NC State University Underwater Robotics Competition

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Abstract

The North Carolina State University Robotics Team is returning to RoboSub 2020 with a completely new vehicle, Seawolf VIII. Seawolf VIII is a major departure from previous robot designs, built with mechanical and electrical robustness, improved control, and increased computational power in mind. The team's primary goal was to create a stable platform for mission advancement in the 2019-2020 season that could be extended with computer vision, acoustics, and pneumatic systems to accomplish tasks. The frame and first iteration of electronics were completed and fully tested in March, after which our efforts shifted online to simulated improvements of the electronics and acoustics system, as well as rewriting the software using Robot Operating System (ROS).

Competition Strategy

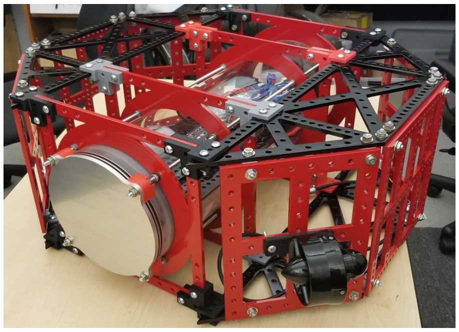
Due to overhauling our mechanical, electrical, and software systems, we elected for a conservative strategy for RoboSub 2020. We aimed to complete the gate, path, and buoys task that we had demonstrated successfully at RoboSub 2018. Additionally, we planned to integrate the previous year of acoustics development into the stretch goal of the Octagon task. However, given the two previous years of highly inconsistent robot functionality with Seawolf VII due to its electrical and mechanical complexity, the primary goal was to build the most robust system possible to provide a platform to rapidly iterate on our sensors, algorithms, and mechanisms. While we have attempted actuator-based tasks in the past, such as torpedoes and dropper, we decided to focus on the navigational tasks this year to simplify the design.

The club splits its focus between the competition and providing the best educational experience for our team members. As such, we sought out multiple research projects for our team members that were either directly relevant or adjacent to the club work so students could build research skills and connections with faculty members, and the club could benefit from their expertise and provide our own resources and expertise towards their projects.

The focus on reliability required a temporary shift away from the traditional club philosophy of custom circuit design. The initial design involved very little custom circuitry, but this design was intended only as a baseline. Custom PCBs were designed while the baseline design was being built, with the intention of integrating them and returning to the baseline if problems were encountered. The majority of the in-person time spent was on building and bench-testing each of the mechanical and electrical components for reliability before integrating them onto the robot.

Vehicle Design

Mechanical



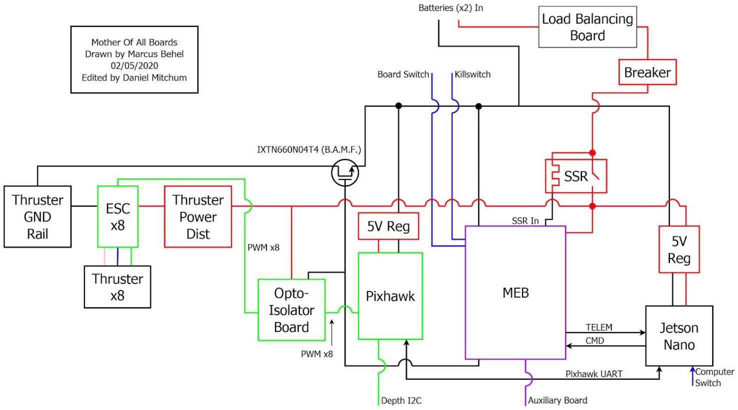
The physical structure of Seawolf VIII consists of multiple 0.25 in thick 6061 aluminum frame sections held together by 3D printed joints and stainless fasteners. The aluminum frame is an improvement on Seawolf 7's design as the acrylic frame of SW7 was fragile and led to many mechanical issues, whereas SW8's design provides structural integrity and prevents external forces from acting on the electronics hull where possible.

The waterproof enclosure that houses the electrical systems is a 2ft x 8in OD cast acrylic cylinder. The decision was made to utilize one hull for both the computer and electrical systems in SW8 after determining that having two separate hulls in SW7 lead to more potential points of failure and made it inconvenient to work on the system as a whole. Through-hull connections are extensively tested to ensure waterproofness. The aluminum end caps themselves are of the same design of SW7 and utilize a double o-ring seal to ensure watertightness.

The new octagonal shape of SeaWolf VIII facilitates a new 8-thruster configuration. This provides stabler attitude and strafe control. The entire frame also has 0.25" holes at even increments throughout the design to allow for modularity. This design feature was kept from SW7 as it allows for the ease of attaching additional or moving existing peripherals without complete structure reconfiguration and facilitates a consistent design standard across all our attachments to allow for mission dependent component swapping.

Electrical

Seawolf 8's electrical system, dubbed the "MOAB"(Mother Of All Boards) features three custom devices, those being the Load Balancing Board, the Opto-isolator Board, and the Main Electronics Board (MEB). These devices tie the rest of the system together, which can be seen in the block-diagram of our system.



The MEB uses an MSP430 Launchpad to switch thruster power by controlling a lowside MOSFET switch, switch system power by controlling a highside solid state relay (SSR) and conduct communications with our computer and future auxiliary devices. The Load Balancing board has been designed to draw current proportionally from two lithium polymer batteries safely, discharging both at the same rate. The Opto-isolator Board optically isolates the rest of the system from the thrusters for killswitching. The Pixhawk flight controller provides stabilization, telemetry and control to thrusters via commands from the Jetson.

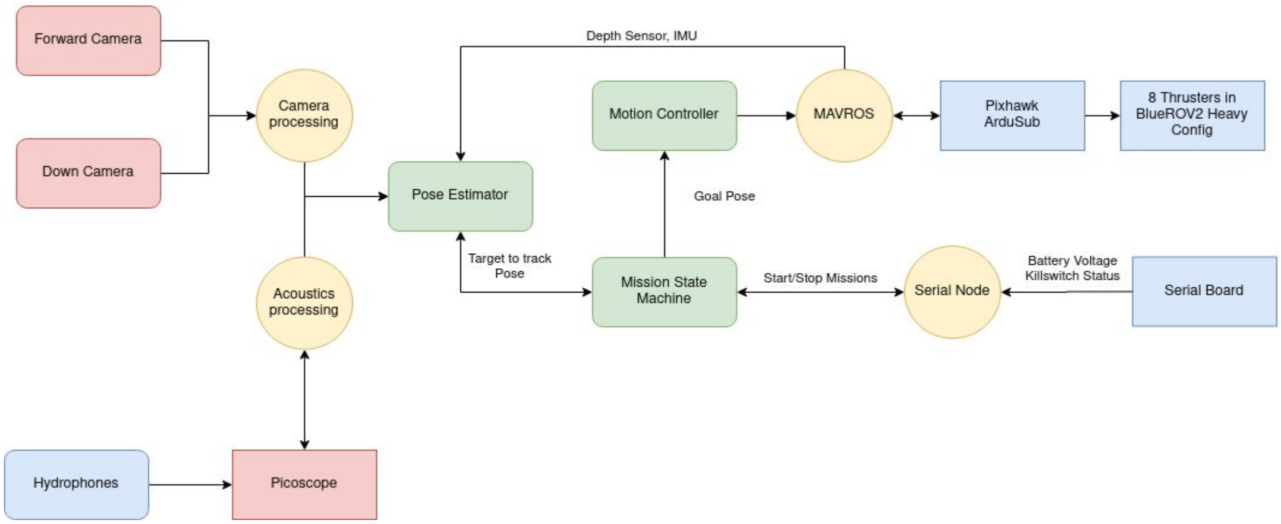
Acoustics

The acoustics system consists of four Aquarian H2C hydrophones, an analog filtering and amplification PCB, and a digital USB oscilloscope. The use of a USB oscilloscope over a system with ADCs and computation on an FPGA or microcontroller allows the system greater simplicity and computational efficiency. The oscilloscope is configurable via Picotech's software libraries, allowing users to set trigger values on the oscilloscope. Once that trigger is reached, an interrupt is sent to our computer running the mission code. The mission code calculates the time-difference between the signals and localizes the pinger using an approximation to the generalized hyperbolic time-difference-of-arrival geometry created by the pinger and hydrophones.

The PCB features a configurable-gain amplifier and bandpass filter with cutoffs at 20KHz and 50KHz, rejecting thruster and ambient noise while amplifying pings. We also researched and implemented three algorithms (a conic approximation, classical multilateration, as well as one with five hydrophones using spherical geometry) to calculate the line of bearing to the pinger from time difference of arrival data.

Software

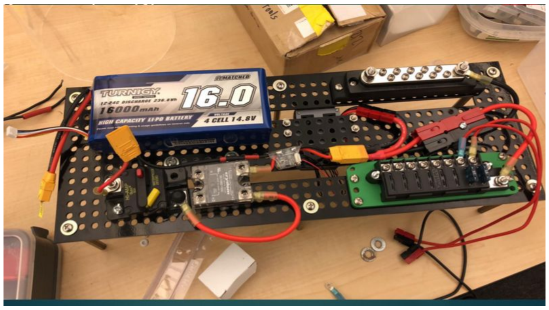
Seawolf 8 Software Architecture



The software system was redesigned from using a set of in-house libraries and simulation tools built over the past 10 years to Robot Operating System (ROS) to take advantage of our upgraded hardware and a rich set of open-source tools. There are four main sections of the code - peripheral interfaces, controllers, sensing, and missions. The peripheral interfaces abstract away serial communications with our custom boards and our Pixhawk flight controller to allow for changes and improvements to the electronics without changing software. The controller takes in a goal pose (orientation and location in space) and attempts to dynamically close the loop on each degree of freedom simultaneously. The sensor nodes track the desired target either through acoustics or through one of the two cameras on the system, and feed the position to the missions. Missions feed the controller and form the bulk of the logic. They are structured as ROS Behavior Trees, which allows us to set up a flexible state-machine architecture to build robust missions based off of sensor data.

Experimental Results

Electrical



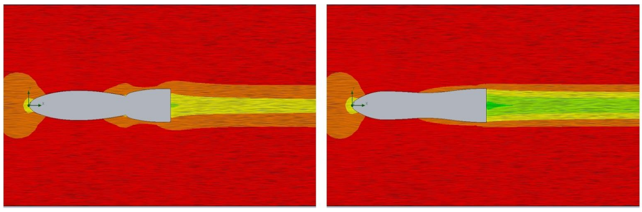
The electronics system was thoroughly benchtop tested before pool testing. We created FlatSub (left), a 1-for-1 replica of the electronics system that was used to prototype and test each component under load and failure conditions before integration into the robot. We estimated the peak continuous load to be around 40A and designed the electronics to handle 80A continuous current. We tested the custom circuitry and safety switches under a full thruster load, which identified an accidental ground connection in the thruster killswitch, leading to the creation of the opto-isolator board to electrically isolate the thrusters from the rest of the electronics when switched off. The first and only pool test went successfully, with no electrical failures. After COVID, we switched our design and testing efforts to LTspice, where we were able to successfully design and verify a PCB that would safely parallel two batteries, balance load between them, and provide safety in event of a short.

Software

Seawolf VIII had one pool test before quarantine began, where we successfully verified the flight controller and manual control. This went smoothly, with some PID tuning issues to resolve. The rest of the new software development was done remotely with two focuses - control and computer vision. The control system has been successfully tested in simulation, both visually and through our automated unit test software using Docker and rostest. Without pool access, we took pictures under various lighting conditions and trained neural networks on them with the goal of building up an effective labeling and training pipeline as well as potentially using transfer learning to retrain the networks. We were able to achieve 70% accuracy on the Octagon images with a relatively small training set of 50 images. By gathering images in varying orientations, light conditions, and amounts of sunlight and water, we hope to generalize these results to actual pool training data.

Mechanical

Any design aspect that requires waterproofness including the main electronics hull, external peripherals, and any through-hull connections were extensively tested under various submerged environments to ensure they were waterproof before any electrical components were housed in them. Multiple sealing procedures and sealants were tested at up to 12ft depth for durations of time ranging from 5-30 minutes to determine points of failure.



Due to COVID-19, we have not had access to our lab, so most of our mechanical testing was performed utilizing static, dynamic, and fluid simulations using SolidWorks. Left is the results of a fluid simulation of different torpedo designs.

Acoustics

The new hydrophones and filtering systems were designed and verified in multiple steps. First the schematics were turned into breadboard circuits and tested with known reference inputs. Extensive tests with the pinger and hydrophones in a bucket in lab were conducted to make sure that the breadboarded circuit behaved as expected with actual signals before finally conducting pool tests, where we were able to easily distinguish a ping with over 60 dB of SNR at a distance of 25 meters. Loose connections on the perf board caused minor failures at this pool test, but were able to be quickly resolved.

We also measured the interference effect of the thrusters' switching on the acoustics system and verified that the thruster switching frequency was at 18KHz. This drove the design of the highpass filter to attenuate thruster effects while passing any pinger signals.

Post-COVID 19, experimental efforts shifted to Python and Matlab simulations for algorithm development and LTspicefor further circuit simulation. We created a simple hydrophone model and used that to iterate and debug our filtering and amplification circuit, before converting it into an Altium PCB for fabrication. We tested each of the three localization algorithms in a Python simulator, comparing them in terms of tolerance of noise, numerical stability, and quantization error from sampling.

Acknowledgments

The NC State University Underwater Robotics Team could not exist without the help of our sponsors and faculty support. In particular, we would like to thank NC State University, the College of Engineering, Solidworks, and Altium. We would also like to thank Dr. John-Paul Ore, Dr. Zeljko Pantic, and our faculty advisor, Dr. John Muth, for their advice and support.

Appendix A

Component	Vendor	Model/Type	Specs
Component Vendor Model/Type Specs			
Frame	Custom		0.25 in 6061-alloy aluminum and 3D printed PLA parts
Waterproof Housing	Custom		Custom aluminum end caps with double o-ring seals
Waterproof Connectors	Fischers	103, 104,105 series	
Bulkhead connectors	SMC		
Thrusters	Blue Robotics	T200	
Motor Control			
High Level Control	BlueRobotics	BlueESC	
Actuators	SMC	C85N8-10T	Single Acting/Double acting
Solenoids	SMC		
Propellers			
Battery	Turnigy	16000 mAh	
Solid State Relay	Crydom	Crydom 100A SSR	
Killswitch MOSFET	IXYS	IXTN660n04t4	
CPU	NVIDIA	Jetson Nano	
Internal Comm Network			
External Comm Interface			
Programming Language 1		Python	
Programming Language 2		C++	
Compass			
Inertial Measurement Unit (IMU)			
Doppler Velocity Log (DVL)			
Camera(s)			
Hydrophones			
Manipulator			
Algorithms: vision	OpenCV		
Algorithms: acoustics	numpy		
Algorithms: localization and mapping	self		
Algorithms: autonomy	self		

Open source software	Opencv, Python, Linux OS, PicoTech, ROS		

Appendix B: Outreach

- College Connections - Running a booth to new NC State Students showing how URC can promote strong engineering fundamentals.
- Engineering Open House - Demonstrating Seawolf to prospective NC State students promoting robotics and problem solving
- FRC and FTC mentorship and volunteering - students mentored two FRC teams and volunteered at multiple FRC events.
- FIRST Lego League outreach - shows robot to middle schoolers and provided design input
- Asheboro Elementary School (Canceled due to COVID-19)
- Donor Tours - Showed robot and lab to ECE VIPs
- College of Engineering Tours - Showed robot to prospective and admitted students

Appendix C: Team Members

Software Team:

- Amalan Iyengar
- Amr Moussa
- Tajah Trapier
- Henry Sneed
- Cameron Incze
- Harshal Suthar

Acoustics Team:

- Shannon Pinnell
- Christopher Mori
- Frank di Lustro
- Justin Hodakowski
- Chloe Hawes

Mechanical Team:

- Kody Jefferson
- Jeremy Hosang
- Nolan Canagello
- Samarth Patel
- Gabriel Chenevert
- Jessica Yabroff

Electrical Team

- Daniel Mitchum
- Jake Keller
- Dheeraj Pannem
- Marcus Behel
- Isaac Hancock
- Byron Qi
- Justin Eiben
- Batu Palanduz
- Vinitha Ravindran
- Christian Baucom
- Elijah Hasskamp