqeedo Propeller, V20	2
Torqeedo Batteries	2
Battery Connector Cables (Black)	3
Battery Connector Cables (Red)	3
Battery Data Interconnect Cable (Short)	2
Battery Ratchet Straps	2
Torqeedo Controller Head	2
Torqeedo Battery Fast Charger	1
Torqeedo Battery Charger Cable	1
Suspension Adjustment Tool	1
Operator Radio Batteries	2
Operator Radio Stand	1

T-9 Lubricant	1
Dielectric Grease	1
Cable Tie Kit	1
Socket Wrench Kit	1
Giant Socket Wrench	1
WD-40 (FOR TRAILER NOT BOAT)	1

- 2 laptops - Make sure they are configured for the test and have q ground control

Chase Boat and Bouys ()

- Red Boat Box
    - Floatation device for tools (pool noodles and string)
    - Black Inverter
    - air pump
- FRC car battery or marine batteries
- 4 Buoys (check that inside cloth buoys that there is a float tube and the pvc pipes)
- Extra float tube
- 4 anchors tied to 50 ft long rope
- Kayak (yellow waterproof bag)
    - **2** seats
    - **2** sets of oars
    - **2** Life vests

Perception Gear (Eesh's car)

- **2** Livox LiDARs
- **2** Oak D Lites
- Microfiber cloth & glasses cleaner
- Perception Rail
- **2** GPS
- GPS Antenna
- RTK and Radio Pelican Box
    - RTK
    - Radio
- motor control throttle head
- Drone
    - Remote controller
    - AprilTags
    - Battery

Electronics (Coach Alex's minivan)

- Mini to micro USB
- Gray electronics box to go on boat

Ground (Coach Alex's minivan)

- **1** Table
- **2-4** chairs
- Canopy
- Generator and gas tank
- AED/CPR Kit
- Scuba gear (goggles, fins, snorkel, air tank, regulator)
- Logistics Pelican Box
    - **6** Walkie talkies
    - Battery beak for the FTC slim batteries
    - **2** FTC slim batteries to power fans (in addition to RoboSub batteries)
    - Extra tools go in this box

        - reusable zip ties
    - Black rolling box
        - WAM-V boat remote controller
        - **2** Computer covers
        - **3** towels
        - Extension cord & black power strip that has usb ports
        - Orange inverter
        - First Aid Kit
        - Boat License/Permit ($7 for boat $2 for Kayak for Lake Miramar)
        - RTK Tripod

Boat (car towing the boat)

- Green boat box
    - Ratchet straps
    - Winch crank for the trailer winch

<u>Before launching</u>

- "Alert local USCG Command Center to report vehicle activity"
- Pods attached securely
- Vehicle restraints removed
- Power on control box
- "Docking lines and fenders"
- Low-level function checks (copy-pasted)
    - Port actuator moves to port and starboard
    - Starboard actuator moves to port and starboard
    - Port motor thrusts to forward and to reverse
    - Starboard motor thrusts to forward and to reverse
    - E-Stop functionality
- Motor pods fasted to hinges, "hinge handle locking pins" in place
- Steering shaft greased
- Shock absorber in good health
- Quick release pins engaged, undamaged, lubricated
- Hinge system greased, closed with locking pin installed

<u>Cleanup</u>

- Procedure 1 (retrieval)
    - Tow the trailer down the launch ramp, submerge to depth sufficient to load WAM-V
    - Manually align WAM-V with submerged trailer
    - Slowly drive WAM-V until front arch engages trailer stop bars
    - Slowly pull WAM-V and trailer out of water
        - Ensure each WAM-V hull settles into the bunks
        - If WAM-V fails to settle, back up trailer to adjust
    - After WAM-V & trailer out of water, shutdown (the WAM-V)
        - Don't let anything get close to propellers
    - Secure WAM-V to trailer

- Procedure 2 (Towing)
    - Attach towing bridle to tow point connections on fore-inboard side of skis (and **not anything else**)

Slimmed Down Checklist
5/32 hex
11/16 or 17mm socket
19 mm socket
Multimeter
Zip Ties (reusable)
snips
QTY 2 + sets of ratchet straps
Side foam
Walkie talkies

Description of the day

	zone	
0947		Began measurement data of linear acceleration during transit axis data
10:23	A	Stopped the measurement data from acceleration
10:50	A	setting up heading offset (antenna 1 corresponds to port and antenna 2 corresponds to starboard). Need to install **coin cell battery** onto the Jetson to ensure tracking system time. Required for gps logging Github to gps script (GPS script logs lat long and heading at each time increment) GPS are mounted on undercarriage ends (61 inches ~ 155 cm +- 3 cm) The heading (using the compass app was ~290) The heading on first init of the GPS was 19

		Utilized a gps offset of -93 to move ccw around the unit circle to match the heading from the differential gps to the compass app on iphone
11:19	B > C	Started script for data logging test 1 transit to zone C
11:35	C > D	Run 1 (can see moment that control loses comms with boat) Undocked and performed maneuvers the antenna was horizontal and not vertical, may have caused reduced range of connection Straight line Turn cw Turn ccw Box ccw Box ccw
11:40	D	This is the time that the controller was erroring out due to low battery
11:43	C	brought back to dock to stop the script and save the data
12:37	D	Run 2 (left the script running until pulled the ASV out of the water)
13:23		Leaving lake ~10 minutes before hand stopped script)

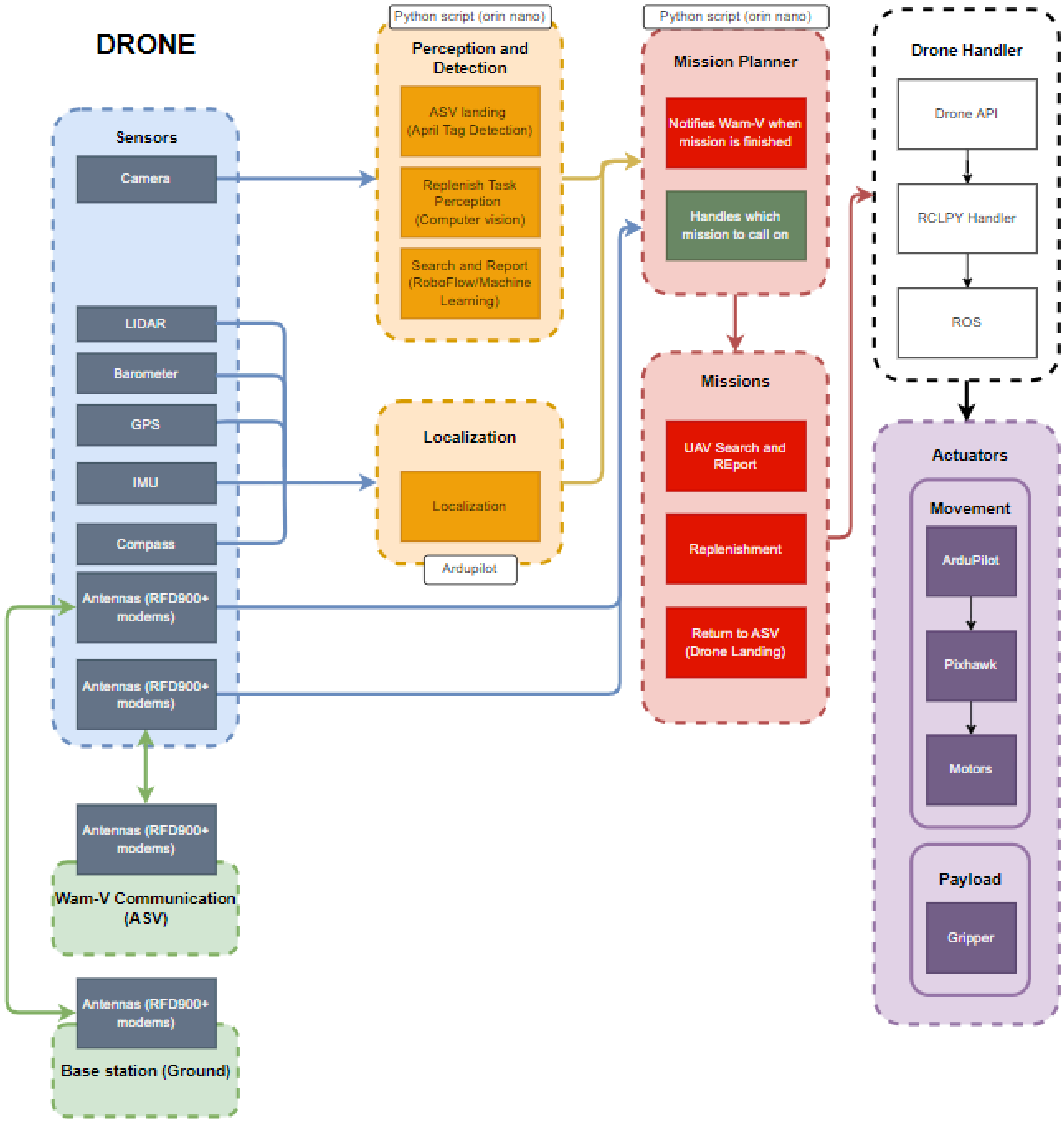


Fig. 15. Drone high level system architecture

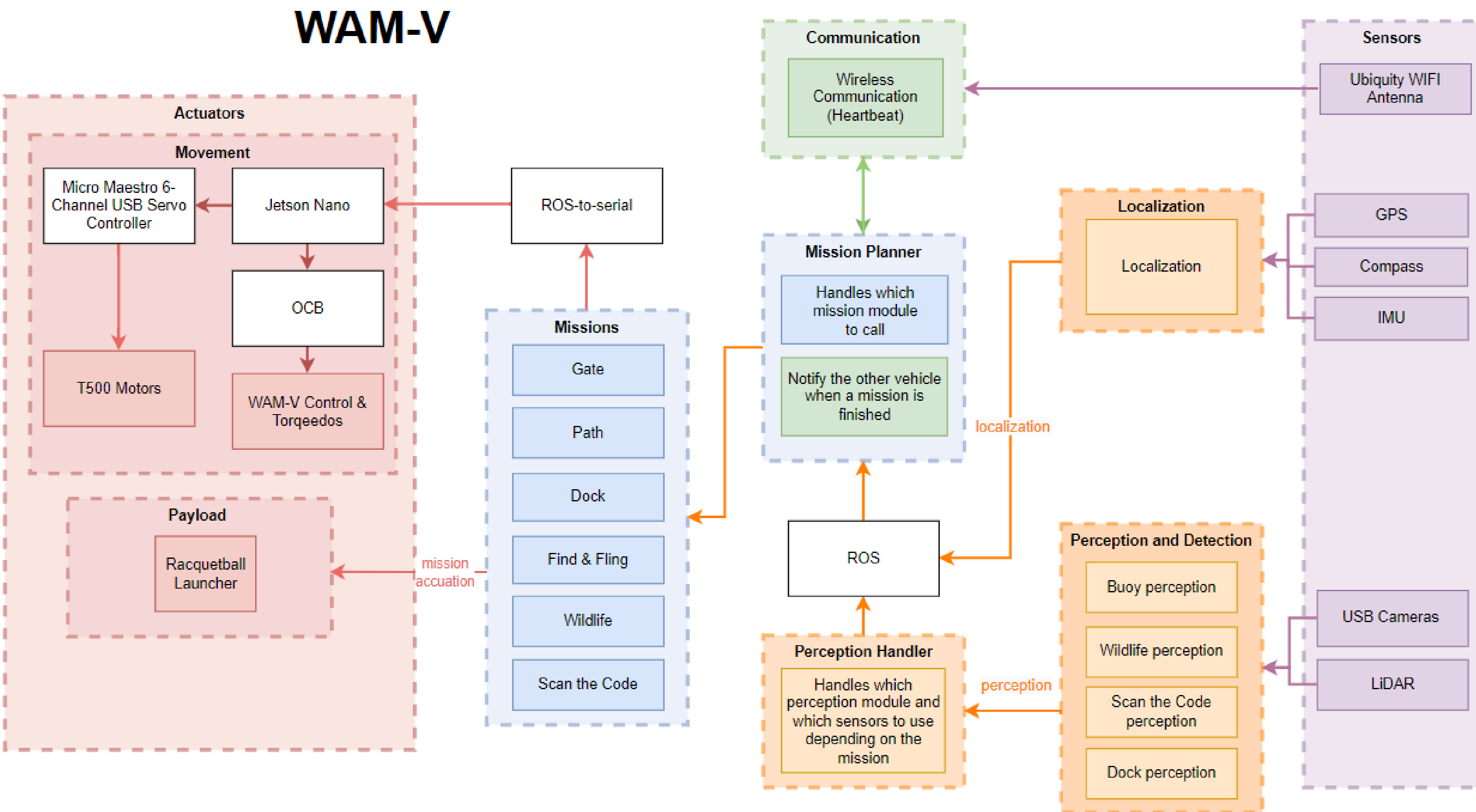


Fig. 16. WAM-V high level system architecture

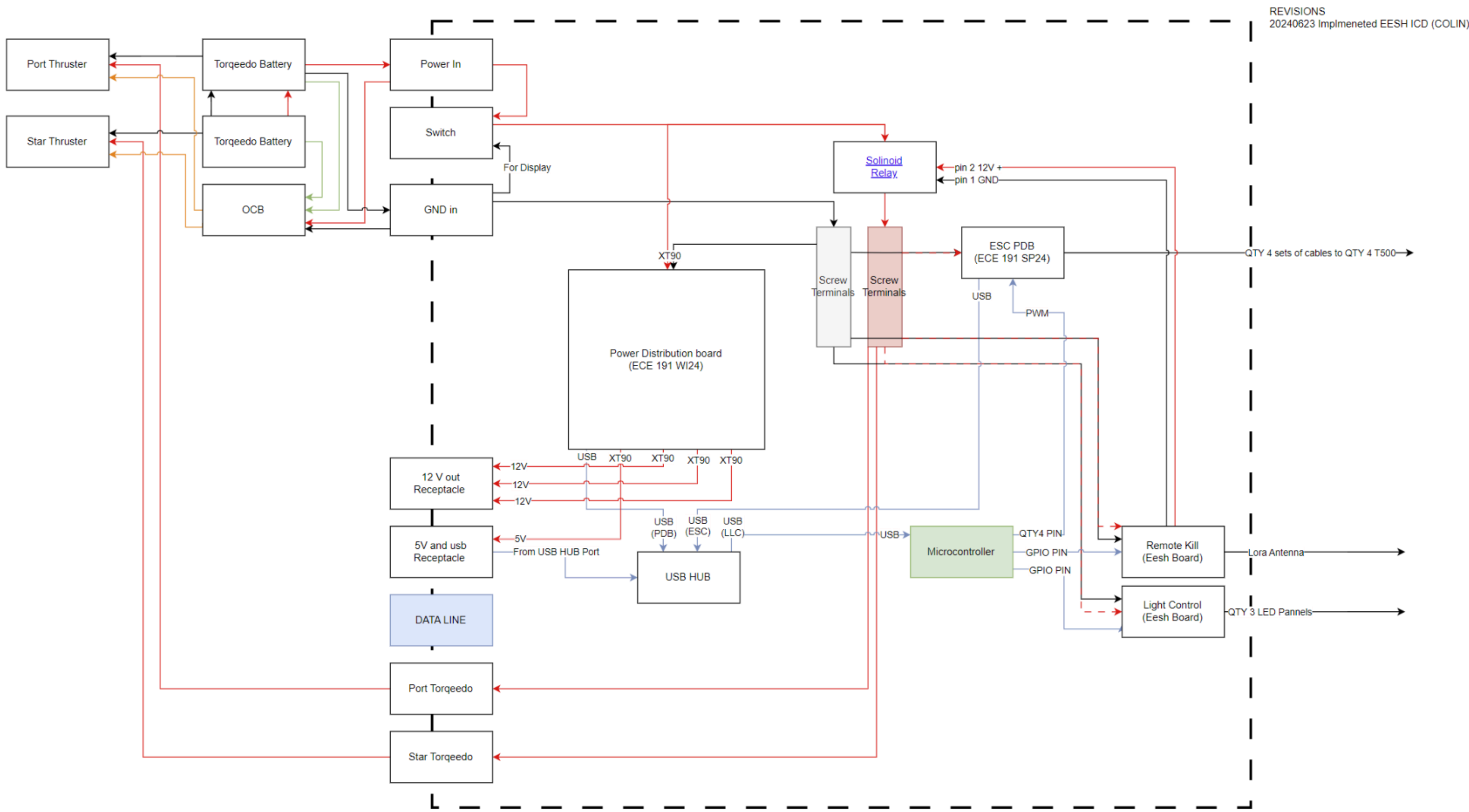


Fig. 17. Contents of power distribution box (STARBOARD side)

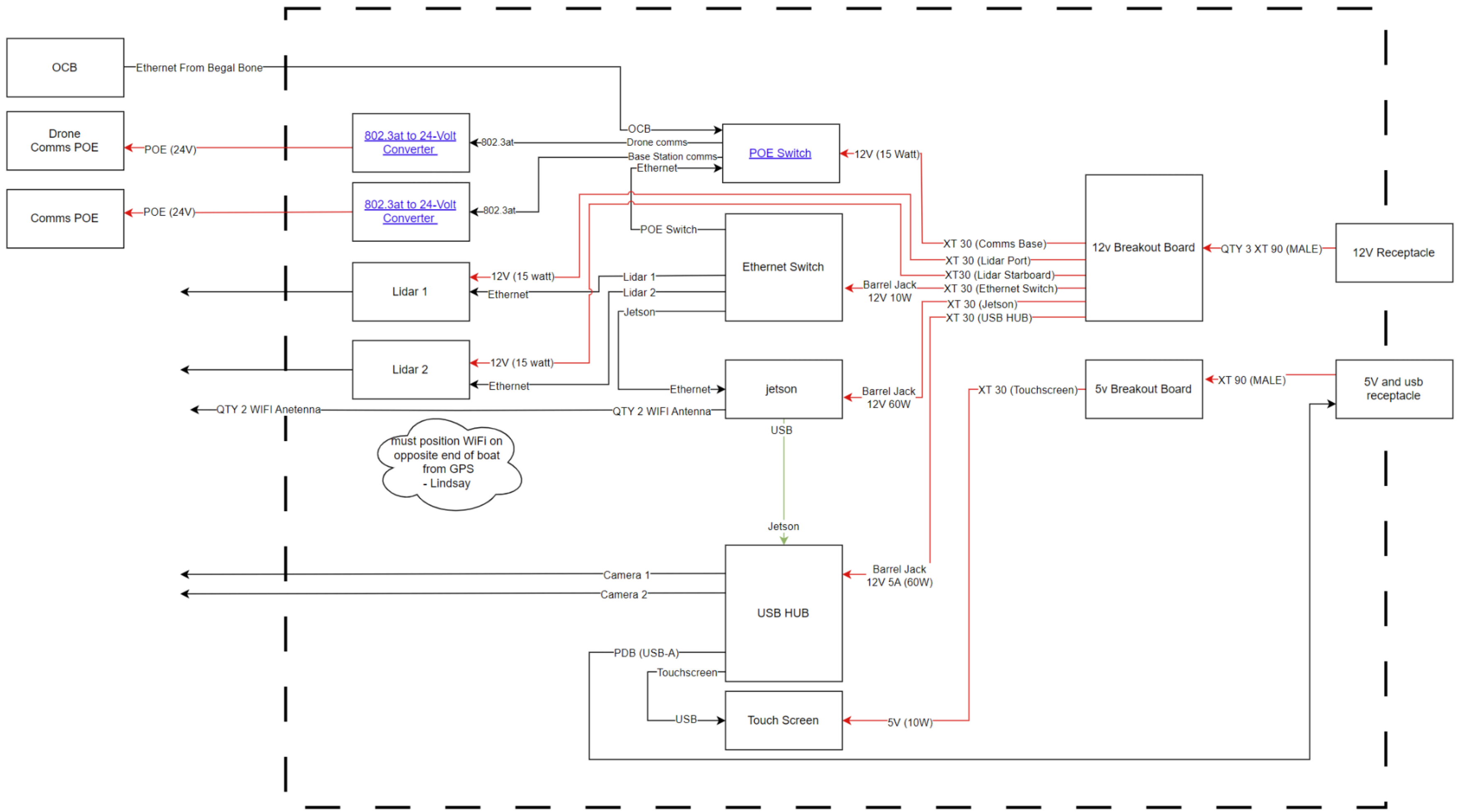


Fig. 18. Contents of electronics box (PORT side)

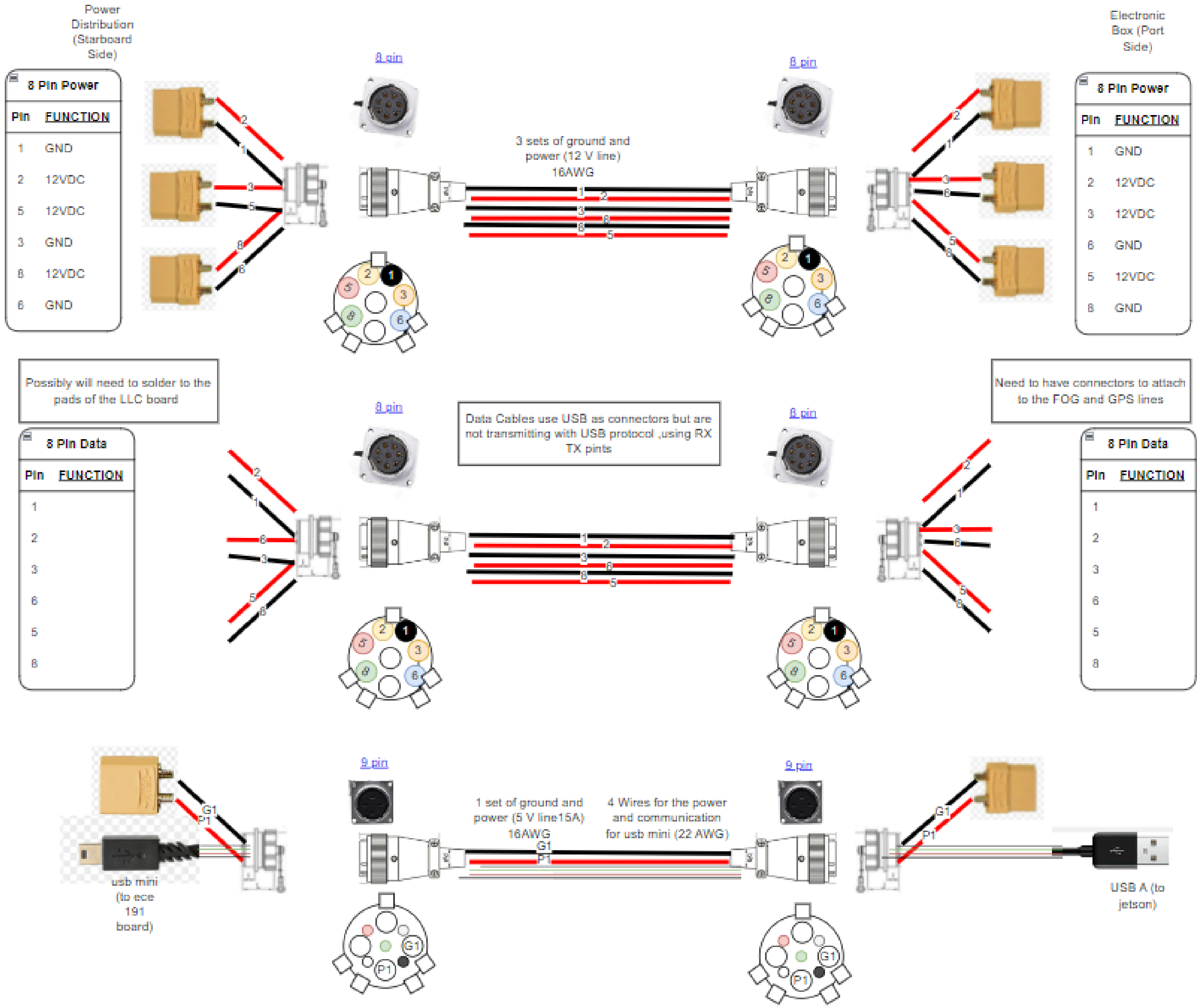


Fig. 19. Power distribution cables

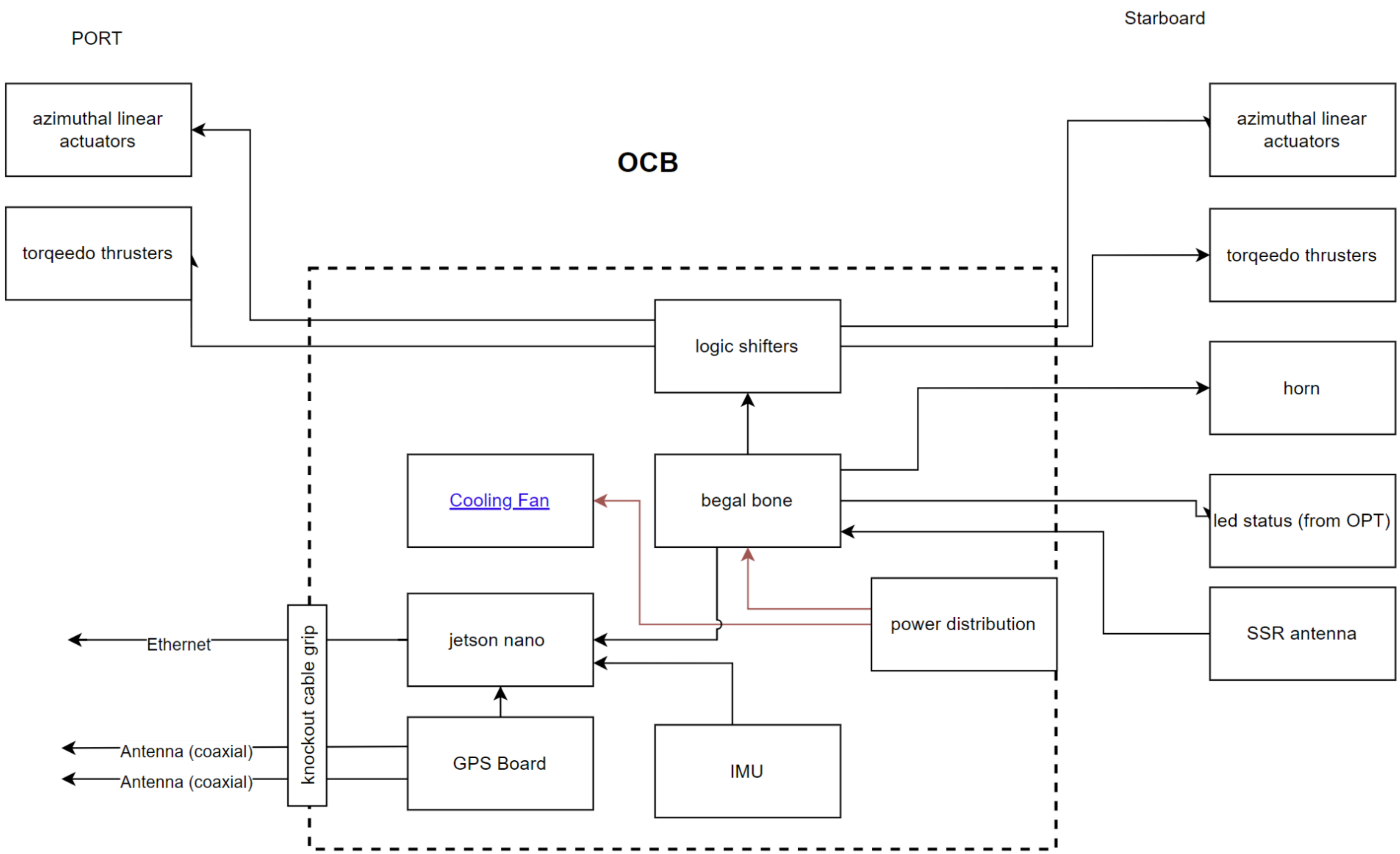


Fig. 20. Contents of outer control box