Amador Valley High School Robotics (AVBotz): Design of Marlin V2 AUV 2025

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***Abstract*—Introducing the fourth generation of our submarine Marlin. Expanding on the mechanical implementations, electrical subsystems and software upgrades of last year, Marlin has many of the tried and tested parts, along with some exciting new additions. We have focused on reliability this year through upgrading our grabber, intake, thruster communication and electrical connectivity, and streamlined computer vision and image detection. We have built this year's Marlin iteration to be our most accurate 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 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. Slalom

The 2025 slalom task introduced a fundamentally different set of requirements from the prior buoy challenge. In response, we redeployed our machine learning–driven vision pipeline—originally trained for buoy detection—to identify and track vertical pipe pairs, enabling dynamic estimation of gate centerlines. Upon detection, the AUV initiates a controlled slalom behavior, executing lateral transitions while maintaining sub-crossbar depth to satisfy bonus scoring criteria. This maneuver is governed by a real-time feedback system integrating camera data, inertial measurement data, and depth sensing, ensuring continuous heading correction and fine-grained positional control.

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 recreate our mission code while the mechanical team's torpedo shooter remained relatively the same. Reusing 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 to fire our torpedoes through the smaller holes, maximizing our points.

E. Octagon

However, again, the octagon task was the most difficult 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 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 worked on many crucial edits to the gravity-based dropper design to increase its strength and stability. With the new addition of a servo hub and a servo mounting plate, we are able to distribute the suboptimal point load that was previously on the servo shaft onto the entire servo hub. By making this change, we can ensure that the whole mechanism is in good condition, increasing long-term accuracy and testing capacity.

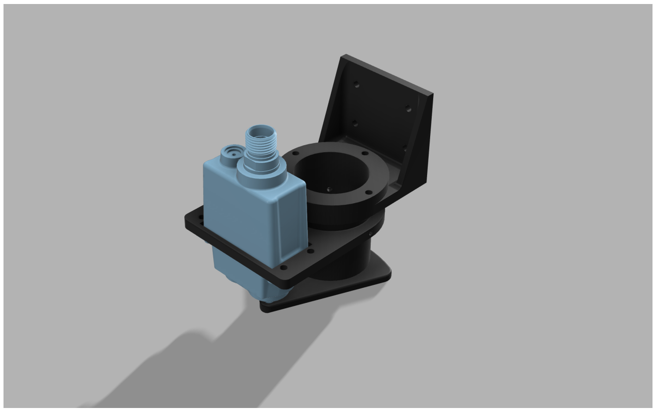

Fig. 1. Updated dropper design with stronger structural integrity

2) New Grabber: Over the past few years, we have faced issues with our grabber fingers being unreliable in grabbing the multitude of props presented in the autonomous test. The newest phase of our grabber project saw a diversification in our grabgers. We created several different 3D-printed iterations of the grabber fingers to give ourselves the best chance of completing this year's collection task with the most accuracy. Due to this year's rounder collection props, our most promising versions have been the simplest ones, a stark contrast to last year, which saw several extra grabbing fingers and thumbs.

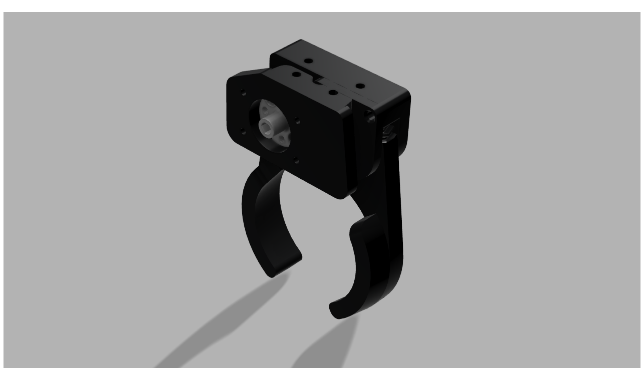

Fig. 2. Rounded grabber fingers tailored to grab the ladle prop

3) Intake: One of the primary challenges posed by this year's Octagon task was the collection of irregularly shaped props, specifically the bottle and spoon, both of which offered minimal consistent geometry for standard grasping mechanisms such as claws. In response, we imrpoved the design of our sweeping intake system, prioritizing performance and reliability. This year's iteration featured significant structural improvements, including modular polycarbonate panels for enhanced durability and alignment precision. At its core, the intake relies on rotating shafts sheathed in surgical tubing, which actively draw objects inward through consistent contact and motion.

To accommodate the variety of object placements, particularly those resting on the Octagon's central trash table, we incorporated a lead screw based vertical adjustment system. This allows the intake to reposition dynamically during a run, ensuring alignment with target objects at varying heights. Not only does this design increase reliability, it also aligns with our broader mission to create long lasting components capable of performing in unpredictable, real world conditions.

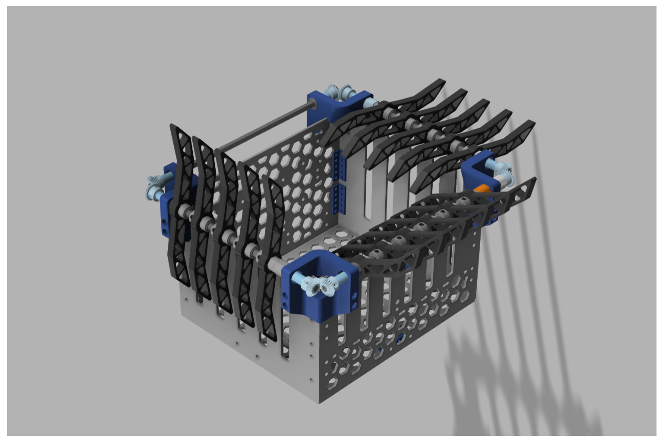

Fig. 3. Intake design, with 3D printed TPU claws for flexible grabbingw.

B. Electrical Subsystem

1) Microcontroller Unit: We developed a new custom hat that sits atop our Arduino Mega microcontroller (MCU) this year. The hat manages all of our submarine's communication protocols like CAN (Controller Area Network), UART (Universal Asynchronous Receiver-Transmitter), PWM (Pulse Width Modulation), and SPI (Serial Peripheral Interface). The hat also integrates our kill switch circuit as well as our AHRS into a singular PCB.

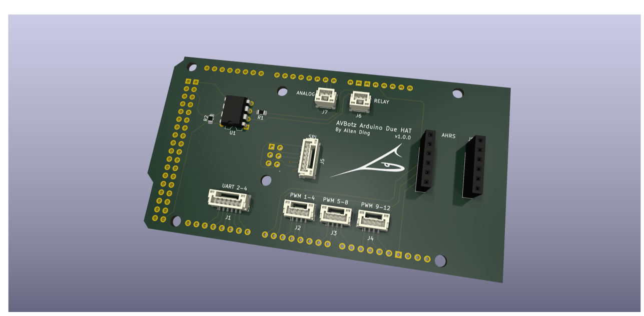

Fig. 4. Custom Arduino Mega "hat"

2) Sensor Stack: The STM Black Pill is the main focus of our sensor stack, acting as a separate MCU that manages our sensors and calculations. The sensor stack contains pressure, temperature, leak, battery voltage monitors that relay key information about our submarine's interior during tethered runs. We replaced all of the sensor stack's screw terminals with JST connectors, except for the temperature sensors. By connecting the sensor stack to the submarine's ID, we could track data from the sensor stack and troubleshoot more reliably.

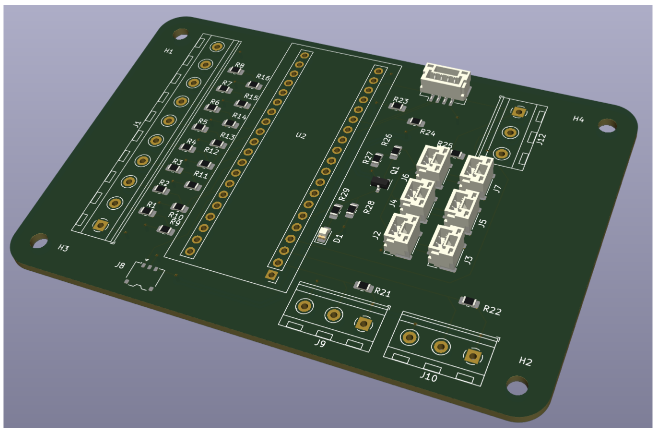

Fig. 5. Sensor stack built to monitor internal pressure, temperature, and voltage.

3) Hydrophone Implementation: We are designing a custom data acquisition board for the Teledyne Reson 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 (25–40 kHz) to pass through while attenuating signals with frequencies outside that range. To achieve this, we are using an active third-order band pass filter comprising an operational amplifier (op-amp) and RC circuits. The filter has a high Gain Bandwidth Product (GBP) of up to 1 MHz, allowing the op-amp to amplify signals with high frequencies and maintain stability in the circuit. In an active bandpass filter, the high GBP of the opamp can ensure that the filter passband is centered at the desired frequency and has a steep roll-off rate. In order to power our data acquisition board, we used another custom board using a dual power supply circuit.

C. Software

1) Upgrading MUSIC algorithm: This year, we switched from using the Multiple Signal Classification (MUSIC) algorithm for estimating the direction of the pinger to using the Root-MUSIC algorithm. The reason for this is that Root-MUSIC is much more computationally efficient than MUSIC and is specifically designed for Uniform Linear Arrays (ULAs), which is the setup of our hydrophones.

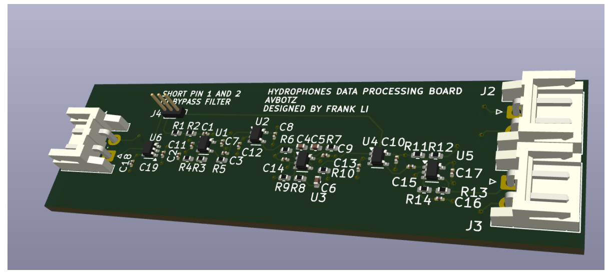

Fig. 6. Hydrophones data processing board.

MUSIC works by computing a spectrum of different possible angles (frequencies), with the peaks being the true directions. However, Root-MUSIC instead finds the roots of a polynomial derived from the noise subspace, which is much faster to implement. Additionally, Root-MUSIC is more accurate in a ULA setup, since MUSIC is limited by the grid resolution of the search space. We also implemented the pinger in the simulation, which allows us to effectively test out sound-based tasks that we weren't able to do before.

2) New Computer Vision Algorithms: This year, we've decided to move away from the contour detection algorithms we have relied on for the past few years. We've discovered two new algorithms that work better for our purposes: DeepSeeColor and SIFT. DeepSee is a model-based color correction system that makes it easier to detect specific parts of an object underwater. SIFT is another computer vision algorithm that detects the features of an object regardless of the size and orientation of the image. Having the ability to detect specific features on an object reliably is essential to correctly orient and move our submarine.

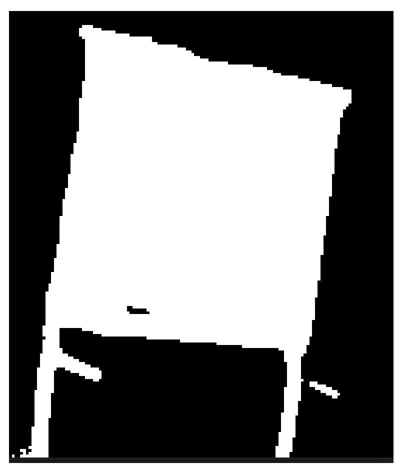

Fig. 7. Identifying the torpedo board with DeepSee

3) Upgraded control and correction system (MPPI and LKF): For many years, the AVBotz control system has been solely PID, with a few upgrades to a cascaded PID control system in the past couple of years. This year, we've introduced a Model Predictive Control system, specifically the Model Predictive Path Integral (MPPI) algorithm. This algorithm finds the best control by simulating thousands of possible trajectories and choosing the best one. The reason why we chose this algorithm is that it makes nonlinear movements much smoother, quicker, and cleaner compared to our Cascaded PID system. This would help in tasks such as this year's slalom challenge. We are using the nav2 framework as it comes with supplementary functions to use in our implementation. Along with MPPI, we've introduced a linear Kalman filter. Last year, we experienced some discrepancies in our data that messed up our movement. We've decided to implement a linear Kalman filter as a backup, just to prevent anything of the sort from occurring this year.

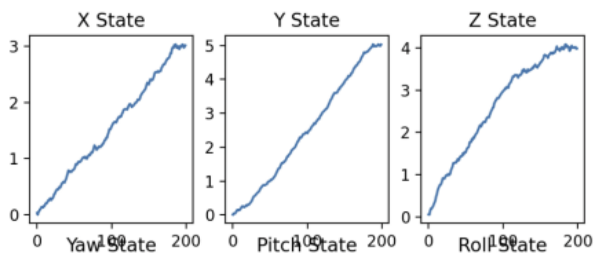

Fig. 8. MPPI movement simulation

III. Testing

A. Mechanical

For the goals for this year, the mechanical team worked hard to reduce, upgrade, and innovate on the current submarine. This year the team took on the task of developing more task-based components and upgrading multiple components in the submarine. Our strategy for this year was to break down the several tasks we had into smaller steps for us to complete. The first step taken included the design and research 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.

B. Electrical

From day one, we were drafting our systems, using a flow chart for power and signal distribution. Through the use of open-source KiCAD electronic design software, the electrical team created a series of custom PCBs this year to streamline different levels of our sensor and communication systems. For example, 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.

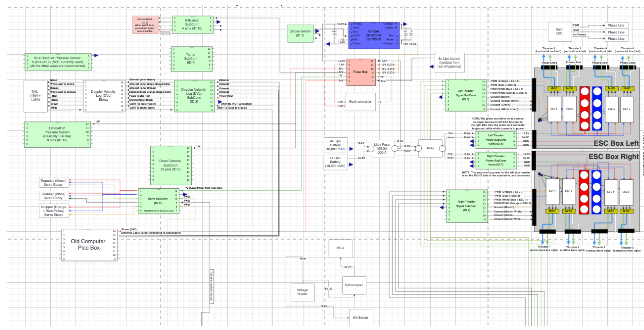

Fig. 9. Power and signal distribution chart.

C. Software

Simulation testing [?] has been the best way software can test our improvements. The moment the new tasks were released, the software team designed the new props in blender and added them 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 hydrophone 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.

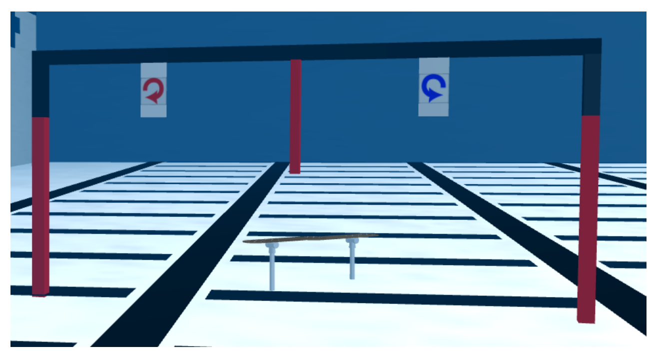

Fig. 10. Simulating the Gate task in the sim.

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 rush to solve the problem.

Acknowledgments

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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)	41
Expertise ratio (HW vs. SW)	3:1 + 9 Business
Testing time: simulation	125 hours
Testing time: in-water	90 hours
Programming Languages	C, C++, Python 3