Amador Valley High School Robotics (AVBotz): Design of Marlin V2 AUV 2024

Angad Bhargav (President); Mechanical: Aadi Dahake (VP), Amber Mo, Alex Wang, Kaustubh Lole, Kedarnath Arunkumar, Meghana Kumar, Noah Bowen, Rachel Schmidt; Electrical: Aarav Jain (VP), Aditya Nalabotu, Allen Ding, Alex Vovenko, Edward Chen, Gaurav Gupta, Frank Li, Raghav Pottabathini, Shaurya Shrivastava, Vedaant Sharma; Software: Aarav Singh (VP), Aarush Tahiliani, Abhinav Garg, Anoushka Lalwani, Gregory Li, Jerry Peng, Kethan Vegunta, Nikhil Sunkad, Ryan Yang, Vansh Chhabra; Business: Nikash Ramakrishnan (VP), Amishi Anand, Arnav Dhole, Athrv Gupta, Janav Rakesh, Ishan Ramakrishnan, Vivaan Sharma, Sameer Indrayan

***Abstract*—Introducing the second generation of our submarine: Marlin. Expanding on last year's mechanical implementations, electrical subsystems and software upgrades, Marlin has a lot of the tried and tested parts, along with some exciting new additions. Reliability was a big focus for this year, which we implemented in our upgraded grabber and new intake, thruster communication and electrical connectivity, and streamlined computer vision and image detection. This year's iteration of Marlin was built to be our most effective and accurate one yet.**

I. Competition Strategy

A. Gate

Similar to last year, our approach to the Gate task this year involves training ML models to detect the correct opening, the distance to the gate, and the angle toward the gate. Using this information, our sub will move through the gate while adjusting its angle and depth to ensure that the sub passes half a meter below the gate. Immediately after passing through the gate, the sub will spin 720 degrees to earn the style points. Since completing the Gate task is necessary to initiate the rest of the course, AVBotz views this task as a high priority.

B. Buoy

Because this year's buoy task varies slightly from the previous two competitions, our approach to the task is different than last year's. Although we still use the the same fundamental vision pipeline in our ML models to detect the buoy, we no longer attempt to ram our sub into the buoy, but instead align with the buoy at a set distance away. Then, our sub is programmed to move around the buoy, following the side we picked at the gate task. We detect the path marker by implementing a color filter to isolate the orange color of the path marker, improving the reliability of our computer vision pipeline.

C. Bin

Because there is a path marker from the buoy to the bins, we can reuse our vision and navigation software for this task, limiting complexity. We follow the direction of the path marker until we find the bins, scanning the floor while moving forward to save time. As there is no lid on the bin to pick up in this year's competition, we no longer need to spend time accurately aligning our grabber with the bin lid. Instead, we directly use our ML models to center our sub with the correct side of the bin, offset our sub so that our marker dropper is above the bin, and then drop the markers with our new one-hole dropper. Based on our simulation testing, our simple approach is not only effective but also time-efficient.

D. Torpedo

The new torpedo task forced our software team to re-create our mission code while the mechanical team's torpedo shooter remained relatively the same. Re-using our image processing techniques to calculate the orientation of the torpedo board so that we could align perpendicular to the board, the software team found it difficult to precisely align to the two smallest octagon holes. This is because our ML models failed to differentiate between the smaller holes and the larger holes. As a result, we decided to isolate the red color of the holes, create a bounding box around each hole, and find the smallest bounding boxes. Through our simulation testing, this was an effective way of firing our torpedoes through the smaller holes, maximizing our points.

E. Octagon

Yet, again, the octagon task was the most difficult for us to complete. Mechanical first 3D printed a grabber with four fingers but modified it to five fingers (a thumb-like contraption) after testing to grab the tube worm. On the software side, lots of simulation testing was required to detect the the PVC pipes, orient with them, and pick each prop up. Another challenge software faced was dropping each prop in a different bin to maximize points, a challenge software is still currently trying to fix. With many more pool tests to come, we plan to continue testing this task.

II. Design Creativity

A. Mechanical Subsystem

1) Marker Dropper: Our mechanical team built on last year's gravity based dropper design through further simplification. The dropper has now been converted from a double-barrel to a single-barrel release. This change reduces the risk of our markers drifting and missing the bins after being dropped, greatly increasing our chance at scoring maximum points.

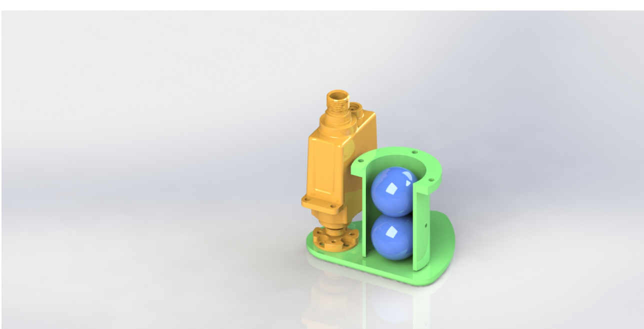

Fig. 1. Partial section view of New Ball Dropper that drops both balls in same servo motion

2) New Grabber: The new grabber has interlacing claws, which allows the grabber to more accurately and truly grab objects, rather than pinching them, which is more reliable and also prevents damage to the servo. The interlacing configuration we went with was a 2-3 finger setup to give us a wider range of grabbing. Additionally, new interlacing "thumbs" were implemented to the grabber to pick up smaller objects such as the tube worm. These two thumbs went through many iterations till we decided on a lofted right and solid left base, for a lightweight, yet rigid hold on all props and good torque despite still using one servo. The grabber thumbs allow for grabbing objects in multiple directions, diversifying our options when attempting the collection task.

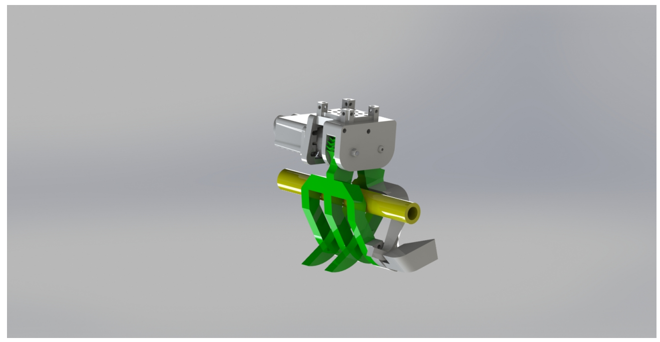

Fig. 2. New interlacing grabber that more reliably grabs horizontal objects

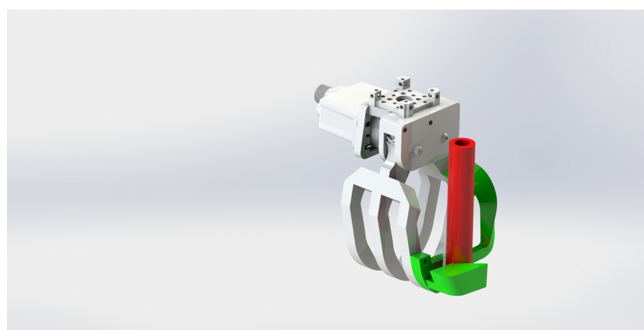

Fig. 3. Grabber fingers to reliably grab vertical objects

3) Hydrophone Mount: To fasten four hydrophones at the front of the sub we used standard metal angled mounts and modeled a combination of panels, brackets, and a solid base to ensure strength despite the minimized size. We modeled a clasping mechanism to guarantee quick insert and modularity. Overall our design allows for the hydrophones to be protected from terrain and have a viable location to receive signals.

4) Intake: A major problem we faced this year was picking up props which were either bigger or had few viable surfaces to grab. We pursued an intake that sweeps props, ensuring maximized efficiency while being a reliable solution to the bigger props with more challenging surfaces. The idea developed from two hollow boxes with cutouts and an empty bottom in combination of spinning shafts with tubes.

We turned our brainstorm into a physical solution by adding a modular panel to the bottom and 3D printing our first design. Although we had setbacks in material choice and rigidity, we overcame them by deciding on polycarbonate panels, stiff surgical tubing, and printed parts to create our design as accurate as possible. We also designed a lead screw system that can change the intakes' height, allowing for pickup at any height. In conclusion, we designed a unique, effective, and systematic way to intake props of all shapes.

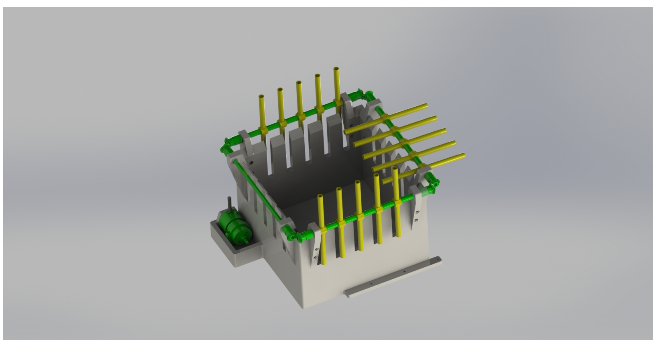

Fig. 4. Intake design, with yellow representing surgical tubing to push objects in.

B. Electrical Subsystem

1) ESC Boxes: At the 2023 RoboSub competition, the electrical team faced hardware breakdowns with our Flipsky ESCs (Electronic Speed Controllers). This year, we are using Blue Robotics ESCs because they are more efficient and have a faster response time. Additionally, we switched our communication protocol from CAN to PWM for simple wiring and debugging.

2) Sensor Stack: We have an STM Black Pill that serves as a separate MCU (Microcontroller Unit) to manage our sensors and calculations for the sensor stack. We originally used the STM Blue Pill, but it was too slow, and the interface was difficult to work with, so we switched to the Black Pill. The sensor stack contains pressure, temperature, and leak sensors that relay key information about the vitals of our submarine during tethered runs. By connecting the sensor stack to the submarine's ID, we can monitor the sensor stack's data and troubleshoot more easily. Along with a battery voltage monitor, the Sensor Stack is filled with an array of sensors that help us further our submarine's capabilities.

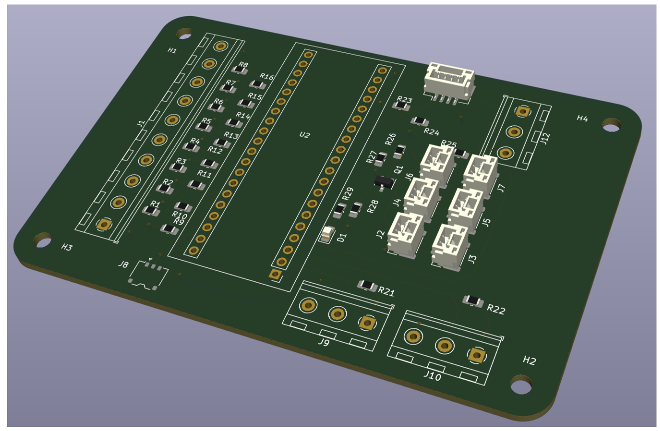

Fig. 5. Sensor stack built to monitor internal pressure, temperature, and voltage.

3) Microcontroller Setup: We switched our MCU from a Nucleo-144 to an Arduino Mega and designed a new hat for it using KiCad PCB design software to create additional connections. The hat possesses multiple JST connections for the CAN (Controller Area Network), UART (Universal Asynchronous Receiver-Transmitter), PWM (Pulse Width Modulation), and SPI (Serial Peripheral Interface) communication protocols, as well as a connection for PNI's NaviGuider AHRS (Attitude and Heading Reference System). This hat sits directly atop our Arduino and has resilient JST connectors instead of Dupont connectors, which were prone to falling out during runs. The Hat connects to our ESC boxes, Sensor Stack, Nvidia Jetson computer, kill switch, servos, pressure sensor, and DVL. Additionally, we were able to incorporate a breadboard circuit for our kill switch to relay the state of our thrusters reliably back to our MCU.

4) Hydrophone Implementation: We plan to implement the AS1 Hydrophones from Aquarian Hydrophones. For this, we need a circuit for the hydrophones that would help us extract the desired signal from the noise and interference in the surrounding environment. The filter allows signals with frequencies within a specific range to pass through while attenuating signals with frequencies outside that range. To attain this we are using an active band pass filter which mainly consists of an operational amplifier. It has a high gain bandwidth product of up to 1 MHz. This means that the op-amp can amplify signals with high frequencies and maintain stability in the circuit. In an active bandpass filter, the op amp's high GBP can help to ensure that the filter's passband is centered at the desired frequency and has a steep roll-off rate.

5) New Tether: Finally, we replaced our old tether cable since our original one was too short for proper testing and had degraded over time. Our new tether features a length of 75 meters which gives us plenty of length for testing. We are using the T568B protocol in order to keep our tether consistent with the rest of the sub.

C. Software

1) MUSIC Algorithm and Filters: This year, we incorporated a hydrophone system to improve our navigation and software filters to eliminate noise for it. Initially, we planned to use IIR filters, such as Butterworth or Chebyshev, but these filters require a constant stream of data, which is infeasible. Thus, we resorted to FIR filters, which can operate on the 25 kHz signals from our hydrophones. Since our hydrophones are in Uniform Linear Alignment (ULA), we utilized the MUSIC Algorithm: calculating the covariance matrix of our array of data and applying an eigenvalue decomposition of this matrix to determine the bearing to our pingers.

2) New Computer Vision Techniques: With the new torpedo task this year, software was forced to change our computer vision techniques. Since the torpedo board's color varied depending on its angle and position relative to the sub, our preexisting simple threshold techniques were ineffective. Instead, utilizing the fact that the color remained relatively consistent throughout the board, we chose to pursue a solution based upon color quantization through K-Means. By clustering similar colors together and creating a contour of the most common non-black color, a contour of the torpedo (torp) board could be accurately detected allowing us to detect the orientation of the torp board. We also had to change our approach for detecting the correct holes to shoot our torpedos through. While we initially chose to identify HSV ranges and implemented a HSV filter that would identify the torpedo board holes based on their red outline, we found that this approach was often inaccurate in a variety of lighting conditions. To combat this issue, we instead chose to threshold and contour the green channel of the BGR image. Given the red outline of the torpedo holes, the green values of these pixels would be close to zero. While this approach did accurately identify the torpedo board holes, it introduced a significant amount of noise. Given the fairly circular appearance of the torpedo board holes, calculating the ratio of perimeter and area and comparing that to a perfect circle could help accurately filter noise and identify the torpedo board holes.

3) Interface Updates: On our preexisting interface that uses the python library Flask, we created a new table in order to display the data of our Dopper Velocity Log (DVL), Inertial Measurement Unit (IMU), and Pressure sensor onto the interface. To do this, we created a socketio, a python library compatible with flask, connection to the backend of the interface. In the backend, we imported service files that format the sensor data that microcontroller receives from the sensors and eventually display on the front end of the interface. To get this sensor data, we send a command to the microcontroller which will then communicate with the PID controller to get the desired data. This data is then formatted to the service files that we imported to the interfaces' backend earlier and are then sent to the front end through socketio, where it will be displayed on the table for the user to see.

III. Testing

A. Mechanical

For this year's goals, the mechanical team worked heavily on reducing, upgrading, and innovating on the current submarine. This year the team took on the task of developing more task based components and upgrading multiple

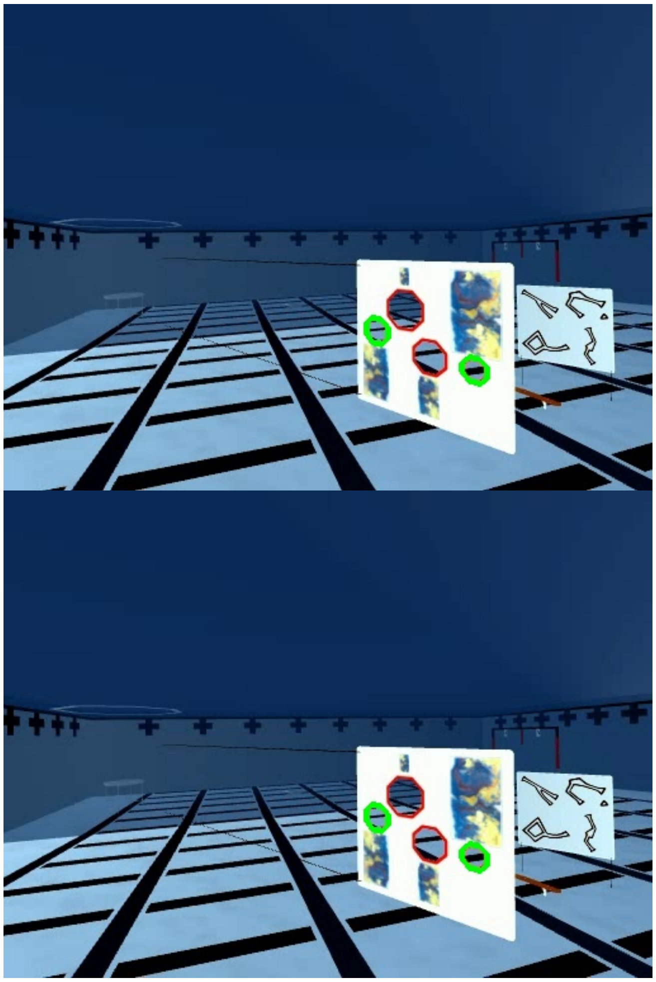

Fig. 6. Our new torpedo holes detection

components in the submarine. Our strategy for this year was to break the several tasks we had into smaller steps for us to complete. The first step taken included the designing and researching process, where we researched, brainstormed, and designed multiple solutions. Our second step was to build our prototypes, and our third step, which was often the most challenging, was to test these designs and make edits whenever necessary. The team knew it was crucial to have as much time and precision during the testing stage, to ensure, and test every possibility, for the most probability of success.

The mechanical team followed this procedure for developing a grabber, torpedo shooter, and ball dropper. After consulting with software's simulations that showed that the configuration with one finger on a side and two fingers on the other was unstable for certain grabbing orientations, we modified the grabber to have two fingers on each edge. We also added an extra inch of length, after discovering that our previous grabber's reach was too short to account for the height of the DHD dividers. For the torpedo shooter, we iterated over multiple torpedo printing settings, manually targeting infill levels that would bring the torpedo as close to neutrally buoyant as we could.

B. Electrical

From day one, we were drafting our systems, using a flowchart for power and signal distribution. Through the use of the open-source electronic design software KiCAD, the electrical team created a series of custom PCBs this year in order to streamline different levels of our sensor and communication systems. Through these PCBs, not only were we able to clean up connections and make the system easy to maintain, we were able to use them as great testing setups. The MCU hat was also convenient to use for testing, as the breakout board provided not only the more robust JST connectors, but also pin headers that are much easier to debug and troubleshoot with. The sensor stack would also prove instrumental during testing, being able to relay important information about our sub such as the temperature in different parts of the rack, the humidity of our MEB, potential leaks, and our battery voltage levels—all vital stats of our submarine during hours long testing runs.

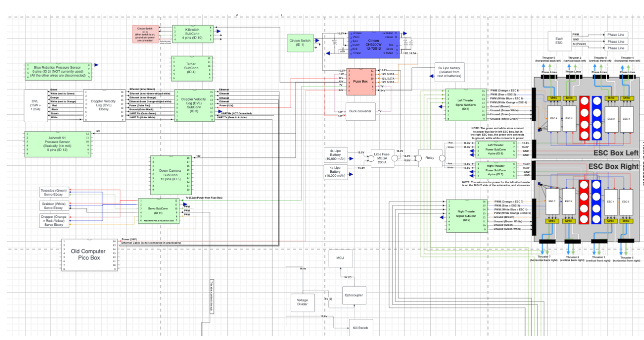

Fig. 7. Power and signal distribution chart.

C. Software

Simulation testing [1] has been software's best way of testing our improvements. The moment the new tasks were released, the software team designed the new props in blender and added it to our gazebo simulation. This allowed us to test all aspects of our mission code, especially our vision code. Additionally, we worked on implementing a simulated pinger sound signal to simulate the hydrophones task of the competition, allowing us to perfect our MUSIC algorithm. Our simulator testing has allowed our pool tests to be very efficient and effective as we know our mission code already works.

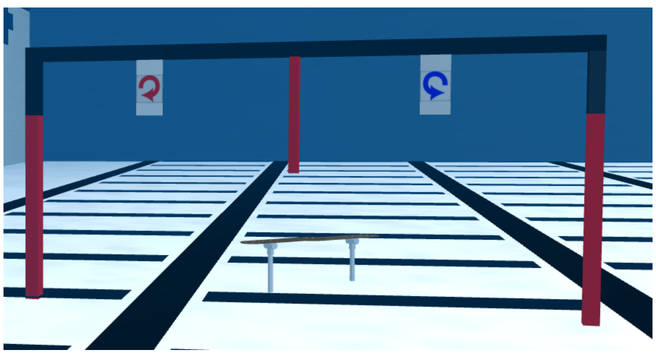

Fig. 8. Simulating the Gate task in the sim.

D. Lessons Learned

The most important lesson we learned is that it is imperative to have clear communication between each subdivision of the club and between officers and members, to ensure that there is no confusion between timelines and goals. Furthermore, we learned that no matter how rigorously we prepare, we will inevitably face technical challenges. Then, the emphasis must be to stay calm even in the midst of a crisis, to think of all possible solutions to solve the problem. Usually, there is a solution if we look hard enough. To deal with this, the emphasis must be to stay calm when mistakes are made, so that we: 1. Can solve the problem at hand quickly and efficiently. 2. Avoid ruining anything else in our haste to solve the problem.

Acknowledgments

None of our work this year would be possible without a community of support. We would like to thank our advisor Mrs. Bree Barnett Dreyfuss for advising us on technical and organizational issues. We would also like to thank Pleasanton Partnerships in Education Foundation, The Rotary Club of Pleasanton, Costco, and Parent Teacher Student Association for their financial support, LDO Motors for generously sponsoring a Voron 3D printer, Rodhe and Schwarz for generously providing a RTH1002 oscilloscope, PNI Sensor Corporation for kindly providing a user-friendly magnetically self-calibrating NaviGuider AHRS, Amador Valley High School for providing us with pool facilities, and our parents for their endless patience and emotional support throughout this season.

References

[1] Liquid-ai, "Plankton: Open source simulator for marine robotics researchers." [Online]. Available: https://github.com/Liquid-ai/Plankton

APPENDIX A: COMPONENT SPECIFICATIONS

Component	**Vendor**	**Model/Type**	**Specs**	**Custom / Purchased**	**Cost**	**Year of Purchase**
Frame	Custom	Aluminum 6061 - T6	90.50cm x 63.50cm x 33.34cm	Custom	Sponsored	2023
Main Waterproof Enclosure	In-House	Acrylic Hull Sealed with Two Rubber O-Rings	Diameter: 24 cm	Custom	$200	2016
Waterproof Connectors	SubConn	Circular Series SubConns	(Varies Based on Series) Micro-Circular Series, Power Series	Purchased	$1500	2015
Thrusters	Blue Robotics	T200 Thrusters	113 mm Length	Purchased	$200 ea.	2022
Electronic Speed Controllers	Blue Robotics	Basic ESC	17.1 mm x 32 mm x 3.3mm, 7-26 V, PWM Communication	Purchased	$38 ea.	2023
Microcontroller: Motor Control	Arduino	ATMega 2560	256 KB Flash Memory, 8 KB SRAM	Purchased	$50	2024
Batteries	ZEEE Power	4S	9000mAh, 14.8V	Purchased	$195	2022
DC to DC Converter	Cincon	CHB200W12-72S12	200W, 16V to 12V	Purchased	$185	2023
Computer	Nvidia	Jetson AGX Orin Developer Kit	414mm x 311mm x 182mm, 275 TOPS, 2048-core GPU, 12-core CPU	Purchased	Sponsored	2022
Internal Comm Network	ROS	ROS2 Foxy	Ubuntu 20.04	Custom	Free	2022
External Comm Interface	-	Ethernet	1 GB/s	Purchased	Included with SubConn	2015
Doppler Velocity Log (DVL)	Waterlinked	A50	5cm–50m altitude range, 600m depth rated, Ethernet and Serial communication, 1 MHz frequency	Purchased	Free	2022
Altitude Heading and Reference System (AHRS)	PNI Sensor	NaviGuider	Heading Accuracy: 2° rms, UART Communication	Purchased	Sponsored	2023

Pressure Sensor	Blue Robotics	Bar-30	Accuracy: ±2.9psi, I2C Communication, Supply Voltage: 2.5-5.5V	Purchased	$85	2023
Front Camera	FLIR	BFS-U3-200S6	Frame Rate: 30 fps, Resolution: 5472x3645, Megapixel: 20MP, Sensor Type: CMOS	Purchased	$750	2015
Front Camera Lens	Computar	VO828-MPY	8mm fixed lens, Resolution: 12MP, Horizontal Angle: 77.3°, Vertical Angle: 61.7°	Purchased	Sponsored	2015
Down Camera	FLIR	BFS-U3-13Y3C-C	Resolution: 1280x1024, Megapixel: 1.3MP, Frame Rate: 170FPS, Sensor Type: CMOS	Purchased	$540	2015
Down Camera Lens	Theia	SY125M	Focal Length: 1.3mm, Resolution: 5MP, Horizontal Angle: 125°, Vertical Angle: 119°	Purchased	Sponsored	2015
Signal Processing	Diligent	Nexys 4 DDR Artix-7	Block RAM: 4,860 Kbits	Purchased	$250	2019
Algorithms: Vision	Ultralytics	YOLOv8s, RGB equalizing filter	5 FPS	Open Source	Free	2023
Algorithms: Acoustics	In-House	MUSIC	Hydrophones	Custom	Free	2018
Algorithms: localization, mapping	In-House	DVL data, image calculations	DVL, IMU, CV	Custom	Free	2017
Algorithms: Autonomy	In-House	Linear instructions	ROS2 nodes	Custom	Free	2022
Open source software	Open source	ROS2, YOLOv8s, OpenCV	Node management, computer vision	Custom	Free	2023

Team Size (number of people)	44
Expertise ratio (HW vs. SW)	23:13 + 8 Business
Testing time: simulation	125 hours
Testing time: in-water	90 hours

Programming Languages	C, C++, Python 3