Qubo IV: RoboSub 2023 Technical Report

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***Abstract*—Qubo is an autonomous underwater vehicle (AUV) that has been continuously improved since 2016. For 2023, Robotics @ Maryland submitted an improved version of Qubo, focused on reliability and modularity in order to build for the future. This version of Qubo boasted an all new computer, a completely redesigned electronics hull, and numerous new end effectors. A new IMU and a stereo camera were also integrated into the system. Significant progress was made towards designing and implementing a custom passive sonar system.**

***Index Terms*—Inertial Measurement Unit (IMU) Finite Element Analysis (FEA) Printed Circuit Board (PCB) Computer Numerical Control (CNC) Universal Serial Bus (USB) Integrated Circuit (IC) Pulse Width Modulation (PWM) Electronic Speed Controller (ESC)**

I. Competition Strategy

Though Qubo has been in development since 2016 [1], last year (2022) was the first time it was capable of competing. Robotics @ Maryland (R@M) went through a complete overhaul throughout the COVID-19 pandemic, including new faculty advisors, new partnerships with the Maryland Robotics Center and Mechanical Engineering Departments, new facilities like the IDEA Factory, etc. With R@M experiencing exponential growth with a young and more diverse member base, the team shifted to an education-first strategy, focused on on-boarding, community events, and volunteering ahead of technical development.

With these challenges, R@M's strategy for the 2023 competition was breadth-first, focused on incremental improvements to all competition categories. R@M had the goal of making it to finals with a simple yet robust submarine design and holistic improvements to the team. The most notable improvement was in the team website and documentation. These advanced competitiveness and also contributed to the longevity of the club, which took priority. To achieve this task, the team played to Qubo's strengths and maximized mobility points.

After thorough analysis of the point system and previous competition scores, it was noted that passing through the gate (with style modifiers and on the correct side), crashing into the correct buoy, and surfacing in the ring was sufficient to progress to finals. As the competition transitioned back to TRANSDEC, R@M prioritized development of a passive sonar system to aid navigation in the murky water and help surface in the ring. Once the robot closed in on the ring, Qubo's new Zed2i camera was used to navigate around it. The team prioritized these tasks, as other tasks required fine control of the robot, which the team did not have last year. The team believed this could be addressed with a better IMU (Inertial Measurement Unit) and by running thrusters at a constant voltage, but there was concern that the motors were not linear enough to provide control without significant oscillation. The team did not have enough control theory experience to resolve this issue before integrating the new system.

At the time of writing, Qubo's sonar system was still in development. Due to uncertainty of readiness by competition date, R@M's strategy shifted to include the marker dropping task. The claw mechanism demonstrated reliability, and integration of that functionality was a safer strategic path forward than the completion of the sonar system. Both efforts were still developed simultaneously due division of labor that avoided overlap.

II. Design Strategy

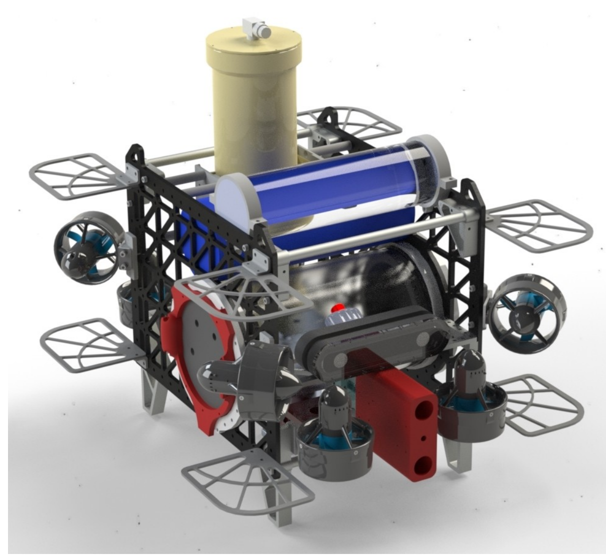

Fig. 1. Rendered CAD model of Qubo.

A. Design Goals

Last year, the team sprinted to have a functional robot to achieve basic autonomy in the competition. This resulted in an unreliable, aged system as a baseline for the following year. To set the foundation for future success, the project underwent a software migration, the integration of a stereo camera, the addition of several end effectors, the restructuring of the electronics hull, and the development of a passive sonar system.

B. Existing Design

The mechanical assembly of Qubo largely remained the same from the previous year. The thruster configuration allowed movement with six degrees of freedom. The bumpers remained in place, but were 3D printed from nylon in the current competition to avoid fracture. For the competition goals set, the mechanical assembly was deemed acceptable. The Blue Robotics T200 thrusters posed a potential problem because their lowest possible speed (using the Blue Robotics electronic speed controllers [ESCs]) caused a significant yaw. The risk of dealing with continuous yaw oscillations was acceptable, as it could be addressed via controller and actuation system improvements. The time required to procure, test, and implement new thrusters and/or ESCs was too costly, and other issues had higher priority. The existing mechanical assembly was compact and light-weight. This garnered points in competition and allowed for ease of transport.

Some sensors from the previous year were kept. Though the Doppler velocity logger (DVL) was from 2006, testing proved it to be viable, and its extra mass reduced yaw oscillation. Also, a new DVL was too expensive. The depth sensors also were kept, as they were functional. The Mako camera was also kept, and was pointed down to track markers between tasks, as well as the possible marker dropper task.

C. Software Migration

1) Simplify Computer Hardware: The previous year, thrusters were controlled by a Texas Instruments Tiva microcontroller, requiring a custom UART-based communication protocol to connect the Tiva to the main computer. Thruster control was transitioned to a dedicated PCA9685 microcontroller driven via I^2C by the main computer. This reduced the learning curve for new members and avoided non-standard communication protocols.

2) Software Stack Upgrades: Many libraries previously used were no longer maintained, so the team upgraded from ROS 1 (Robot Operating System) to ROS 2 Humble Hawksbill. Code was transitioned to run in Docker containers, allowing the software team to use the library versions without hardware restrictions. This also reduced the need to purchase the latest hardware, lowering costs.

ROS 2 has official support for micro-controllers (https://micro.ros.org/), presenting the ability to add embedded computers for peripherals and meet real-time latency requirements.

D. Stereo camera

Qubo was outfitted with a ZED 2i stereo camera, giving it depth perception. Most infrared depth cameras are not designed for use in water—especially murky water—, so the team chose the ZED camera because it detects depth purely with binocular vision and an onboard machine learning model.

Depth information helped in pre-qualification and similar tasks, where the code previously struggled to reliably detect the gate and pole. Machine-learning based detectors were avoided, since training images would have to be re-collected and the model re-trained at competition. Instead, a traditional OpenCV-based detector was used and tweaked manually. Traditional detectors struggle underwater due to loss of contrast and blue-shift underwater, but given that pool elements were essentially floating in a vacuum, an accurate depth map provided a high-contrast image that could detect the gate with pixel thresholding algorithms. The results of this approach are in Figures 2 and 3.

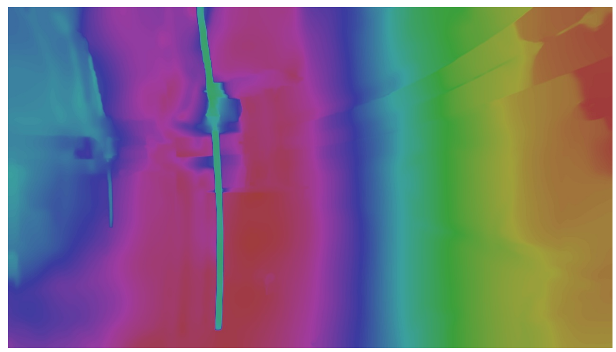

Fig. 2. Stereo camera depth map.

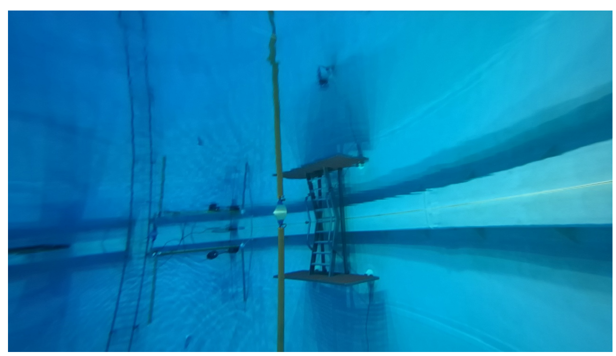

Fig. 3. Stereo camera colored image.

While distance from objects (such as the gate) were triangulated from a single detection, objects such as the vertical pole offered a challenge. This was due to sparse information available to estimate distance from a monocular image. For the vertical pole detection task, the stereo depth map provided an accurate estimate of the pole position.

E. End Effectors

After Qubo's infrastructure took full shape, end effectors, or mechanisms used to help a robot interact with its environment, were designed and implemented. The major end effectors needed for this competition were a two prong claw and a torpedo launcher, which are discussed below.

1) Claw Mechanism: In order to interact with markers and bins during competition, a compact claw was developed. Unlike a traditional claw that opens in an angular motion about a fixed axis, R@M's new design utilized a rack and pinion to open and close the claw, as seen in Figure 4. This

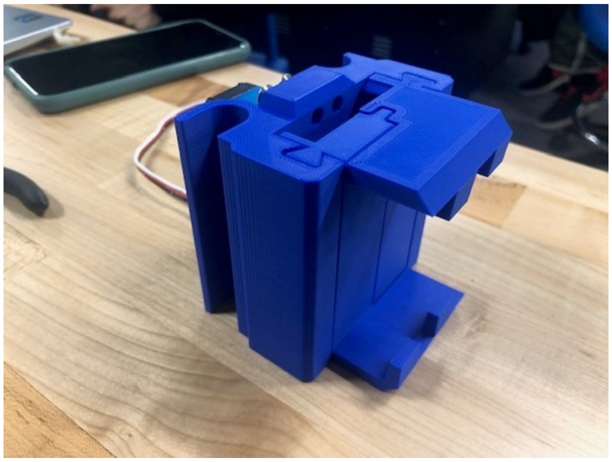

Fig. 4. Final claw design. Its compact rack and pinion design gave the claw arms much more support than a rotating-arm method.

created a linear motion instead, which provided extra support on the sides and a more consistent range of motion. It was also very compact, staying within the 4 inch height limit while remaining effective. This was the major inspiration for adding legs to Qubo, as they allowed the claw to mount in the center of Qubo, giving adequate room to successfully strike the bins and drop markers.

2) Torpedo Launcher: The goal of the Torpedo Launcher was to launch two torpedoes independently from each other with one motor. This functionality allowed for multiple attempts to shoot at a target, giving the robot the ability to reposition itself and shoot again while only using one actuator. In the past, this part of the challenge was absconded from the competition strategy. As a result, development of this functionality was entirely novel for the team, and needed to be efficient and timely.

The Torpedo Launch System experienced an iterative design process. Throughout this process, each iteration sought to increase the robustness of operation of the launcher while also taking advantage of the IDEA Factory 3D printing facilities for rapid prototyping. The Torpedo Launcher underwent three design iterations. The first iteration was completed over the course of Summer 2022 as a proof of concept. The second iteration took place in Fall of 2022 to produce a working model. The third iteration took place in Spring 2023 to produce a torpedo launcher that would be competitive. Since this launch system is an attachment to the main body, each iteration was developed independently of most of the other subsystems. This allowed for efficient division of labor during the iterative process, while also allowing the team to have each iteration compatible with a submarine chassis that was largely reused from last year. The first iteration was developed as a proof

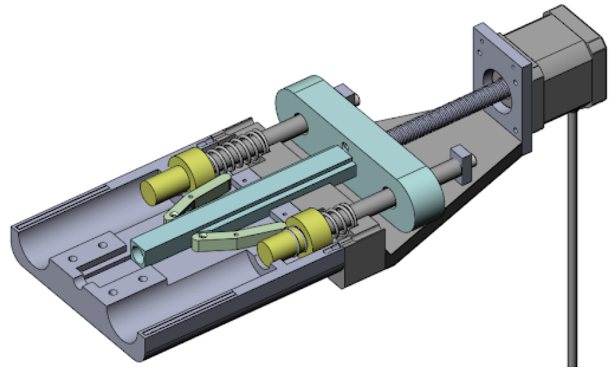

Fig. 5. CAD model breakdown of the torpedo launcher (version 3). It utilizes an offset ramp system to allow independent firing with just one actuator.

of concept for launching a torpedo from the Qubo robot. It launched a single torpedo, and had to be manually primed with a rod. While this iteration was useful for familiarization with the general structure of a torpedo launcher, it did not meet the end demands for the launcher. However, it gave the team a framework for future development, especially in context to the new facilities the team had access to this year. The 3D printing facilities were critical to the rapid prototyping necessary for the next two iterations. It was for this reason why, upon completion of this iteration, the continuation into the next iteration was fairly smooth.

The second iteration sought to support multiple torpedoes, while also priming its own springs and firing mechanism. Upon the completion of this iteration, the aim was to have a launching mechanism that would be viable for competition, even if not perfect. Through rapid prototyping, a design was eventually reached where the launcher used a single motor for a double action mechanism, in which the same mechanism could prime and fire. Upon completion of this design, the team developed a functional multi-torpedo launcher that met the minimum requirements for competition. Yet, a few potential improvements were noted. One, there was an opportunity to condense the overall structure of the launcher. Two, there was an opportunity to increase the structural integrity of the launcher.

The third iteration accomplished both of these objectives. Again, the rapid prototyping was critical for decreasing the structural components progressively while also maintaining ease of assembly. Ultimately, a condensed frame was accomplished by assembling a stepper motor on rear of the launcher. During simulation and testing, it was revealed that structural stress resistance and fluid dynamics of the torpedoes were viable for competition, verifying the benefits achieved from the third iteration of the launcher design.

F. Electronics Updates and Hull Restructure

The most significant change to the system was the overhaul of the electronics hull. One of the biggest problems previously faced with the system was assembling it by connecting the electronics inside the hull. No planning was done for the previous year, with only a couple 3D printed pieces holding parts. This led to it taking multiple hours to open up and close the hull, which made it almost impossible to debug possible connection issues. This was especially a problem because the compression of wires and cables inside the hull had the potential to cause disconnects or even shorts. In addition to this, the power distribution board, which took power from the battery and broke it out across different regulators to power the system, had several issues. It was poorly documented, used non-common components, and was crudely assembled without any of the current reader ICs it had been designed with. It was also determined a newer computer was needed because the TX1 the team had was falling out of support and more graphics processing power was needed to handle image recognition and multiple video streams.

With the overall design goal for the year being to build a reliable platform for the future, it was determined that a new power board needed to be designed. This new power board, seen in Figure 6, has key features like running thrusters from 12V power instead of battery voltage. Battery voltage is not

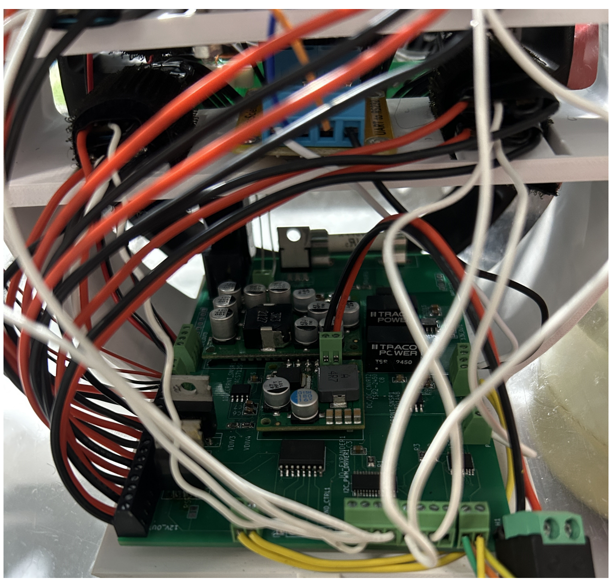

Fig. 6. The power board placed inside of the electrical hull. This was custom made to support the large current pulled from 8 thrusters and break out multiple voltages for end effectors and other electrical components.

constant over time, but the thrust over input PWM curves for the thrusters and ESCs are dependent on voltage. Another key feature is the inclusion of ICs that communicate with the computer over I^2C and monitor voltage and current on the board. The PCA9685 is also located physically on the power board. MOSFET switches have also been implemented on the 12V bus, which can be actuated by the computer in case of a current surge or critically low battery voltage.

For the hull reorganization, the team considered using a backplane to connect components in the electronics assembly, which would eliminate the problem of compressing wires inside the hull. This was decided against because the time to develop the backplane was too long, and the software team is dependent on a working platform to test code outside of simulation. The solution was to instead create a small PCB to route all of the connections through on the more busy endcap. That way, this PCB can serve as a barrier between all the connections coming from the inside of the endcap and the electronics assembly inside the hull. This allows the installment of the electronics assembly inside the hull to be much faster than it was previously.

G. Passive Sonar System

Although the sonar system was unfinished at time of writing, the team completed a design that could work for preliminary testing. The team chose to create a system that delivers a bearing to the pinger, instead of attempting to calculate a distance directly. This is because the latter would involve the near-field approximation, which might not function so well at larger distances. Also, a distance to the pinger could be calculated from a bearing by using a known pinger depth and Qubo's depth from the sensor. Multilateration is used to find a bearing to the pinger from time difference of arrival (TDOA) between at least 4 hydrophones and the known distance between each hydrophone [2].

To find TDOA, the team chose to find the rising edge of each ping by thresholding in the frequency domain. This differed from other teams' systems which used phase difference in the past to calculate TDOA. By using the rising edge of the pings, it was expected that the system would be affected less by multipath in an environment prone to echoes than systems that use phase difference. This is because the front edge should have always been free of distortion from constructive and destructive interference caused by multipath. There was only one shortest path if it was direct. This feature was highly desired because environments prone to echoes are commmon. In the previous year, many teams struggled with sonar in the Eppley pool for this reason. Also, though the competition is held San Diego this year (which has an acoustic testing pool designed to dampen echoes), that location is not guaranteed every year, and the system must also be tested in pools with no acoustic dampening.

The plan was to implement the system on Zynq hardware. This would allow the system to run in real time as the programmable logic (PL) can be used to implement the sliding DFT [3] (discrete Fourier transform) and receive data from the custom data acquisition (DAQ) board at a sample rate of 500kS/s (per hydrophone). The processing system (PS) can be used to do the do pinger bearing calculation and the thresholding logic. ROS and Linux could be run on the PS to easily communicate the pinger information to the main computer.

III. Testing Strategy

A. Mechanical System Testing

Throughout the development of Qubo's many new mechanical systems, extensive testing was necessary for proof of concept, waterproofing, hydrodynamic and structural applications. Rapid prototyping using 3D printers and resin printers allowed for quick testing of conceptual designs, especially during development of R@M's custom torpedo launcher. Creating custom enclosures while ensuring no damage came to Qubo's expensive electronics meant finding a way to effectively test a hull's seals. Custom torpedoes were also developed to ensure the launcher fit on Qubo, and their hydrodynamics were simulated using Ansys. Finally, FEA analysis was conducted on many structural components using SOLIDWORKS Simulation. All of this testing was crucial to properly planning before manufacturing, where part failure would lead to a more arduous design cycle.

1) Rapid Prototyping: R@M takes pride in designing as much as possible from scratch, including PCBs, structural components, enclosures, and soon a sonar system. While this created an invigorating robotics experience, it also slowed development and required many iterations. For example, the Zed2i camera mount was redesigned four times to account for waterproofing issues, perfecting tolerances, and properly fitting the USB cable. To test the functionality of press fits and tight tolerances, 3D and resin printing techniques were used over manual machining. While machining parts may produce a more robust part, 3D printing had an immensely faster turnaround. Resin, when used properly, may be used as a replacement for Delrin or other hard plastics for enclosures. These parts may be used to test dimensions and fittings, and limit arduous machining to only the first iteration.

2) Waterproofing Enclosures: To ensure that Qubo's expensive electrical components were safe in deep water, an extensive vacuum testing plan was developed for testing the effectiveness of enclosures. In previous years, R@M sunk enclosures deep underwater for hours and later checked for water inside the system. This was a flawed approach, as this took far too long and required access to a deep pool to fully qualify the system as ”water proof”. Enclosures also need constant testing as O-rings may vary in effectiveness as they are moved around - for example, dust may collect on the O-ring or the lubricant may dry during enclosure opening/closing. To resolve these concerns, a vacuum system was purchased to apply a negative pressure and check for leaks. A positive pressure was not applied as enclosures are designed to withstand large inward forces. This vacuum either remained at the pressure it is set to, around -10 psi, or slowly moved back to atmospheric pressure if there was a leak. To find the leak, the enclosure was placed underwater and the vacuum quickly revealed bubbled around the problem area. This expedited the development of safe, effective enclosures for Qubo, which was crucial for finishing battery and camera hulls for competition.

3) Hydrodynamic Testing: As the torpedo launcher was developed, a crucial constraint was added to its length that prevented normal toy torpedos from fitting in the system. This meant a custom torpedo was needed, one that was smaller yet still able to glide towards a desired target. To optimize the torpedo design, the simulation software Ansys was used. Ansys provides free simulation software to students, including structural, material, dynamic, and fluid dynamic modelling capabilities. The fluid dynamic software Ansys Fluent was used to produce a velocity profile as seen in Figure 7. This design has a shallow drag profile, meaning it is hydrodynamic but potentially unsteady as drag aids the direction of travel. In the future, Ansys will be useful in improving the design while staying within necessary design constraints. Although this testing has not occurred as of writing this, once the torpedo launcher is fully functional on Qubo, multiple torpedo models will be tested to determine which will travel furthest and most accurately at different depths.

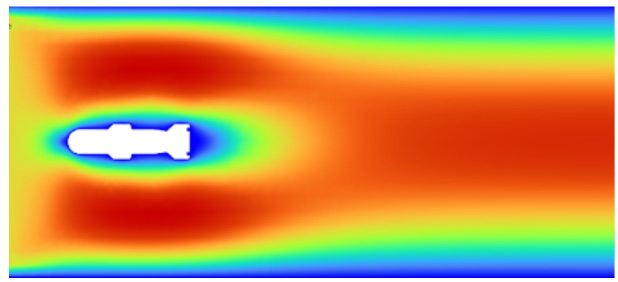

Fig. 7. The Ansys velocity profile of the current torpedo bullet. Red indicates maximum velocity, while Blue indicates zero velocity (and therefore more resistance from the torpedo).

4) Finite Element Analysis: FEA was performed in SOLIDWORKS for multiple reasons. All team members had access to SOLIDWORKS through the educational institution, and Qubo was created in SOLIDWORKS, which kept modeling and analysis in the same environment. Third, due to previous experience, the team knew that SOLIDWORKS could analyze von Mises Stresses. Finite Element Analysis was performed in two locations: The Torpedo Launcher and the Legs of Qubo.

The Torpedo Launcher had internal mechanisms subjected to high stresses during the priming stage of firing a torpedo, particularly at the base of the firing sled of the launching mechanism. The sled, during its second iteration, experienced roughly a maximum 3000 psi on material with a 6500 psi yield strength. To decrease stress concentration, webbing was added at the base of the stem during the third iteration of the design process. The webbing dropped the maximum stress experienced during priming to 20 psi, which was less than a single percentile of the yield strength. Qubo's legs were evaluated to ensure that they could support the weight of the submarine and withstand sudden shock or impact. For a tolerance of impact, the team used a threshold of four times the force subjected from weight of the robot. Upon analysis, it was shown that each leg held up to 50 lbs before fracture/failure. Since Qubo is roughly 50 lbs, the legs meet the requirement for impacts.

B. Low-Level System Testing

The goal of low-level testing was to ensure the system had motor control functionality and was able to receive data from the sensors. This was done incrementally while integrating the system to make debugging as efficient as possible.

First, a PWM generator IC was integrated on a test board to ensure it would work for driving ESCs. An oscilloscope was used to analyze the precision of the PWM output. Once the ESCs were sucessfully driven, they were attached to the driver subsystem, which included the thrusters, computer and custom power board. When the power board was assembled, it was tested with a separate power supply to ensure it supplied the correct voltages to each power bus. Then, other I^2Cdevices on the power board were tested to ensure the current and voltage sensing was functional and accurate. Accuracy was assessed by using a multimeter for voltage and driving each bus and a lab power supply to measure current draw. Before integration, each sensor was bench tested to ensure the data could be read by the main computer. Unfortunately, the accuracy of most of the sensors was not bench tested effectively because they required being in the water, but creating waterproof connections for bench testing was not feasible in the time allotted. This included the DVL, depth sensor, and the camera because it was impossible to know real functionality until they were underwater. Due to procurement delays, the system was not updated until the writing of this document. Because of this, the design cycle had to be expedited, meaning testing had to be done during application. For example, Qubo would submerge roughly a meter and the depth meter was analyzed to determine calibration. To benchmark the DVL, a constant PWM was applied to the ESCs to produce constant lateral movement and compared the data to rough estimates made in real time. Even though this testing is not precise, it is still useful to ensure sensor functionality.

To test motor control of the system both out of water and in water, a testing strategy was developed to ensure all 6 degrees of freedom could be achieved. An Ethernet tether was connected to the computer in the hull. With a joystick configuration that allows all 6 degree of freedom motion, the thrusters were observed conducting different maneuvers. Knowing which thrusters should be on and off for each maneuver, the correct configuration could easily be determined. This test was mainly used to show that the integration of the actuation subsystem with ROS was working correctly. It also gave a rough idea of how well the robot controls in the water.

The goal of testing with the sonar subsystem up to this point was to create a proof-of-concept for the design choices. The team made a frame of PVC pipe that was the dimensions of Qubo and the team submerged it about a meter underwater when testing. The team organized four hydrophones so that they form an orthogonal basis. This simplified the multilateration calculations. The team gathered hydrophone data using an oscilloscope and that data was saved to CSV files. An Ethernet cable was used to carry the signals for this test. Using MATLAB, the team applied a digital low pass filter to the data and clear pings were seen. A sliding DFT was used along with a threshold in the frequency range of the pinger to find the front edge of each ping (this was implemented in MATLAB). The time of arrival of each ping was put into the multilateration algorithm (a single matrix multiplication done on a vector) along with the coordinates of each hydrophone to get a reasonable bearing to the pinger from the hydrophone array. This was consistent across several distances and different pinger positions.

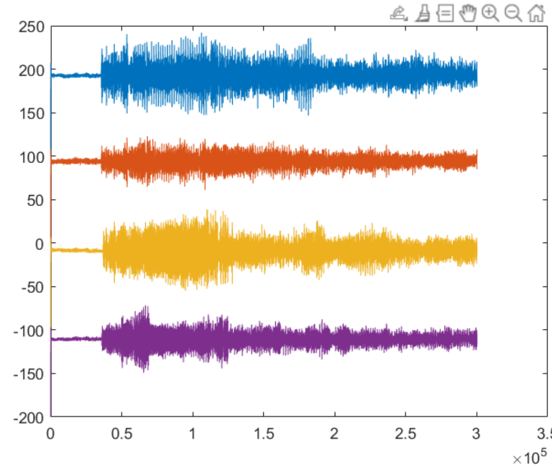

Fig. 8. A ping that was recorded and put through a low pass filter (60kHz cutoff). The raw signals were very noisy, likely because the cable is unshielded.

C. High-Level System Testing

For high-level system testing, the team tested the robot on previous competition tasks and on the pre-qualification task. The team made progress on the pre-qualification task, which validated the general localization, control, and computer vision systems. Additionally, tasks such as torpedo shooting, need to only be slightly tweaked from last-years competition to be effective in this coming year. The team planned on practicing on last-years targets so that the torpedo detection algorithm could be easily adapted to this year's task.

Finally, the team had extensively tested the locomotion ability by driving the robot in tele-operated mode over an Ethernet tether. The team drove the robot in this manner much faster than needed in competition. This validated that the motor configuration moved accurately, and that the new electronics system can comfortably handle the currents from the motors beyond the maximum autonomous thrust limits.

Acknowledgments

Robotics @ Maryland would like to thank the Space Systems Laboratory at the NBRF for lending their lab, time, and tools to the team. The team would also like to thank Dr. Akin specifically for acting as the team advisor over the years, as well as the new advisors Dr. Mitchell and Dr. Zhang. The team was grateful to Ivan Penskiy for allowing the team to use space and tools in the new Robotics and Autonomy lab in the new IDEA Factory. R@M also thanks the Aerospace, Electrical and Computer Engineering, Mechanical Engineering and Computer Science departments for lending their space, time, and money to the team. Additionally, the team thanked Robotic Research LLC, the Mechanical Engineering Department and the Maryland Robotics Center for their generous donations.

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APPENDIX A: OUTREACH

D. Events

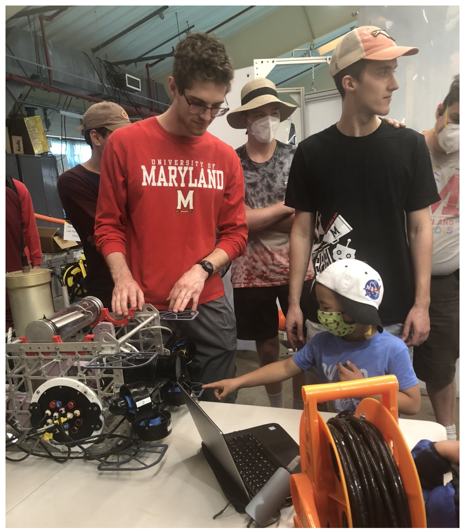
1) SeaPerch 2023: This year SeaPerch was hosted at UMD, so the team gave tours of the NBRF and demonstrated Qubo in the team pits in Eppley Recreational Center.

2) Maryland Day: Every year, R@M participated in Maryland Day, where organizations across campus get to present themselves to friends and family of UMD. This year, R@M ran two tables and inspired all ages with exciting robotics demonstrations.

3) Computer Science Showcase, Anne Arundel County Public Schools: The team attended a Computer Science Showcase with Qubo and the new stereo camera, letting middle school students look at themselves through Qubo's new depth-image upgrade.

E. Tours

R@M gave over 10 tours of University of Maryland robotics and engineering facilities to a variety of students and high school educators. R@M supports the Maryland Robotics Center through constant volunteering to spread word about robotics to communities abroad.



Appendix B: Component List

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase
Buoyancy Control	NBRF Stock	Foam	Purple	Custom	$0	N/A
Frame	Custom	N/A	Aluminum, Water Jetted	Custom	$200	2017
Waterproof Housing	Blue Robotics	6in	Acrylic and Aluminum Endcaps	Purchased	$400	2022
Waterproof Connectors	Blue Robotics	Penetrators	M10 Potted Connectors	Purchased	$5	2022
Thrusters	Blue Robotics	T200	11.2 lbf forward thrust, 350 watt	Purchased	$200	2017
Motor Control	Blue Robotics	Basic ESC	7-26 V, 30 amps max	Purchased	$36 x 8	2017
PWM control	NXP Semiconductors	PCA9685	16 PWM channels	Purchased	$14.95	2023
Actuators	N/A					
Propellers	N/A					
Battery	Gens Ace	GA-B-45C-5000-4S1P-Deans	14.8v, 5000mah	Purchased	$36	2017
Converter	Custom PCB		12V, 5V, Fuse, Current and Voltage Monitoring	Custom	$50	2017
CPU	Nvidia	Jetson Xavier NX	16 GB RAM	Purchased	$699	2023
Internal Comm Network	I^2C, GigE, USB 3.0, UART, RS232					
External Comm Network	Ethernet					
AHRS	Vectornav	VN-100	2° accuracy heading and tilt	Purchased	$1,100	2023
DVL	Teledyne	Explorer	+/- 5 m/s range, +/- 0.4% accuracy	Purchased	$12,000	2008
Vision	Stereolabs	ZED 2i	HD Stereo Camera	Purchased	$500	2023
Vision	Allied Vision	Mako G-131C	1280 x 1024 GigE Camera	Purchased	$450	2017
Algorithms: Vision	OpenCV	Various basic vision processing algorithms			N/A	N/A
Algorithms: Other	Kalman Filter	State estimation and sensor fusion			N/A	N/A
Programming Language 1	C++ 14			N/A		
Programming Language 2	Python 3			N/A		
Open-Source Software	ROS 2 Humble Hawksbill			N/A		
Open-Source Software	Docker			N/A		