NC State University Underwater Robotics Competition

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Abstract

The North Carolina State University Robotics Team is returning to the RoboSub 2019 with an iterated version of Seawolf VII. Seawolf VII is an underwater autonomous vehicle equipped with inertial, visual, and acoustic sensing designed to complete a set of tasks with its thruster-based navigation and pneumatically actuated mechanisms. To accomplish these goals, we upgraded our computer to handle higher computational load at lower temperatures, replaced our thrusters, and added pneumatic capabilities to our robot.

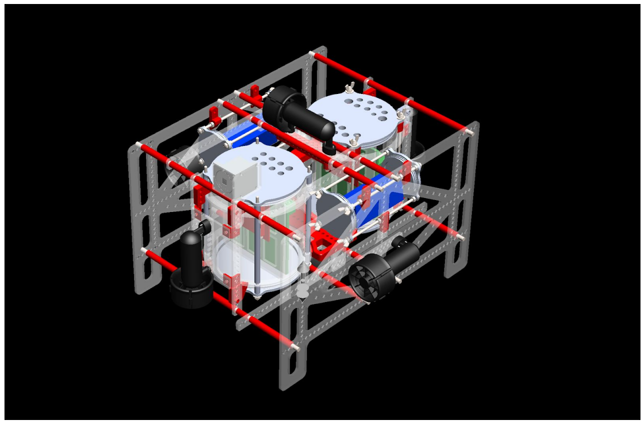
Competition Strategy

Our competition strategy is primarily based around executing the navigational tasks with our acoustics and computer vision system, as well as accomplishing the torpedo-based tasks. After issues with our computer overheating and thrusters leaking at RoboSub 2018, we spent the majority of our time this season redesigning our computer and thruster systems to be more robust. Due to this, we focused our competition scoring efforts on building and improving systems we could test before integrating it onto the robot. Our software team used footage from last year’s event, along with footage gathered at our pool tests this year, to develop computer vision algorithms for this year’s targets, primarily the gate, path, and buoy.

In addition, we used data compiled from last year’s acoustics runs to develop a new acoustic navigation system for this year’s robot. We have previously demonstrated competency in computer vision tasks, especially gate and path, so we focused on scoring additional points without increasing hardware complexity significantly. Because we already had the hardware set up for acoustics with our hydrophones, as well as a pinger that we could do data collection and testing with locally, we focused on implementing acoustics missions to increase our scoring after the basic computer vision tasks were completed.

Vehicle Design

Seawolf VII was designed with modularity in mind to maximize our ability to rapidly prototype, develop new solutions, and debug problems as they arose. After failures with Seawolf VI involving the monolithic hull and electrical board, we separated components into logical units and encased them in hulls, and split our electrical board into separate components. This modular design allowed us to rapidly prototype and debug components much faster than previous versions. When we had failures on one of our electrical boards, isolating it and replacing the malfunctioning components was a much quicker process than when it was all on one monolithic board. Mechanically, our hulls and frame were designed to maximize our ability to add new components, peripherals, and waterproof enclosures quickly, due to our perforated acrylic frame.



Mechanical

From the mechanical point of view, we decided to stick with last year's modular design due to its ease of replacing and adding new components. The innovation in this year's robot can be seen in the improvements made to the robot. The frame of the robot was tweaked to further reduce the effect of stress concentration at critical joints. While keeping up with heavy utilization of 3D printing in our mechanical designs from last year, we added 3D printed boots to the legs of the robot and braces to the side of the frame to counteract the lateral bending moment in our frame.To improve our acoustic efficiency we designed and fabricated an array matrix that would allow the hydrophones to be mounted in different configurations. We gave equal importance to balancing creativity and functionality. For example, the handles for the robot were changed to be more ergonomic but at the same time allowed us to express our design creativity. With the help of the electrical team we were able to create an integrated pneumatics board powered by an arduino that was packaged into a waterproof enclosure along with solenoid valves that are arranged in a 6x2 manifold. This allowed us to organize the pneumatic tubing and allow for clean and tidy connections.

Electrical

Seawolf VII's electrical boards are split into five units, each connected to various sensing and power peripherals, all connected by a backplane. The power board takes raw battery input and connects them in parallel with reverse-polarity-protection and short circuit protection circuitry in order to balance the current draw between the two batteries and shut one off in case of a short circuit. The conversion board regulates that power through one switching regulator and two linear dropout regulators to the peripherals, including the computer, microcontrollers, and the acoustics system. Consistent to our theme of modular design, there are three microcontrollers, each with limited, dedicated functionality. The power board microcontroller measures voltage and current from the batteries and shuts off the boards when the voltage dips too low to protect batteries and our peripherals. The thruster board microcontroller takes a serial input with each of the desired thruster outputs and outputs six PWM signals to each of our thrusters. Finally, the serial board microcontroller handles serial communication from the computer and multiplexes communication between the rest of the microcontrollers.

Acoustics

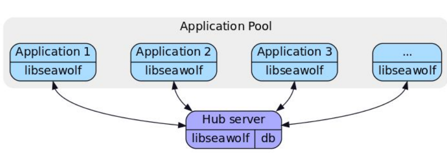
The acoustics system consists of four HTI hydrophones, a new analog filtering and amplification board we designed this year, and a digital USB oscilloscope. The use of a USB oscilloscope over a similar system with ADCs and computation on an FPGA or microcontroller allowed us to implement our acoustics system far more simply and with greater computational efficiency. The oscilloscope is configurable via Picotech's software libraries, allowing us to carefully set trigger values on the oscilloscope. Once that trigger is reached, it sends an interrupt to our computer running the mission code. By offloading the triggering logic to the oscilloscope, we freed up valuable computational resources on our computer to only process acoustics data when a valid signal was present.

Because the oscilloscope dictated when there was a valid ping, reducing the false positive rate of signal detection was critical. Without filtering, the signal to noise ratio with thrusters on was less than -20dB, making signal indistinguishable from the electromagnetic interference from the thrusters. We designed an analog frontend filter and amplifier with selectable gains via a DIP-switch. When we integrated this into our acoustics system, we were able to achieve a SNR of 120 dB and easily distinguish pings.

We also improved our algorithms this year. By doing time-domain cross-correlation instead of frequency-domain phase shift calculation, we were able to move our hydrophones further apart. This added noise resistance to our system, which is critical as small errors in time difference calculation can lead to large errors in angle of arrival. The location of a pair of receivers and the time difference of arrival of the ping defines a hyperboloid in 3-dimensional space. The intersection of three such hyperboloids gives the position of the pinger. We found that this multilateration calculation was very susceptible to noise, so we focused on calculating just the angle of arrival, rather than angle and distance. To calculate the angle of arrival, we treated our four hydrophones as four independent sets of three receivers and computing the least squares residual between them. Because the distance to the pinger is significantly greater than the spacing between hydrophones, we showed that the hyperboloids could safely be approximated as cones, greatly reducing the computational complexity of calculating those intersections.

Software

Our software system is a publish/subscribe architecture to a hub server, part of Libseawolf, a set of libraries developed by the club since its founding in 2004. Applications to interface with peripherals, perform stabilization with software PID controllers, and control thrusters each communicate through hub with other applications. Mission code sits on top of these applications interfacing with hub to create state-based sequences of actions waiting on transitions of data in hub.

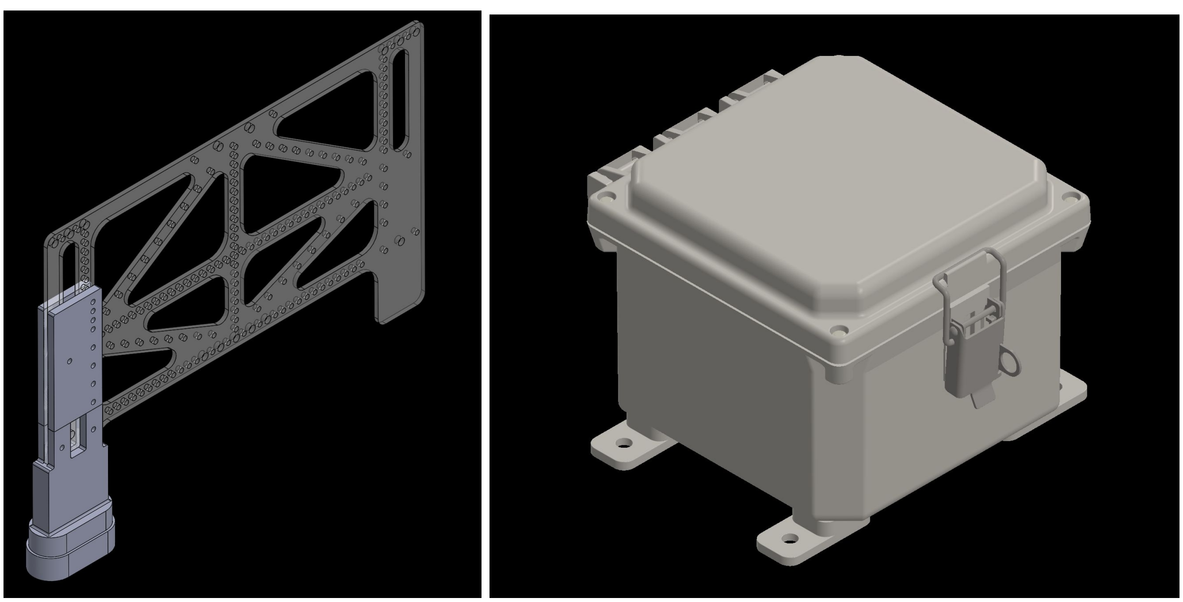


This year, our team was not able to test in the water as much due to issues reserving a pool. To remain prepared for running missions, the software team worked on improving our custom-made simulator with improved graphics and configurability. Last year, the team created a simple 3d engine that used basic shape drawing functions to render rough shapes of the entities the robot would encounter. This year, we expanded on this rough engine and added in the ability to use 3d object files inside our simulator. However, this engine was slow since it used custom rendering algorithms. It will be improved next year by using OpenGl to render entities.

Experimental Results

Mechanical

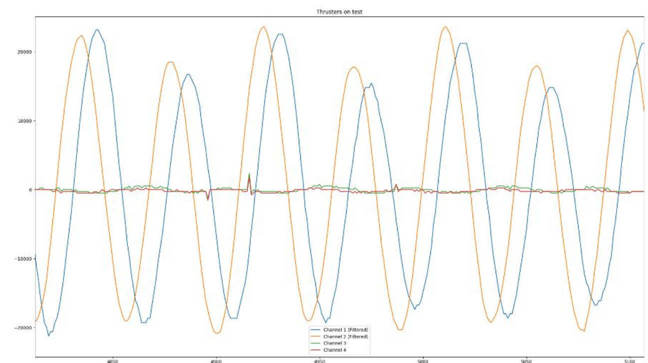
This year, the mechanical team focused on improving the frame and pneumatics system of the robot. The original frame of the robot had some structural issues, with two of the four legs breaking during competition last year due to the fragility of the original acrylic legs as well as poor handling of transporting the robot. To fix these issues, we decided to rework the frame by removing unused holes in the frame to add more material for support. In addition, the team 3D printed boots and plates to help improve the points of contact on the ground and reinforce the frame. To solve the issue of poor handling, we also 3D printed handles that fit over the battery hulls for easier transportation of the robot. Another system that the mechanical team improved this year was the pneumatics system that powers our torpedo launchers and droppers. To update our old system from last year, we decided to move to a manifold system that helped centralize all of our tubing for the system. In addition, we tested the waterproof capabilities of IP67 and IP68 enclosures at an 11ft depth for extended periods of time in order to replicate the most optimal conditions during competition. These tests provided the data necessary to help us make the best decision when selecting an enclosure for the pneumatics circuitry necessary for powering and controlling the system.



Seawolf VII boots on redesigned frame, left, and Polycase enclosure for pneumatics, right

Acoustics

Acoustics testing this year was done with the goal of maximizing signal to noise ratio and optimizing receiver spacing. We were able to successfully achieve over 120dB of gain through our bandpass filtering and amplification board, which used a combination of off-the-shelf butterworth filters with our own passive filtering circuit to provide 8th-order filtering and user-selectable between 8x and 512x amplification. To develop our algorithms and optimize our receiver spacing, we created a mechanical rig to stabilize the robot inside a PVC cage with extenders to place the hydrophones at a known distance. This allowed us to do integration testing of our system, as well as spin up the thrusters to verify that we could successfully reject noise



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Filtered vs. Unfiltered Hydrophone Signals

Acknowledgments

The NC State University 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, NC Space Grant, PicoTech, Fischer Connectors, and Altium. We would also like to thank Dr. Hoon Hong, Dr. Rudra Dutta, and our faculty advisor, Dr. John Muth, for their advice and support.

Appendix A: Expectations

Subjective Measures

	Maximum Points	Expected Points	Points Scored
Utility of team website	50	50	
Technical Merit (from journal paper)	150	150	
Written Style (from journal paper)	50	50	
Capability for Autonomous Behavior (static judging)	100	100	
Creativity in System Design (static judging)	100	100	
Team Uniform (static judging)	10	10	
Team Video	50	50	
Pre-Qualifying Video	100	0	
Discretionary points (static judging)	40	40	
Total	650	610	

Performance Measures

	Maximum Points	Expected Points	Points Scored
Weight	See Table 1 / Vehicle		
Marker/Torpedo over weight or size by <10%	Minus 500 / marker		
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	0	
Gate: Pass through 60% section	200	100	
Gate: Pass through 40% section	400	300	
Gate: Style	+100 (8x max)	100	
Collect Pickup: Crucifix	400 / object	0	

Follow the "Path" (2 total) 100 / segment	100 / segment	200	
Slay Vampires: Any, Called	300, 600	100	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	0	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200, torpedo (max 2)	300, 200, 200, 0	
Stake through Heart: Move lever	400	0	
Stake through Heart: Bonus - Cover Oval	500	0	
Expose to Sunlight: Surface in Area	1000	0	
Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	500	
Random Pinger second task	1500	1500	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	T x 100	500	

Appendix B

Component	Vendor	Model/Type	Specs
Component Vendor Model/Type Specs			
Frame	Custom		Laser cut acrylic and 3D printed PLA parts
Waterproof Housing	Custom		Custom aluminum endcaps with double o-ring seals
Waterproof Connectors	Fischers	103, 104,105 series	
Bulkhead connectors	SMC		
Thrusters	Blue Robotics	T100 and T200	
Motor Control			
High Level Control	BlueRobotics	BlueESC	
Actuators	SMC	C85N8-10T	Single Acting/Double acting
Solenoids	SMC		
Propellers			
Battery			
Converter			
Regulator			
CPU	Simply NUC	7i7DNBE Board Kit	
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	2.4, 2.7/3, Debian	

Appendix C: Outreach

- Math Science Education Network, Students in Programming, Robotics and Computer Science - Providing a hands-on NXT robotics lesson to underserved youth, demonstrating how STEM careers are attainable for these students and providing a sense of ownership over their own education.
- 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
- New Technologies Expo - Presented to local community and industry leaders promoting work happening at NC State and at the college
- NC Space Grant Symposium - Presented research and development practices to sponsors, students, and faculty at NC universities
- NC State University Computer Science Open House - Presented acoustics research being done as independent study in Computer Science
- FRC and FTC mentorship and volunteering - students mentored two FRC teams and volunteered at multiple FRC and FTC events.
- 360 Virtual Lab Tour - The 360 virtual tour to the URC lab in NC State University is part of a pilot/test project from US Ignite, part of the National Science Foundation, that gives the opportunity to K-12 schools in rural areas to be exposed to the latest technology in STEM in affordable way utilizing fast internet network (known as the gigabit project).