# Team Inspiration's Autonomous Underwater Vehicles: Onyx and Græy

Chase Chen (team lead), Colin Szeto, Brandon Tran, Huy Tran, Leonard Wright

**Abstract— In its sixth year in RoboSub, Team Inspiration continued improving the capabilities of its Autonomous Underwater Vehicles (AUVs), Onyx and Græy. Chief among these improvements is a new navigation algorithm to aid in localization to the general area of each mission, utilizing a mission grid. Facing unexpected power drops during testing, we developed two power paths with a separate battery for the thrusters. With the acquisition of an improved Attitude and Heading Reference System (AHRS), we implemented sensor fusion to achieve more reliable navigation.**

## I. INTRODUCTION

Team Inspiration is an autonomous vehicle team that accepts any student with passion and grit. Since 2011, our members have competed in multiple robotics challenges, including FIRST, RoboSub [1]–[5], RobotX [6], RoboBoat [7], SUAS, and Robocar. This year, with the addition of several talented members from local high schools, the UCSD capstone team, and a new collaborative internship program with San Diego Mesa College, Team Inspiration is expanding its mentorship and technical training initiatives. Notably, 78% of the team roster consists of first-year students in RoboSub. These new contributors bring fresh perspectives and energy to the team, supporting the continued development and refinement of our AUVs Onyx and Græy, for RoboSub 2025 (Fig. 1). Annotated Onyx and Græy CADs and schematics are shown in Appendix C.

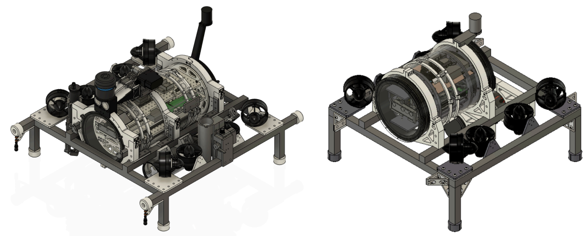

Fig. 1: CAD of Onyx (left) and Græy (right).

## II. COMPETITION STRATEGY

Our strategy is to deploy two AUVs and divide the tasks between them. This provides a platform for inter-vehicle communication points and maximizes the time bonus points. It also serves as an introduction to swarm technologies. We aim to enhance our navigation capabilities by refining our approach beyond dead reckoning and computer vision (CV). We will improve navigation by achieving the following:

- Sensor fusion of the Doppler Velocity Log (DVL) with a barometer and heading sensors (including a Fiber-Optic Gyroscope (FOG) and a better Inertial Measurement Unit (IMU)). Utilization of the DVL to track translational position and the heading sensors to track the azimuth heading.
- Coarsely navigate to the general mission area based on observations of the competition layout, similar to real-world mission planning, utilizing geographic features. Then, use CV to fine-tune the final approach.

### A. *Onyx and Græy Mission Sequence*

Onyx will complete *Gate, Bins, Beacon Localization, Torpedoes*, and *Octagon,* while Græy will complete *Coin Toss*, *Gate*, *Slalom*, *Style*, and *Return Home*. Onyx and Græy will achieve inter-sub communication, coordinating and synchronizing mission maneuvers. The order of task completion in a mission run is shown in Fig. 2 [8].

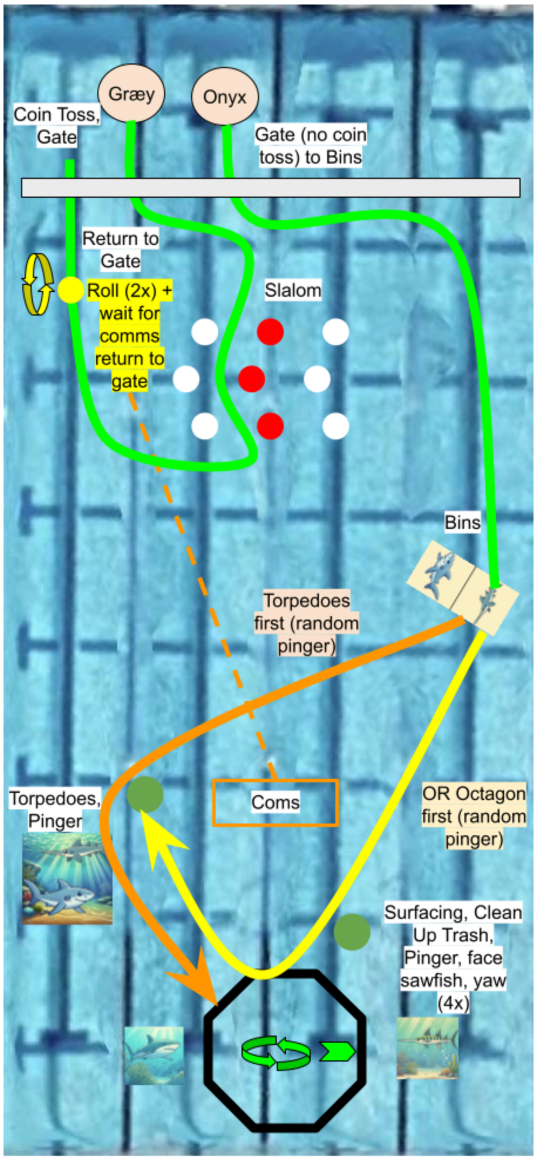

Fig. 2: Planned competition run

## B. *Order of Mission Development*

*1) Gate:* This task is first priority since it must be completed before any mission is scored. It utilizes CV for each AUV to identify and pass underneath the sawfish panel via the forward camera. The side of the gate picked is noted for *Slalom,* while the fish the AUV passed under is noted for *Bins* and *Octagon*.

2) *Coin Flip*: This task is of second priority due to its simplicity. We will request a coin flip to randomize Græy's orientation in water. Græy will submerge and yaw to face the gate using the VectorNav IMU, and identify the sawfish panel with the forward OAK-D camera. Græy will pass through, save the gate location on an internal map, and proceed to the *Slalom*, afterwards returning to the *Gate* to roll two revolutions for style points. To save time, Onyx will pass through the gate without a coin flip to proceed directly to *Bins*.

*3) Slalom:* This task is the third priority since the team can utilize a similar strategy from the 2024 *Buoy* mission. Upon localization, Græy will adjust its depth to be level with the pipes and center its location to the pipes. For each red pipe, Græy will utilize the forward USB camera to approach the pipe to a fixed distance, then move laterally corresponding to the gate. Græy then proceeds towards the next pipe or mission.

*4) Octagon - Surfacing:* This task is the fourth priority since gaining these points only requires navigation via computer vision of the octagon, a capability demonstrated in our past competition runs. Upon localization, Onyx will approach the Octagon using the front-facing camera for approach, the bottom camera to center prior to surface, then yaw to face the sawfish and surface.

*5) Return Home, Style, and Intersub Communication*: The long-distance navigation demonstrated for surfacing can be applied to return to the starting gate. After completion of *Slalom*, Græy will localize near the gate and perform the *Style* mission by rolling two revolutions. The roll maneuver is reserved for the mission conclusion to minimize impacts on the accuracy of the navigation system. Græy will then standby to receive a signal from Onyx that all her missions are completed. These packets will be sent until Græy successfully transmits an acknowledgement packet, confirming receipt of the information. Græy will then pass back through the gate, and both AUVs will perform a celebration yaw with clockwise and then counterclockwise motion.

*6) Bins:* Onyx will utilize the forward camera to approach the bins and the bottom-facing camera to align the marker dropper with the sawfish side. After accounting for the offset of the dropper from the camera, Onyx will drop two markers into the bin.

*7) Torpedoes:* The alignment requires greater precision than for *Bins*. After localizing, Onyx will utilize the camera to first align and fire a torpedo through the sawfish hole, and next aligning and firing through the reef shark target. This task will require offset pointing due to the position of the camera and the torpedo shooter.

*8) Pinger Detection:* This task utilizes a hydrophone array to detect the pinger. We will request a random pinger. If the pinger at the octagon is activated first, Onyx will perform the *Octagon* mission before proceeding to the *Torpedoes* mission. If the pinger at the torpedo target is activated first, Onyx will perform *Torpedoes*, then proceed to the *Octagon*.

*9) Octagon - Cleaning Trash:* This is the most challenging task for Onyx. It requires localizing, identifying, grabbing, and releasing objects. A customized Newton Subsea Gripper will be used, aided by the bottom-facing OAK-D camera, to grab each piece of trash, surface with it (facing the sawfish), and place each in its respective bin. After completion, Onyx will yaw for a corresponding number of revolutions to the pieces of trash in the bins. As a backup plan, Onyx will push the trash into one of the bins for collection points.

## III. DESIGN STRATEGY

### A. Mechanical Subsystem

Our main vehicle frame utilizes 80/20 aluminum extrusions that provide for the ease of mounting the main electronics enclosure, thrusters, and payloads. The frame can be assembled quickly at a low cost. The AUVs have a holonomic thruster configuration along with four vertical thrusters to ensure 6 degrees of freedom. The thrust vectors are aligned to the center of the vehicles, ensuring the vehicle can travel forward and laterally while minimizing unintended rotational motion. More details about our mechanical subsystem can be found in our 2021 Hull Design video [9].

### B. Electrical Subsystem

In the previous competition, our AUVs were significantly impacted by electromagnetic interference (EMI) from the pool structure. Taking advice from Bumblebee Autonomous Systems [10] and The Ohio State University [11], we acquired a VectorNav VN-100 IMU. The automatic Hard and Soft Iron (HSI) calibration feature mitigates magnetic interference from electromagnetic and metallic sources, respectively [12].

After the failure of our Flipsky anti-spark switches, we decided to transition to a relay and reed switch (Fig. 3) because the Flipsky switches automatically power off after 30 minutes of perceived inactivity.

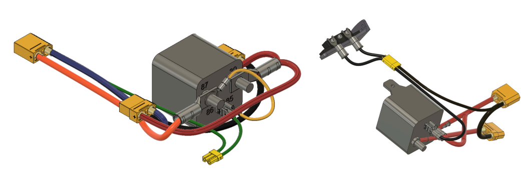

Fig. 3: CAD of the new kill switch system.

The new kill switch was configured to power off only the ESCs and thrusters. However, the capacitors on those components caused a voltage drop that shut down the main computer upon activation of the kill switch. To resolve this, we reconfigured the power system to utilize one battery for the thrusters and a separate battery for the remaining components. Power schematics are provided in Appendix C.

### C. *Software Subsystem*

Our codebase is written in Python and organized into distinct core modules for easier management and scalability (including Sensor Core, Localization Core, Robot Control Core, and Mission Planner Core). Robot Operating System (ROS) is utilized for interprocess communication.

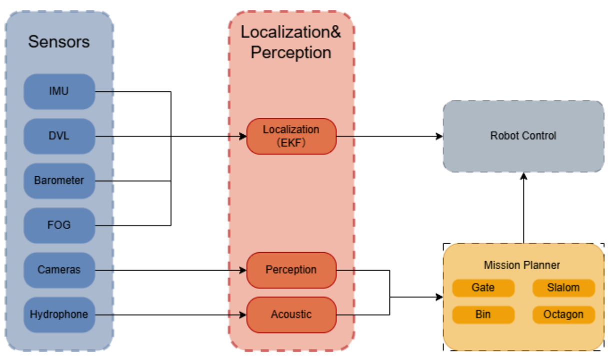


Fig. 4: Current software stack

1) *Robot Control:* The movement of our AUVs is governed by PixHawk Cube Orange flight controllers utilizing ArduSub. Our software utilizes ROS topics to transfer sensor data from the IMU, FOG, DVL, and barometer to a class called RobotControl via our Application Programming Interfaces (APIs). The sensor information and Proportional-Integral-Derivative (PID) control govern the direction and magnitude of commands for the AUV's translational and rotational movement. These commands are sent via a Micro Air Vehicle Link (MAVLink) extendable node for Robot Operating System (MAVROS) topic to the flight controller, which interprets them to send Pulse Width Modulation (PWM) signals to the thrusters.

2) *Localization & Navigation:*

a) *Computer Vision:* We developed a robust object detection algorithm using OpenCV2 and You Only Look Once version 8 (YOLOv8). We prioritized pattern and shape detection since it proves more reliable than color-based detection in the presence of varying sunlight angles and blue hues from the surrounding water. We automated the labeling of the *Slalom* pipes with HSV-based color segmentation (see Appendix B.6), allowing us to quickly train YOLO models and accurately detect the pipes in challenging lighting conditions. We will also generate simulated images with varying angles and lighting conditions for a more robust model. During competition week, we will populate our dataset with footage from the competition environment for all missions.

b) *Navigation Algorithm:* Our navigation algorithm, similar to real-life mission planning, maps the competition into a grid and follows a pre-planned sequence. The algorithm utilizes a DVL to track translational movement, while the IMU and FOG track the azimuth heading. This enables the AUV to navigate to the general area of each mission, where objects are within the limited detection range of the cameras. The AUV will then search by yawing within a range of headings based on the general location of the course object. For example, the AUV may search for the *Slalom* channel by yawing 60 degrees in each direction, then approaching forward for a distance if the pipes are not detected.

c) *Station keeping:* We plan to utilize the DVL to write a station keeping function for the *Torpedoes* mission and for Græy's standby before *Return Home*. When called, the function will save the AUV's position vector. A PID control loop will send forward and lateral commands to the flight controller to correct any drifting until another process signals the function to stop.

3) *Sensor Software and Sensor Fusion*:

We utilized the VectorNav IMU Software Development Kit (SDK) to integrate the IMU into the AUV software [13]. We conducted bench-top tests, including thruster-vibration simulations in MATLAB, to validate a single-stage, low-pass Finite Impulse Response (FIR) filter on the IMU (see Appendix B.7). We then applied this filter to both accelerometer and gyroscope channels to suppress high-frequency vibration noise. We will fuse the filtered acceleration and gyroscope streams via a complementary filter for roll and pitch, and then within a quaternion-based extended Kalman Filter (Fig. 5) to compute the raw roll, pitch, and yaw outputs directly from the denoised IMU data. This custom approach will gain precise control over noise covariances.

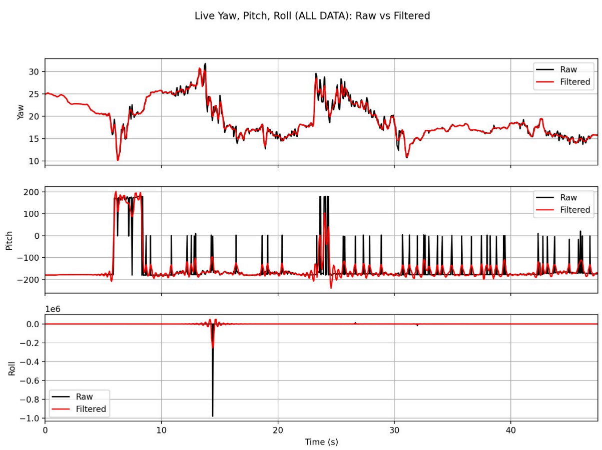


Fig. 5: MATLAB low-pass filter design

The University of California, San Diego (UCSD) capstone team fused the IMU alongside the DVL [14]. We will continue by fusing the FOG while utilizing the flight controller's stabilized flight mode to restrict motion on the pitch and roll axes outside the style maneuver. This will further improve the accuracy of our navigation system.

4) *Mission Planning:* Each mission is governed by event flags, which can be a mission timeout or a boolean value indicating mission success/failure. Once a flag is triggered, the AUV transitions to the next mission. For example, after dropping the markers for *Bins*, a boolean value is sent to indicate mission completion, prompting navigation to the next mission. When all of Onyx's flags are activated, she will communicate with Græy to begin the *Return Home* sequence.

## IV. TESTING STRATEGY

### A. *Testing Approach*

We utilized the systems engineering approach, which breaks mission requirements into the simplest components, to guide our testing strategy. The use of unit/component tests, especially those in-air or test bench, ensures rapid testing prior to integration. The subsystem tests are performed for individual functions or for a simple mission, such as *Coin Toss*. System testing includes multiple sensors and mission sequencing. During each test, the team documents the state of the AUV and each step through a test plan template (Appendix B.1). Detailed blog information of our testing is provided on the team website. [15]

### B. *Unit Test Case Studies*

*1) Modems Unit Test:* To verify our acoustic modems were functioning properly, we wrote a small script that has one modem send a preprogrammed message to a receiver. More details can be found in Appendix B.3.

*2) VectorNav IMU Unit Test:* Before integrating our new IMU, we had to verify that it could precisely sense rotational movement in all three dimensions. We performed this test within the AUV to verify that the Hard and Soft Iron calibration was mitigating the EMI caused by the other electronic components. For a full explanation of the test procedure, see Appendix B.4.

### C. *Subsystem Test Case Study: Electrical Subsystem Testing*

We tested the reliability of the new kill switch system to ensure smooth operations during water testing. After finding Græy's main computer powered off upon activation of the thrusters, we utilized a multimeter to provide connectivity testing and followed with an oscilloscope. We verified that a significant voltage drop occurs upon activating the thrusters (Fig. 6). After providing a separate power source for the thrusters, the kill switch did not impact the main computer. For a more detailed explanation of the test process, see Appendix B.2.

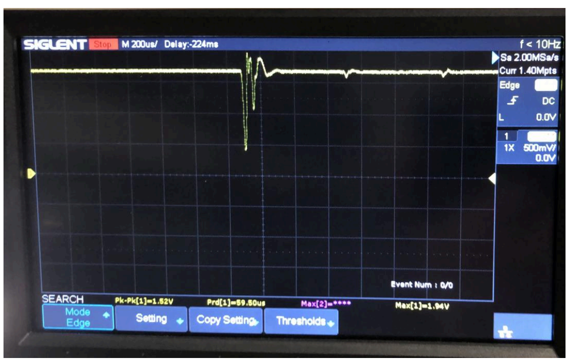


Fig. 6: Voltage drop on an oscilloscope.

### D. *Systems Test Case Study: Prequalification Tests*

The prequalification maneuver aligns with our objective of maximizing our water time during competition week. Græy's prequalification run (Fig. 7) was key to verifying that Græy could maintain depth while helping the newer members learn the controls. A more detailed description of the testing process is in Appendix B.5.

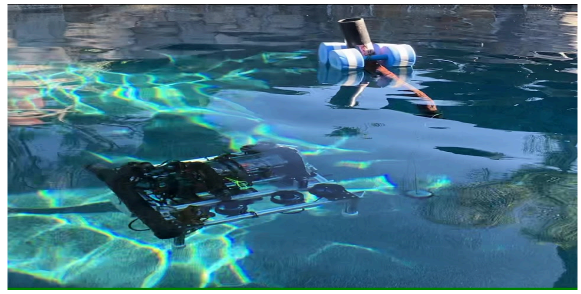

Fig. 7: Græy's prequalification run

## V. ACKNOWLEDGEMENTS

Team Inspiration would like to thank the following sponsors for monetary and equipment donations:

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

*Platinum*: Nvidia, Seebyte

*Gold*: Kenautics, Qualcomm, and tinyVision.ai.

*Silver*: Blue Trail Engineering, Blue Robotics, Chris Freeman, and Medtronic.

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

We are thankful to our alumni Eesh Vij, Lindsay Wright, and Keith Chen for sharing their knowledge. We are grateful for our collaboration with Bumblebee Autonomous Systems, The Ohio State University, and Team Simplexity.

We are thankful for our mentors Alex Szeto, Jack Silbermann, Teresa To, Amit Goel, and Venkat Rangan for their help with planning logistics and educating us with best practices.

Team Inspiration would additionally like to thank the Office of Naval Research and RoboNation for the opportunity to compete in a prestigious competition like RoboSub.

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

## References


[1] K. Chen, A. Talamantez, K. Goel, A. Prasad and L. Wright, "RoboSub 2024 Technical Design Report," Team Inspiration, San Diego, CA, USA, 2024.

[2] E. Vij et al., “The Design of Team Inspiration’s 2023 AUVs,” Team Inspiration, San Diego, CA, USA, 2023

[3] A. Goel et al., “The Design of Team Inspiration’s 2021 AUVs,” Team Inspiration, San Diego, CA, USA, 2021

[4] C. Szeto et al., “The Design of Team Inspiration’s 2020 AUVs,” Team Inspiration, San Diego, CA, USA, 2020

[5] M. Szeto et al., “Team Inspiration 2019 RoboSub Journal,” Team Inspiration, San Diego, CA, USA, 2019

[6] E. Vij et al., "Maritime Robotics - Autonomous, Unmanned, Multi-Domain Vehicles Challenge," Team Inspiration, San Diego, CA, USA, 2024.

[7] K. Chen, C. Szeto, B. Tran, L. Wright, “The Design of Team Inspiration’s 2025 RoboBoat Autonomous Surface Vehicle,” Team Inspiration, San Diego, CA, USA, 2025

[8] RoboNation, “Team Handbook - RoboSub 2025,” 2025. [Online] https://robonation.org/app/uploads/sites/4/2025/04/2025-RoboSub_Team-Handbook-04_25_25.pdf

[9] Inspiration Robotics 11128, San Diego, CA, USA, *RoboSub 2021 - Hull Design*. (Aug. 2021). Accessed: Jun. 30, 2025 [Online Video]. Available: https://www.youtube.com/watch?v=5O3wI03UST4

[10] A. A. Winarto et al., “RoboSub 2023 Technical Design Report,” NUS, Singapore, 2023

[11] N. Becker, A. Dellacqua, B. Knutson, M. Oinonen, R. Pafford, C. Tucker, “Design Review of *Talos*: An Autonomous Underwater Vehicle by The Ohio State University’s Underwater Robotics Team”

[12] P. Guo, H. Qiu, Y. Yang, and Z. Ren, "The soft iron and hard iron calibration method using extended Kalman filter for attitude and heading reference system," in 2008 IEEE/ION Position, Location and Navigation Symposium, Monterey, 2008.

[13] VectorNav, “VectorNav Control Center,” 2025. [Online]. Available: https://www.vectornav.com/resources/software

[14] R. Nambimadom, June Park, Andy Zhang, Sharfa Pital, Justin Nguyen, Purush Ram, “Sensor Fusion and Localization for Autonomous Underwater Vehicles,” University of California San Diego, San Diego, CA, USA, 2025.

[15] Team Inspiration, “Inspiration Robosub 2025 Team Website,” [Online]. Available: https://www.inspirationrobosub.com/robosub-2025-1 (accessed June 30, 2025)

[16] Mathworks, “designfilt - design digital filter - MATLAB,” 2025. [Online]. Available: https://www.mathworks.com/help/signal/ref/designfilt.html

APPENDIX A

COMPONENT SPECIFICATIONS

| Component | Vendor | Model/ Type | Specs | Custom/ Purchased | Cost | Year of Purchase |
|---|---|---|---|---|---|---|
| AUV Hull Form/ Platform (Frame, Waterproof Housing) | 80/20 Inc. | 1010 aluminum extrusion | Weight: 25 oz<br>Size: 22 in x 7.9 in | Purchased and machined in lab | $234 | 2019 |
| | ePlastics | Acrylic tube, 8 in. series | Size: 8" diameter | Donated | $343 | 2019 |
| Waterproof Connectors | Blue Trail Engineering | 10 cobalt series dummy plug<br><br>10 cobalt series locking sleeve<br><br>4 cobalt series cable termination kit | https://www.bluetraiengineering.com/product-page/cobalt-series-dummy-plug<br>https://www.bluetraiengineering.com/product-page/removable-cobalt-locking-sleeve<br><br>https://www.bluetraiengineering.com/product-page/cable-termination-kit | Purchased | $201 | 2020 |
| | Blue Robotics | 1 7.5mm HC Wetlink penetrator | https://bluerobotics.com/store/cables-connectors/penetrators/wlp-vp/ | | $12 | |
| Intersub communication | Succorfish | Delphis V3.3 | https://succorfish.com/wp-content/uploads/2023/01/DELPH | *Donated by a sponsor* | *Donated by a sponsor* | 2023 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | IS-Data-Sheet_V9_3.2.pdf | | | |
| 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 |
| Gripper | Blue Robotics | Newton Subsea Gripper | Grip Force: 28 N Jaw Opening: 2.75 in https://bluerobotics.com/store/rov/bluerov2-accessories/newton-gripper-asm-r2-rp/ | Legacy | $329 | 2019 |
| Torpedoes | Blue Trail Engineering | Under-water Servo SER-2000 | https://www.bluetrailengineering.com/product-page/underwater-servo-ser-20xx | Custom | $215 | 2023 |
| Marker Dropper | Blue Trail Engineering | Under-water Servo SER-2000 | https://www.bluetrailengineering.com/product-page/underwater-servo-ser-20xx | Custom | $215 | 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 |
| | Mouser | Murata MYBSS054R6EBF | 54V Power supply<br><br>https://tinyurl.com/inspirationRegulator | Purchased | $22 | 2023 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | AliExpress | 100A Ideal Diode | 100A Ideal diode | Purchased | $72 | 2023 |
| | Custom | Unified Power Controller | Three: 12V 3A, 5V 3A, 3.3V 1.2A Power supplies | Custom | $400 | 2023 |
| Motor Control | Blue Robotics | Basic ESC | 30A brushless ESC https://bluerobotics.com/store/thrusters/speed-controllers/besc30-r3/ | Legacy | $36 apiece | 2019 |
| CPU | Nvidia | Nvidia Jetson Nano | 1.4 GHZ clock speed<br>4 GB RAM | Purchased | $99 (On Græy) | 2021 |
| | Nvidia | Nvidia Jetson Xavier NX | https://developer.nvidia.com/embedded/jetson-agx-xavier-developer-kit | *Donated by a sponsor* | On Onyx | 2024 |
| Teleopera-tion | Blue Robotics | Fathom-X and Fathom-X Tether Interface (FXTI) | Communication: USB 2.0, Ethernet 10/100 https://bluerobotics.com/store/comm-control-power/tether-interface/fathom-x-r1/ | Legacy | Installed | 2023 |
| Inertial Measure-ment Unit (IMU) | Pixhawk | Invensense® MPU 6000 3-axis acceler-ometer/ gyroscope | 32-bit ARM Cortex M4 core with FPU 168 MHz/256 KB RAM/2 MB Flash 32-bit failsafe co-processor | Legacy | Included with Pixhawk on Græy and on Onyx (compass) | 2019, 2022 |
| | Dampener | XTORI Pixhawk dampener | Materials: plastic and rubber<br>Weight: 17 g | Legacy | $8 | 2021 |
| Doppler | Teledyne | Explorer | Velocity Range: ±12 | *Loaned* | *Loaned* | 2023 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Velocity Log (DVL) | WaterLinked | A50 | m/s<br>Long Term Accuracy: ±0.3% ± 0.2 cm/s<br>https://www.uniquegroup.com/wp-content/uploads/2022/10/Explorer_DVL.pdf<br><br>Velocity Range: ±3.75 m/s<br>Long Term Accuracy: ±1.01%<br>https://waterlinked.com/web/content/15701?unique=b4aef6d930bb256c64bae4e0ead8c56661bf12f0 | *by a sponsor*<br><br>Purchased | *by a sponsor*<br><br>$ 5990 | 2020 |
| Fiber Optic Gyroscope (FOG) | Fizoptika Malta | VG103 S2LND | Input range: 200 °/s<br>https://fizoptika.com/docs/fiber_optic_gyro_specification_vg103s-2lnd.pdf | Purchased | $3,060 | 2023 |
| Camera(s) | Blue Robotics | Low Light HD USB Camera | Pixel count: 2MP<br>1080P Onboard H.264 compression chip 32x32mm | Legacy on Græy<br><br>Purchased for Onyx | $198 (1x) on Græy (2x) on Onyx | 2019 |
| | Luxonis | OAK-D Wide Camera | 12 MP Resolution<br>60 FPS max frame rate<br>Focus (Full Frame): 60cm - ∞ | Purchased | $ 548 (1x on Græy) (2x on Onyx) | 2024 |
| Hydro-phones | Custom | Hydro-phone 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 | $315 | 2020 |
| | Aquarian | AS-1 | Linear range: 1Hz to | Legacy | | 2019 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Audio & Scientific | Hydro-phone | 100kHz ±2dB Horizontal Directivity (20kHz): ±0.2dB Horizontal Directivity (100kHz): ±1dB Vertical Directivity (20kHz): ±1dB Vertical Directivity (100kHz): +6dB -11dB<br><br>https://www.aquarianaudio.com/as-1-hydrophone.html | | | |
| Algorithms (acoustics) | Custom | Fast Fourier Transform (FFT) | - | | Free | 2020 |
| 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 |
| | Ultralytics | YOLO | YOLOv8 | | Free | 2023 |
| Localization and Mapping | In-house | Custom | DVL, Hydrophones, CV | | Free | 2021 |
| Mission Planner | In-house | Custom | Mission planner | | Free | 2024 |
| 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.1: Test Template

<table>
<tr><td rowspan="3">Testing Plan Template</td><td></td><td colspan="2">Approval Authority</td></tr>
<tr><td></td><td>[Names of Members ]</td><td>[Description of members’ position]</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td>Date:</td><td colspan="2">Mission Title:</td></tr>
<tr><td>Test #:</td><td>Location:</td><td>Risk:</td></tr>
<tr><td>Software Version:</td><td>Hardware Sensors Mounted:</td><td>Hardware Sensors Used:</td></tr>
<tr><td colspan="3">Scope: <u>Primary:</u><br><u>Secondary:</u><br><u>Tertiary:</u></td></tr>
</table>

<table>
<tr><td>Attendance</td><td>Test Notes</td></tr>
<tr><td></td><td>Resources Needed:<br>Environment:<br>Expected Results:<br>Prerequisites:<br>Risk Management:</td></tr>
</table>

| | **Validation Step Description** | **Expected Result** | **Result** | **Reference to Data** | **Pass/Fail** |
|---|---|---|---|---|---|
| | | | | | |

Appendix B.2: Electrical Integrity Testing

1) Required Equipment:
   - Græy (with exposed electronics)
   - Magnet
   - BlueRobotics 14.8V, 18 Ah Lithium-ion battery
   - SIGLENT SDS 1104X-E Oscilloscope with Probes
   - 16 AWG wire
   - Fork Terminals
   - Cable cutter
   - Cable stripper
   - Crimping tool
2) Procedure A Steps
   a) Connect battery to Græy
   b) Ensure Jetson's green power LED is on. If not, disconnect the battery and repeat (a)
   c) Wait until Jetson's fan is running
   d) Apply the magnet to the reed switch repeatedly for 20 seconds
   e) If the Jetson powered off, proceed to Procedure B
3) Procedure B Steps
   a) Disconnect the battery from Græy
   b) Use the cable cutter to cut 16 AWG wire: 4 cm red and 4 cm black
   c) Use the cable stripper to remove 0.5 cm of cable on each side of each wire
   d) Twist the exposed metal on one side, place a fork terminal, and use the crimpers to attach
   e) Place the black cable on the ground terminals (bottom side)
   f) Place the red cable on one of the outer eight power terminals (top side)
   g) Disconnect the electronic component terminals from the ground side
   h) Power on the oscilloscope and connect a probe
   i) Connect the probe to the test leads on the oscilloscope.
   j) If waves are not square, use included screw to compensation tune until waves are square
   k) Connect the hook to the exposed red cable lead and the ground clipper to the black cable lead
   l) Connect the battery back to the Græy
   m) Use the large horizontal knob on the oscilloscope to zoom out to 1 second.
   n) Ensure that the **roll** and **search** buttons are lighted - if not, press them
   o) Take a magnet and trip the reed switch, then quickly press the **Run | Stop** button.
   p) Use the small horizontal knob to translate the voltage drop to the center of the plane
   q) Use the large horizontal knob to zoom into 200 microseconds and view the voltage drop
4) Pass/Fail Criterion
   a) The test is considered passing if upon connection of the battery, the Jetson powers on, and repeatedly applying a magnet to the reed switch for 30 seconds results in the Jetson staying on.
   b) The test is considered failing if the Jetson does not power on upon connection to the battery, or if the Jetson powers off upon applying a magnet to the reed switch
5) Results: In mid-May, the Jetson would eventually lose power when the magnet is repeatedly applied to the reed switch for 30 seconds. Since a sudden loss of power presented unacceptable risks for losing time in a run and corrupting the Jetson, we initially mounted a capacitor in parallel in front of the Jetson. However, the other components were still power cycled. A power cycle to the FathomX resulted in a loss of tether connection for up to 10 seconds. We ultimately opted to provide a separate power source for the ESCs and thrusters, ensuring none of the other components were impacted by voltage drops. After this modification, conducting this test did not result in Græy's Jetson powering off.

## Appendix B.3 Modem Communication Test

1) Required Equipment:
   - Two Delphis Succorfish Modems
   - Two laptops with GitHub Repo
   - Two USB-RS232 adapters
   - Container with water
2) Steps
   a) Place the modems in the container with water
   b) Connect each modem to a laptop using the USB-RS232 adapters
   c) Ensure each laptop is running the dev_branch of the robosub_2025 git repository: https://github.com/InspirationRobotics/robosub_2025/tree/dev_branch
   d) Run /tests/laptop_modem_test.py
   e) Input the filepath of the serial port. For windows and mac, this is a COM port, while for linux systems this is typically /dev/ttyUSB0. Refer to device settings for the port name
   f) Have one laptop and modem as the **sender**, while the other will be the **receiver**
   g) Have the sender input the unique address of the receiver
   h) Watch the screen of the laptop connected to the receiving modem for the packets to print on the screen
3) Pass/Fail criterion
   a) The test is considered passing if the laptop connected to the sender provides the correct information to /tests/laptop_modem_test.py and the receiver is able to retrieve the sender's packets and print them to its connected laptop
   b) The test is considered failing if incorrect information is provided for the laptop connected to the sending modem, or if the receiving modem is unable to receive acoustic packets to print to its laptop's screen.
4) Results
   a) The receiving modem was able to parse around 50-75% of the acoustic packets sent. To account for packet loss, the sender will send packets until receipt of an acknowledgement from the receiver.

Appendix B.4 IMU Unit Test

1) Required Equipment:
   - Græy with VN-100 IMU mounted
   - BlueRobotics 14.8V, 18 Ah Lithium-ion battery
   - Laptop
   - Tether spool (Fathom-X attached)
   - Tether extension
   - USB-C to RJ45 adapter
   - RJ45 cable
   - USB-A to USB-B cable
2) Procedure A Steps
   a) Connect battery to Græy
   b) Ensure Jetson's green power LED is on. If not, disconnect the battery and repeat (a)
   c) Attach tether extension to tether penetrator on Græy's end cap
   d) Attach tether spool's end to tether extension
   e) Connect laptop via USB-C to RJ45 adapter and RJ45 cable to the RJ45 port in the FathomX of the tether
   f) Connect laptop via USB-A to USB-B to the USB-B port on the FathomX
   g) If this is the first time using this laptop's interface to connect to Græy, statically configure the wired interface's IP address to be 192.168.2.1 with a subnet mask of 255.255.255.0
   h) SSH to Græy via inspiration@192.168.2.2
   i) Run ls -laR /dev | grep platform to ensure the flight controller port name didn't change - refer to /config/graey.json. If so:
      i) Modify /opt/ros/melodic/share/mavros/launch/px4.launch to configure the correct port
   j) Run cd robosub_2025; git checkout dev_branch
   k) Utilize tmux or screen to run four terminals:
      i) roscore
      ii) source /opt/ros/melodic/setup.bash; roslaunch mavros px4.launch
      iii) python3 -m auv.device.pix_standalone
      iv) rostopic echo /auv/devices/vectornav
3) Testing Procedure Steps - for each test, perform the following:
   a) Record the initial IMU measurement for the desired motion - x for pitch, y for roll, z for yaw
   b) Manually rotate the AUV on the desired axis by a specific number of degrees (see Procedure C)
   c) Record the change in the IMU measurement for the desired motion
4) Procedure C Steps: Perform the above Testing Procedure Steps for the following:
   a) Pitch for 90 degrees
   b) Pitch for -90 degrees
   c) Roll for 90 degrees
   d) Roll for -90 degrees
   e) Yaw for 90 degrees
   f) Yaw for -90 degrees
5) Pass/Fail Criteria
   a) The test is considered passing if the IMU reported changes in orientation within 5 degrees of the actual orientation changes for the five tests in Procedure C
   b) The test is considered failing if the IMU reported changes in orientation that deviated more than 5 degrees from the actual orientation changes for any of the tests in Procedure C
6) Results

a) During development of software functions to integrate the VN-100 IMU on 06-19-25, we performed the above tests to verify the IMU was properly recording the AUV's pose. The above tests passed.

## Appendix B.5 Græy Prequalification Maneuver

1) Required Equipment:
   - At least 3 team members
   - Græy
   - BlueRobotics 14.8V, 18 Ah Lithium-ion battery
   - Wireless Router
   - Extension Cord
   - Power Strip
   - Laptop with GitHub Repo
   - Prequalification Gate
   - Red PVC Pipe (marker)
   - Three 10 lb weights with ropes
   - Two Pool noodle segments
   - Four floaties
   - Authorization to utilize a neighbor's pool
   - 2 push carts
   - Vacuum Pump with 12V regulator
   - Smartphone
2) Procedure A Steps:
   a) Utilize the push carts to bring the equipment to the neighbor's pool
   b) Set up extension cord, power strip, and power on wireless router
   c) Tie weights to each side of the gate and the red PVC pipe - attach pool noodles to gate and floaties to pipe
   d) Place gate at one side of the pool (leaving 3 m for the AUV) and the marker 10 meters from the gate
   e) Utilize the pre-deployment checklist:
      i) Rig the 12V regulator between the power supply and the vacuum pump
      ii) Unscrew OK caps in electronics/battery chambers and insert vacuum tubes
      iii) Pump out air to a set pressure (ex: -10 Psi) then wait 15 minutes.
      iv) If pressure increases, terminate the test and begin leak inspection. Otherwise let air in and test the other chambers.
      v) Replace OK caps.
      vi) Press them with index finger to remind yourself that they're on
      vii) Remove DVL cover
      viii) Place dummy plug on any uncovered penetrators
      ix) Place AUV in water and record the time in water log
      x) Engage magnet to reed switch to power the thrusters
3) Procedure B Steps:
   a) Connect laptop to wireless router
   b) SSH into Græy via 192.168.8.141
   c) Run **ls -laR /dev | grep platform** to ensure the flight controller port name didn't change - refer to /config/graey.json. If so:
      i) Modify /opt/ros/melodic/share/mavros/launch/px4.launch to configure the correct port
   d) Run cd robosub_2025; git checkout dev_branch
   e) Utilize tmux to run four terminals:
      i) roscore
      ii) source /opt/ros/melodic/setup.bash; roslaunch mavros px4.launch

iii) python3 -m auv.device.pix_standalone
iv) **Mission Terminal**

4) Procedure C Steps
   a) Draft a plan for prequalification movements
   b) Run unit tests of **robot_control.movement()** to gauge how far Græy travels forward, backward, and laterally over defined periods of time (ex: 15 seconds). Standardize the PWMs sent to the thrusters.
   c) Run unit tests of **robot_control.set_heading()** to verify Græy can yaw to a specific Azimuth heading
   d) Write a script **/tests/motion_tests/motion_test.py** that executes movements based on the plan from (4a). Utilize **robot_control.set_heading()** to standardize the direction Græy is facing before approaching the marker/gate
   e) Save changes, push to GitHub, and pull them to the AUV
   f) Have one team member position Græy 3 meters behind the gate
   g) Have a team member ready to record the run via smartphone
   h) Run **python3 -m tests.motion_tests.motion_test** in the mission terminal
   i) Record the run with the smartphone
   j) If the run failed (see (5)), adjust the amount of time Græy moves forward/laterally/backward according to observations
5) Pass/Fail Criteria:
   a) The test is considered passing if <u>all</u> of these criteria are met:
      i) In Procedure A, if the pressure inside the chambers did not change after 15 minutes during the vacuum tests
      ii) Græy stayed underwater during the entire prequalification run
      iii) Græy traveled 3 meters to pass through a gate, then around a marker at the same depth 10 meters from the gate, then back through the gate
      iv) Græy stayed within view of the smartphone camera for the entire prequalification run
   b) The test is considered failing if any of the criteria in (5a) are not met.
6) Results: **robot_control.set_heading()** was not utilized during the run due to modifications that caused a crash. Development for the prequalification script began on 06-15-25, and a full run was recorded on 06-17-25.

## Appendix B.6 HSV-Assisted Automated Label Generation for Perception Training

1) Equipment Requirements
   a) To execute this test, the following equipment is required:
   b) An AUV (Græy or Onyx) equipped with either a Luxonis OAK-D Wide or a BlueRobotics Low-Light HD USB camera.
   c) A laptop running Python (OpenCV 4.x and a YOLOv8-compatible environment).
   d) A pool environment containing mission props (e.g., red PVC pipes for Slalom tasks).
2) Procedure Steps
   a) Image Collection: The AUV is deployed in the pool to capture RGB images and video from multiple angles under varying lighting conditions.
   b) HSV Segmentation Tuning: An interactive Python GUI is used to fine-tune HSV thresholds in real time, ensuring robust segmentation of the target color (see Fig. 8). The trackbar interface enables precise adjustments of the lower and upper HSV bounds until only the desired object (e.g., a red pole) is accurately masked.
   c) Automatic Bounding Box Generation: After thresholding, contours are extracted from the color mask, and bounding boxes are computed around detected objects (Fig. 8). These boxes are labeled by class and exported in YOLO-compatible text format for subsequent model training.
   d) Model Training & Evaluation: The labeled images are uploaded to Roboflow, split into training, validation, and test sets, and used to train an object detection model (Fig. 9). Model performance is assessed using standard metrics (e.g., mAP@50, precision, recall) on held-out test images.
3) Pass/Fail Criteria
   a) The test is considered successful (Pass) if:
      i) The trained model achieves an mAP@50 score exceeding 0.9 on the test set.
      ii) Color segmentation reliably detects mission objects without requiring significant manual correction.
   b) The test is considered a failure if:
      i) Segmentation fails to consistently identify mission objects.
      ii) Detection performance is unsatisfactory on validation or test images.
4) Results & Discussion
   a) Our automated HSV labeling system drastically cut down annotation time, making the process much faster.
   b) When tested on a small dataset (~250 images), the Roboflow-trained model performed exceptionally well, scoring 99.5% mAP@50, 99.2% precision, and 100% recall. This approach also makes it easy to adapt to new environments—like competition pools—by quickly relabeling and retraining the model.
   c) However, we found that HSV-based bounding boxes struggled with lighting changes, reflections, and occlusions, leading to inconsistent masks and unreliable distance estimates. Switching to a YOLO model solved these issues, providing stable, real-time detection even in challenging pool conditions.

d) In summary, combining fast HSV labeling with YOLO training gave us the best of both worlds: efficient annotations and reliable real-world performance. Also facilitates rapid domain adaptation, allowing quick relabeling and retraining when transitioning to new environments (e.g., competition pools).

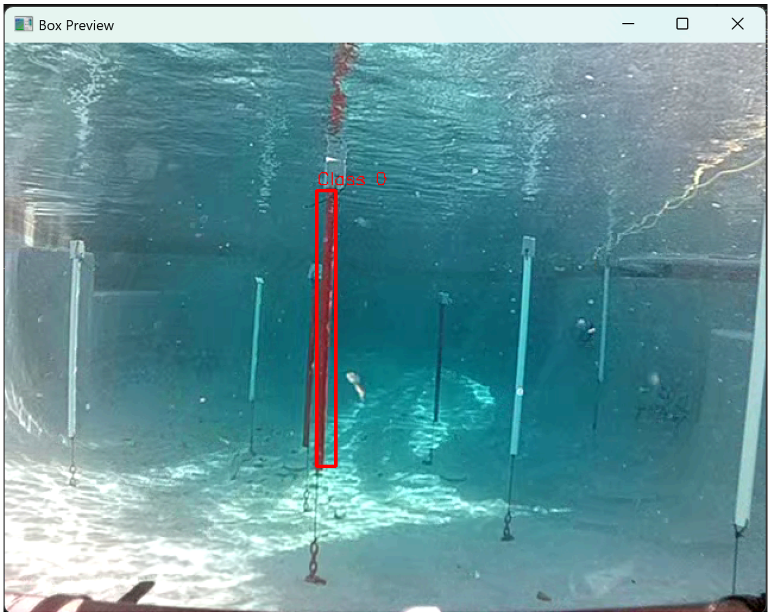


Fig. 8: Automated bounding box preview for detected red pole (“Class 0”).

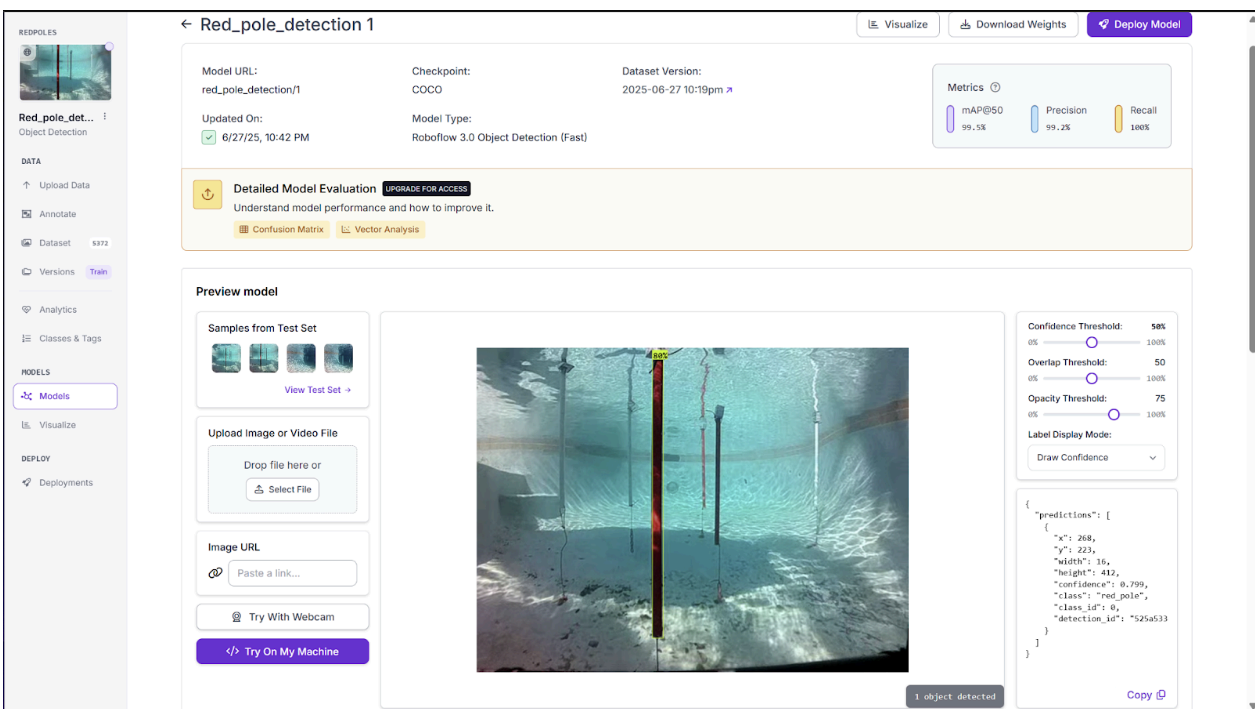


Fig. 9: Roboflow object detection model evaluation metrics for “red_pole” detection.

## Appendix B.7 IMU Low-Pass Filter Simulation

1) Equipment Requirements
   a) VectorNav VN-100 IMU mounted on a rigid bench fixture
   b) Host PC with MATLAB R2025a and Signal Processing Toolbox
   c) Thruster-vibration simulation script
2) Procedure Steps
   a) Data Acquisition
      i) Record 66.8 s of stationary VN-100 horizontal-axis accelerometer data at ~40 Hz.
      ii) Remove DC offset from each axis: **acc0 = acc - mean(acc);**
   b) Noise Injection & FFT Analysis
      i) Inject a 0.5 m/s², 25 Hz sine wave into the data to emulate thruster vibration.
      ii) Compute and plot the FFT of zero-mean clean vs. noisy signals (Fig. 10).
   c) Filter Design & Application
      i) Design a low-pass Finite Impulse Response (FIR) filter (2 Hz passband, 4 Hz stopband, 1 dB ripple, 60 dB attenuation) using MATLAB's designfilt function [16].
      ii) Apply zero-phase filtering: **accFilt = filtfilt(designedFilter, acc0 + noise);**
      iii) Plot filtered spectrum (Fig. 11).

   d) Time-Domain Validation
      i) Overlay original zero-mean (blue), noisy (cyan), and filtered (red) traces (Fig. 12).
3) Pass/Fail Criteria
   a) The test is considered passing if:
      i) FFT shows ≥ 60 dB attenuation at 25 Hz (no visible spike).
      ii) Time-domain RMS error < 0.005 m/s² with no distortion of low-frequency content.
   b) The test is considered failing if there is a residual 25 Hz energy > –40 dB or a waveform distortion is observed.
4) Results & Discussion
   a) FFT of the zero-mean clean (blue) vs. noisy (red) data confirms a sharp 25 Hz disturbance (Fig. 10).
   b) The filtered spectrum (green) demonstrates complete removal of the 25 Hz peak with minimal ripple (Fig. 11).
   c) Time-domain overlay verifies high-frequency jitter suppression while preserving the underlying acceleration waveform (Fig. 12).

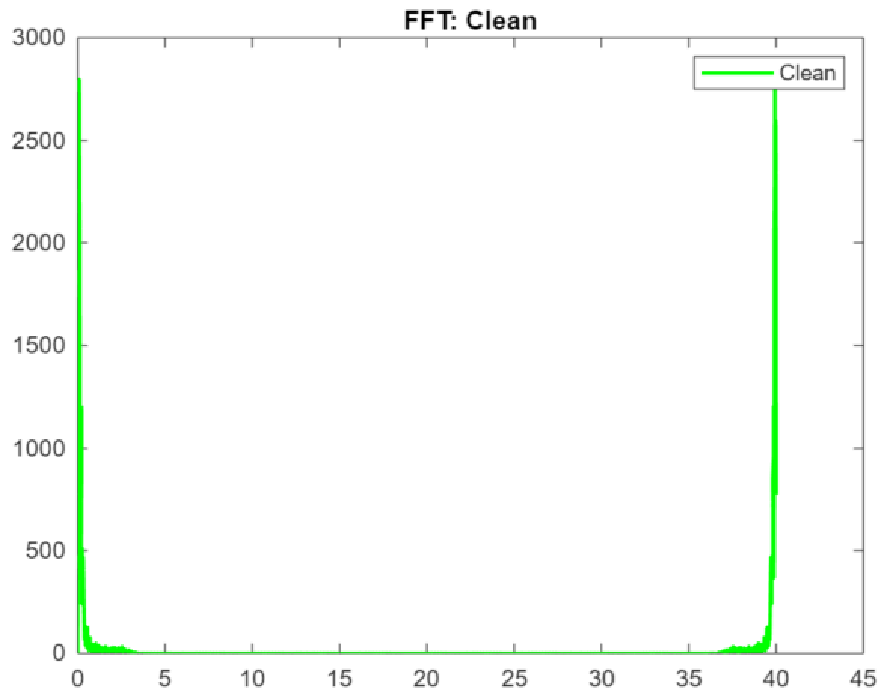


Fig. 10-11. FFT magnitude of the zero-mean clean (blue) vs. noisy (red) accelerometer signal, showing the 25 Hz disturbance; FFT clean (green)

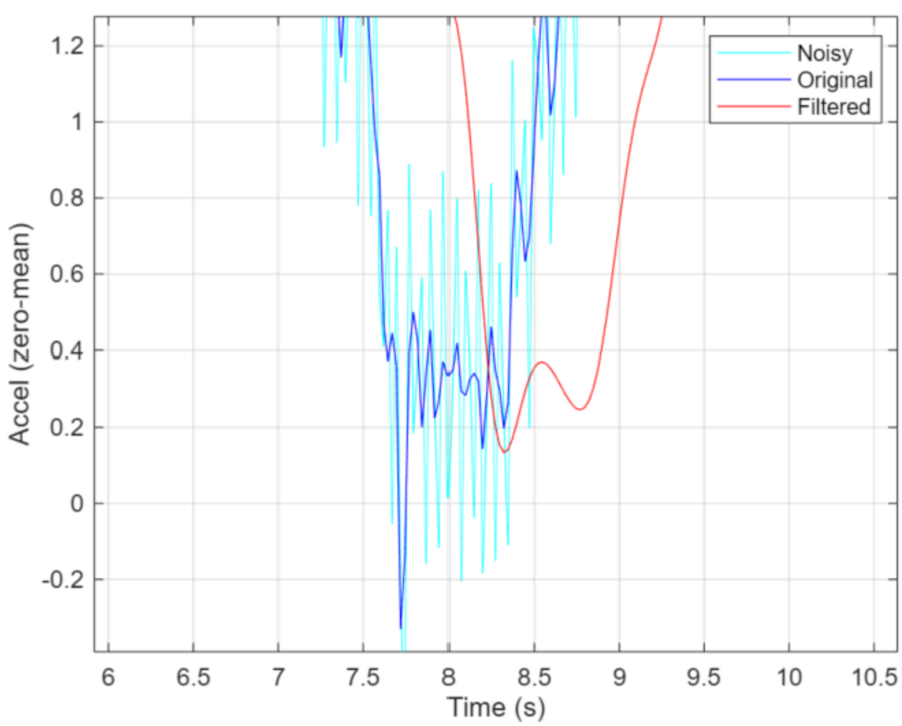


Fig. 12. Time-domain overlay of zero-mean (blue), noisy (cyan), and filtered (red) accelerometer signals

## Appendix C: Supplemental Diagrams

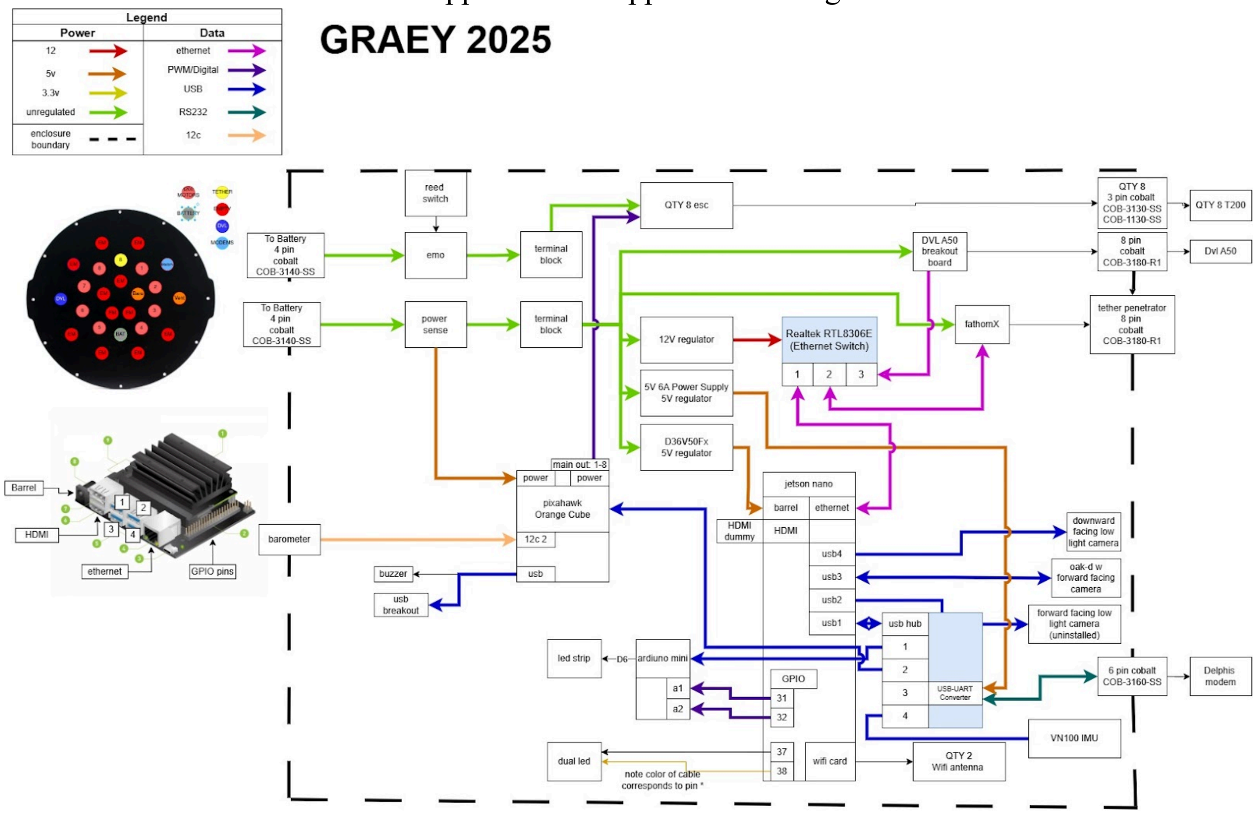


Fig. 13: Græy's Schematic

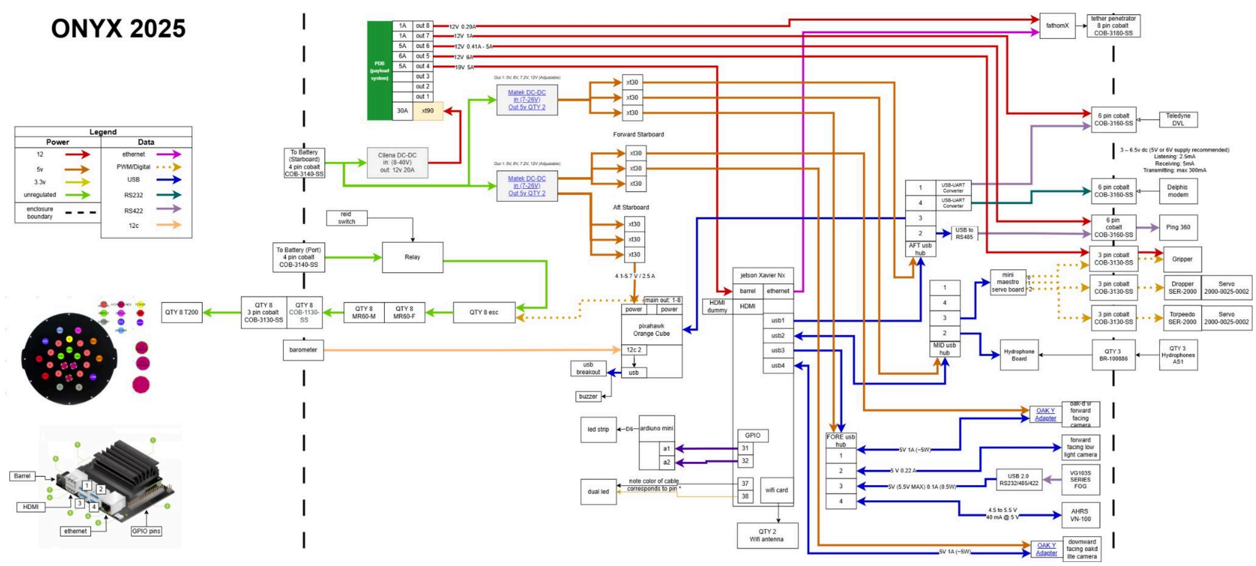


Fig. 14: Onyx's Schematic

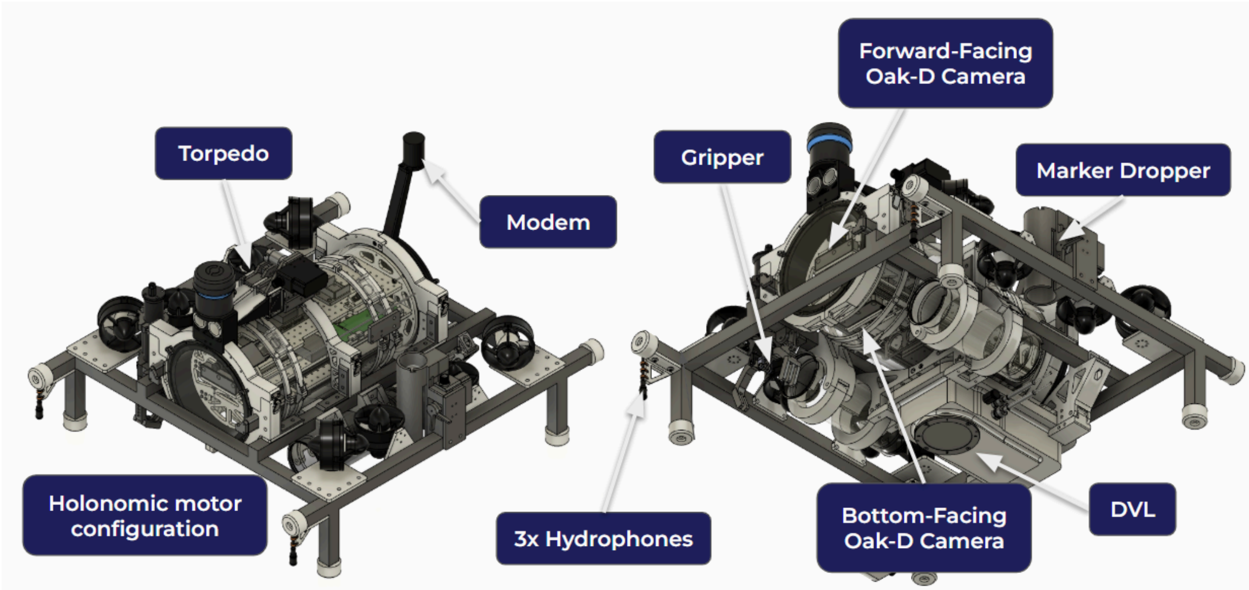


Fig. 15: Labelled CAD of Onyx

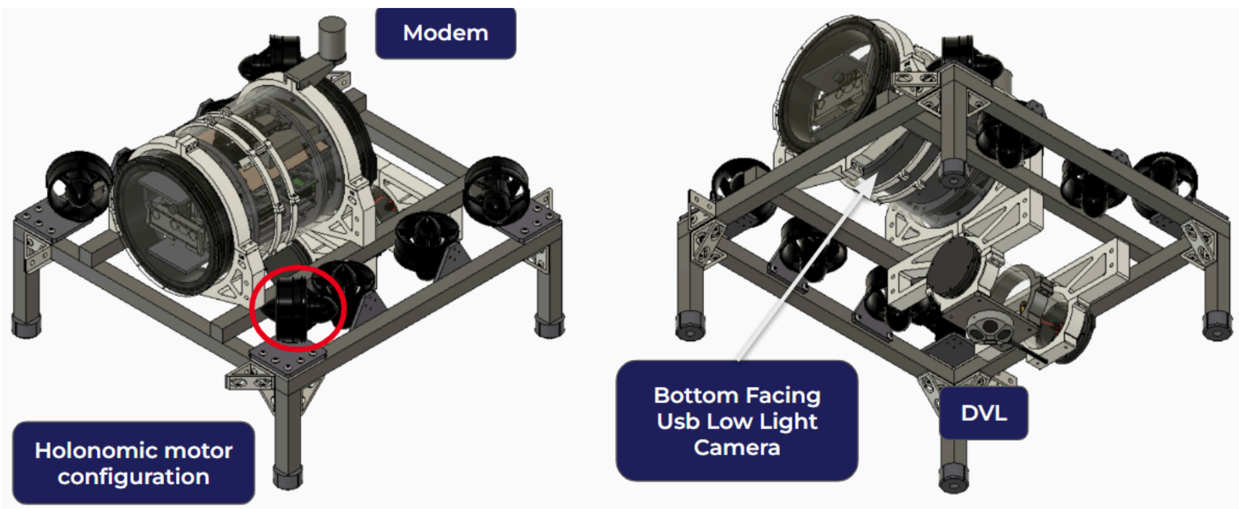


Fig. 16: Labelled CAD of Græy