Research and Design of Seawolf VI

Underwater Robotics Club @ North Carolina State University

C. Guseman, G. Howell, A. Malone, B. Manning, M. Settle, J. Smith, and D. Wertz

Abstract— **Seawolf VI is the sixth in a series of submersible autonomous robots developed by the Underwater Robotics Club (URC) at North Carolina State University (NCSU). The URC is a group of undergraduate students whose goal is to give these students an opportunity to apply their knowledge to solve real world problems, as well as exposing them to new disciplines. Introduced in 2014, Seawolf VI has been fine-tuned and heavily modified to improve its performance in both the 2015 and 2016 RoboSub Competitions, consisting of an underwater obstacle course of vision and acoustic tasks which the robot is required to navigate autonomously. This paper will describe the different components of Seawolf VI, the motivation behind the design, and some recommendations for future iterations of the team.**

I. INTRODUCTION

Seawolf VI is an autonomous, unmanned underwater vehicle (UUV) designed by the Underwater Robotics Club (URC) at North Carolina State University. The URC is composed of NC State Students from a variety of engineering and education disciplines with the collective goal to bring Seawolf to the Annual International RoboSub Competition held in San Diego, California. As a participant in this competition, the URC team is pitted against several challenging underwater tasks which must be completed autonomously, including swimming through gate structures, shooting torpedoes through targets, dropping a projectile in a specific bin, navigating towards an acoustic pinger, and other manipulation tasks. As a result of this, the URC team finds that this competition is a great way to bring students together and apply the skills they learned in class to help each other succeed.

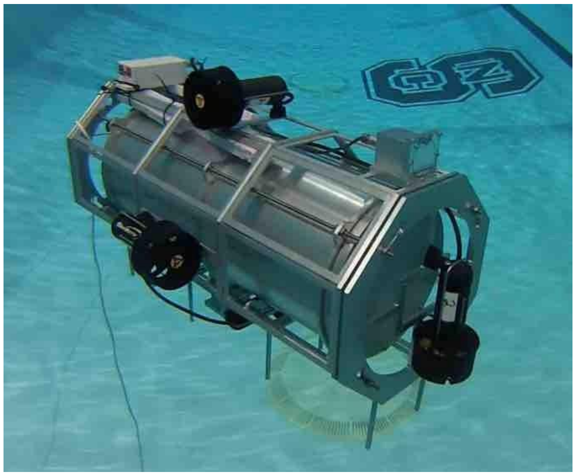

Fig. 1. *Seawolf VI*

II. DESIGN STRATEGY

Seawolf VI was designed with the underlying idea of modularity such that any part could be easily replaced as if it were a plug and play kit. This mentality is meant to fit the role of the program as a whole, whereby new members come in with new ideas all the time. Mechanical-wise, Seawolf's frame has 24 removable panels, which can be customized to hold various thrusters and peripherals depending on the needs of the team. In terms of software, Seawolf is operating upon a custom framework the team calls libseawolf, which is tailored to running software for robotics applications. As part of this framework, the team uses shared variable architecture that allows for writing independent scripts for controlling the robot, processing data, streaming camera feeds, and more. Electrical-wise the team has broken down the previously two large board system into six boards with dedicated functions. These boards are meant to function independently such that they are practically modules in a larger system. Overall, this allows for parallel development in URC's robotics program, where people can work independently on their own modules, and work together to integrate them at the appropriate time.

In approaching the RoboSub course, the URC team expects Seawolf to complete the gate and path tasks with ease. Every obstacle beyond this will be a first for Seawolf VI, but the team also aims to perform buoys using an improved buoy detection algorithm developed using the OpenCV image processing library. With the addition of a new pneumatics system on the robot, the URC team will be attempting to do the set course (torpedoes) task and weigh anchor (bins) task. However, the added challenge with both of these is that there is only an acoustic pinger designating these tasks. In order to adapt to this, the team is preparing two methods to place itself in front of the bins and torpedoes tasks, whereas the primary method utilizes acoustic tracking as intended, and the secondary method combines Seawolf's strafing and vision capabilities to place itself in front of the set course (torpedoes) task. Also, depending on the operational range of the acoustics system, the URC may attempt to get Seawolf VI to surface in the octagon as well.

III. VEHICLE DESIGN

A. Mechanical

1. Design Overview

Mechanically, the goal of Seawolf VI was to create not only the team's first fully machined aluminum robot, but also a design that would allow for easy modification to the outer frame. This interchangeable frame would allow for the team to easily design and replace components to Seawolf VI as ideas were prototyped and the challenges of the RoboSub course were released. To start Seawolf VI would be designed to fit the thrusters and cameras, however it would evolve over time to include all necessary peripherals including a grabber, dropping mechanism, and torpedo launcher. These attachments would continue to be developed throughout the year building off previously used designs and new additions that best fit Seawolf's needs.

Initially, the entirety of Seawolf VI was designed in the Solidworks 3D Modeling program to allow for easy modification and replication of parts. The finalized CAD files were sent to be machined off campus using a Tormach Personal CNC Mill. Modified panels were 3D printed using PLA filament on a Lulzbot TAZ 5. Peripherals components were 3D printed using impact resistant PLA filament on a MakerBot Replicator 2 or Fusion3Design F306.

2. *Frame*

The base frame of Seawolf VI was designed using a modular system of various panels designed to be crafted and swapped out. The robot includes twenty-four panels secured in three sections supported by threaded metal rods. Originally, all panels were machined aluminum, however replacement panels were 3D printed instead to cut down on production cost, time needed for creation, and overall weight of the robot.

Fig. 2. *Seawolf VI Solidworks Rendering*

3. *Hull*

The computer and other electronic hardware is primarily enclosed within Seawolf VI's aluminum cylindrical hull. The cylindrical shape was chosen for its capability to resist deformation under pressure. Inside of the hull are two horizontal shelves; the top shelf host the computer and slots for additional electrical boards attach, while the bottom shelf secures the batteries. These shelves are supported by 3D printed bars attached to the end caps to ensure everything is secured in case the robot rolls or moves unexpectedly. This year the layout of the shelves has changed to allow for electrical boards to be changed as needed and so the team may access the batteries in between runs without having to remove the computer. Each end of the hull is sealed with an endcap that has a specially sized O-ring to fit snuggly and waterproof the hull when screwed shut. End-caps are secured with eight bolts around the outer rim that screw directly into the cylinder hull. The rear endcap includes the built in pressure transducer as well as several 104 series Fischer Connectors to connect the thrusters and peripherals to the electronics inside.

4. *Thrusters*

Seawolf VI utilizes six Seabotix DC Brushed Thrusters. They all run at 24V, which comes directly from the robot's main power connector.

Fig. 3. *Seawolf VI, fully assembeled frame and hull with thrusters*

The thrusters located on port and starboard are used to control forward and backward motion, along with yaw rotation. Thrusters located on the bow and stern are used to control the robot's depth and pitch movement. The final two thrusters located on the top and bottom of the robot are used to control roll and allow the robot to strafe.

5. *Pneumatics*

Seawolf VI brings a new pneumatics system capable of firing torpedoes, dropping markers, and using an active grabber to the 2016 competition. The system is controlled by the main computer via serial commands to an Arduino housed outside the main hull in a waterproof box. Inside the box alongside the Arduino are six electronic flow valves and pneumatic tubing. Once prompted by the main computer, the Arduino will send signals to the valves to open them. This will cause air to travel from the air tanks into the linear actuators, causing them to rise and creating movement. This movement is then manipulated by a module to fire a torpedo, drop a marker, or activate a grabber. The used air in the pneumatic system is then exhausted back into the high volume box where the pressure drops to a low, safe level. If pressure in the box becomes too high, the box will act like a one-way valve and allow air out into the surrounding water without water entering the box.

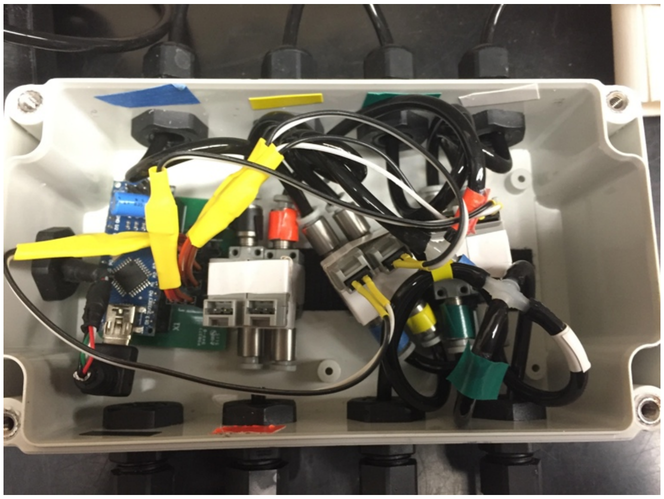

Fig. 4. *Inside the pneumatics waterproof containter. The arduino and solenoids are located in this enclosure*

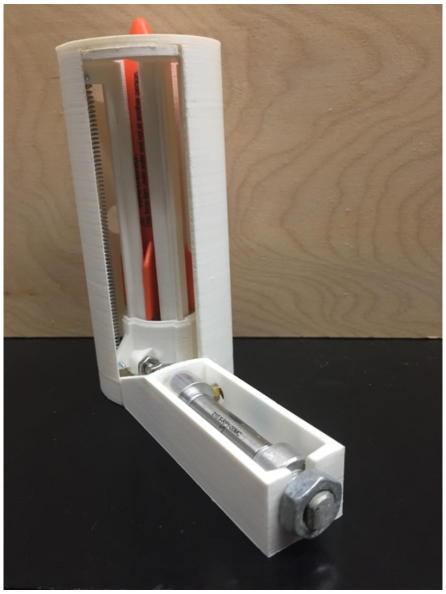

Fig. 5. *Torpedo shooter*

6. Problems

While this new pneumatics system is a vast improvement from peripheral control system constructed in the past it is not perfect. Through trial and error the club has discovered that teflon tape does not survive well in water. Because of this semi-constant maintenance is required for the air reservoirs in the system to keep them from bleeding air. Additionally the stainless steel coating on the pneumatics needs to be reapplied with a protective enamel about every month to keep them from rusting and becoming inoperable.

7. Improvements

Despite careful planning there were still flaws to Seawolf VI's initial design. The metal panels were not as sturdy as hoped resulting in some bending and being stuck in place unable to be easily removed when needed. Additionally, these panels proved to be costly and time consuming to have made resulting in the switch to 3D printed replacements that could be made in a short time in house. Inside the hull the shelves for electronics were originally held in place by small machined knobs that proved to be too fragile and had to be replaced with the 3D printed slots used now. Along with this the spacing for wiring inside the hull had to be reorganized to prevent wires getting caught in the endcaps resulting in flooding inside the hull.

As for the new pneumatics system, while it is a vast improvement from peripheral control system constructed in the past, it is not perfect. Through trial and error, the club has discovered that teflon tape does not survive well in water. Because of this semi-constant maintenance is required for the air reservoirs in the system to keep them from bleeding air. Additionally, the stainless steel coating on the pneumatics needs to be reapplied with a protective enamel about every month to keep them from rusting and becoming inoperable.

Currently the team has already begun the planning and construction of their next robot, Seawolf VII. A majority of this robot's design has resulted from what was learned from the mistake made with Seawolf VI. This robot will be built using a set of acrylic hulls and frame to cut down on weight and allow the team to see the inside of the hulls to monitor electronics. Seawolf VII will feature four separate hulls with two smaller containers housing the batteries and two larger main hulls housing the computer and other electrical boards. This robot will feature the team's first use of two VideoRay thrusters along with the use of four Seabotix thrusters to hopefully increase mobility. Similar to Seawolf VI, the design has been developed with modularity in mind to allow for the easy removal of peripherals and outer components to fit the current needs of the robot. Seawolf VII is expected to be continually developed into 2017.

For pneumatics, the club discovered quickly that for this system to survive underwater higher quality equipment was required. This became prevalent when several cheaper actuators rusted and broke when only exposed to water for an hour or even less. Additionally, throughout the prototypes rotational motion replaced with linear motion because of the efficiency it offered. Lastly, the team discovered that small diameter tubing was an optimal choice for its volumetric efficiency. By having smaller tubing the system operated at a lower power but could operate many more times per tank refill. Perfect for the team's low power needs during testing periods.

B. *Electrical*

1. *Design process*

The electrical design is highly optimized for modularity. As such, design process and design recommendations are discussed at the beginning and end of each sub section below.

2. *Inertial Measurement Unit (IMU)*

This year, the robot will be using the SparkFun 9DOF "Razor" (SEN-10746) as its Inertial Measurement Unit (IMU). Previously the team used a LORD 3DM-GX1, but there was some difficulty behind the fact that the calibration software for this using is closed source, and the team wanted something easier to use overall.

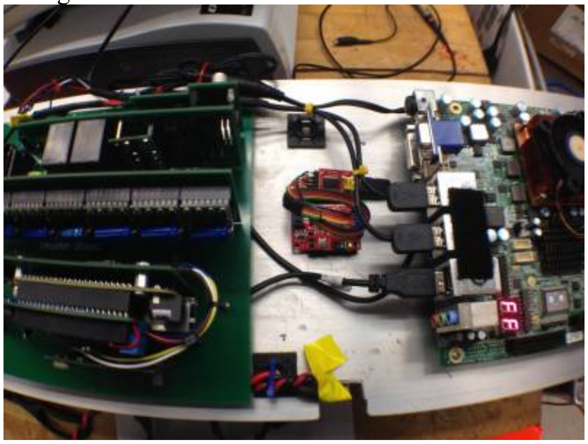

Fig. 6. The IMU is placed in the center of the board that holds the electronics inside of the hull.

3. *Pressure Transducer*

A Measurement Specialties US331 analog pressure transducer is used to measure depth. It is mounted through a hole in the end-cap and connected to the electronics board where the microprocessor reads the sensor value refer to Fig. 8

Fig. 7. Pressure transducer mounted to the end-cap

As a future consideration, the URC team has found the sensor to be susceptible high frequency noise. Both electromagnetic coupling and pressure vibration in the water tend to make this sensor look really noisy. As such, the recommendation is to always test the depth sensor when the robot is completely assembled (the aluminum hull provides a good deal of shielding from electromagnetic coupling), and note that a software-based low pass filter is trying to filter out the various high frequency pressure vibrations experienced in water.

4. *Cameras*

Seawolf VI has two USB HD Microsoft LifeCam Cinema cameras. Previous versions of Seawolf were limited by cameras with a small field of view, but these cameras provide a wide 74-degree field of view. These off the shelf webcams also feature auto exposure to compensate automatically for changing lighting conditions. They communicate directly to the computer through USB. One camera faces down, to be used mainly for the path mission. The other camera faces forward to be used for navigation.

Fig. 8. Camera and Camera Enclosure

5. *Electronics*

Seawolf VI's custom electronics system design was completely revamped this year. Previously, Seawolf's electronics system was composed of two custom motherboard printed circuit boards (PCBs) with localized sections for power management, thruster control, peripheral interfacing, and serial communication to the main computer. The URC team found this design too limiting, due to the fact that important system sub-blocks were "buried" in the motherboard such that it was always difficult to troubleshoot issues and/or expand that the design for more capabilities. Thus, the URC team came up with the new six PCB design shown in Fig. 9 and 10.

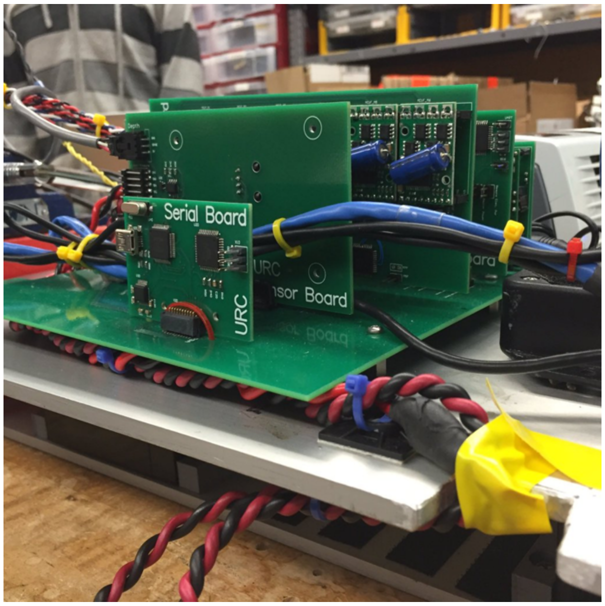

Fig. 9. Side view of new PCBs

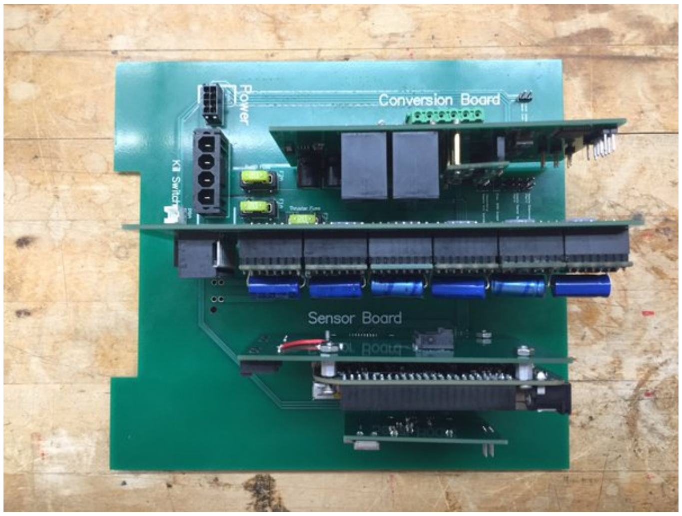

Fig. 10. Top view of new PCBs

The table below summarizes electrical system design:

PCB Name	Description
Power Board	Contains relays and power management electronics for connecting 24V lithium ion batteries to the robot. Also contains an onboard microcontroller for telemetry purposes and embedded intelligent control over power management electronics.
Serial Board	Presents a single USB connection that will grant bidirectional communication between the main computer and all the other peripheral electronics in the electronics system. It is the hub of computer-to-electronics communication.
Conversion Board	Contains various voltage regulators and DC-to-DC converters for converting a 24V input to 12V, 9V, and 5V outputs for all other other onboard electronics to use.
Thruster Board	Provides an I2C interface for controlling up to six Seabotix thrusters and two VideoRay thrusters simultaneously.
Sensor Board	The connector hub for all peripheral devices and sensors. This board provides connectors for the depth sensors, IMU sensor, acoustics system, and an (optional) local barometric pressure sensor.
Blackplane Board	The "motherboard" for all boards listed above. This board has connectors and copper traces for connecting all the boards together properly.

This design gives the URC team an electronics system with better power management capabilities, troubleshooting convenience, and greater expandability in the future. Additionally, the team was able to re-optimize their connector locations, which helped to reduce cable clutter in the robot.

6. Microcontrollers

Seawolf's electrical system functionality is made possible by embedding three ATxmega32 microcontrollers in the system. On the power board, an ATxmega32D4 controls the main power relays, provides low voltage detection, and offers remote power switch capabilities to Seawolf. The Thruster board has an ATxmega32D4 for creating the I2C interface for controlling up to eight individual thrusters. Lastly, the serial board has an Atmel ATxmega32A4 which allows the main computer to interface with the other boards and various sensors in Seawolf. These microcontroller based designs are meant to allow for a high degree of upgradability, as a firmware change can be made much quicker than a hardware change. As such, knowledge in low level embedded system programming is highly recommended for future electronics system developers.

7. Power

The new electrical system design made Seawolf VI a 24V (±4V), single source robot. That is, all electrical systems and functionality within Seawolf can be made possible by connecting a single 24V voltage source to the robot. Additionally, the power board features a load balance controller for efficiently and safely connecting up to two voltage sources in parallel, even if they individually are at two different voltages. This gives the URC team a good deal of flexibility when it comes to powering the robot. If the team wishes to save on weight, they can use a single 24V 5000mAH Lithium Polymer (LiPo) battery. If the team wishes to double operation time, they can connect an additional battery. This also grants the team active battery hot swapping capabilities. If the team wishes to operate off of low current wall AC power, there is a wide selection of 19V laptop chargers available and would work as an acceptable DC power source.

This power configuration is a big change from the previous electrical system design used in Seawolf VI at the 2015 RoboSub competition, which was a dual 24V source design. That is, the previous design used an independent 2x12V lead acid battery pack for powering the thruster system, and an additional 2x12V LiPo battery pack for powering the other supporting electronics. Requiring 4 batteries total, Seawolf VI 2015 was negatively buoyant without the aid of extra low-density foam board. This design choice was made to isolate sensitive electronic sensors from electrical noise that may occur on the thruster circuits. However, after the URC had realized that a good deal of headroom lies between the 24V thruster circuit and the 3.3V-12V "sensitive" electronics, it was figured that isolation will come from the various voltage converters used in Seawolf's electrical system alone. After testing with the new electrical system in Seawolf VI 2016, the URC has found this assumption to hold true.

Also, it is worth mentioning that one of the most notable results of the change to a single source design is a significant weight savings. The combined move to a single source design and all LiPo battery power system has made the robot very positively buoyant. After adding some external weight to Seawolf VI 2016 to "tune" for 0.5% buoyancy, Seawolf can achieve at least 30 to 60 minutes of operation time in the water with two parallel 5000mAH packs.

8. Computer

The computer's processor is an embedded Intel Core i72710QE on a mini ITX form factor motherboard, donated by Intel. It is shown in Figure 12. Most of the computer's speed is put toward image processing, but Seawolf leverages the use of the processor's four cores as part of running the URC's modular robotics framework, libseawolf. Also, this computer is fairly low power, as a single 5000mAH LiPo battery powering the computer alone will run for about three hours on one charge.

Fig. 11. Onboard Computer

9. Improvments

Overall, the future plan for electronics is to maintain the current hardware for Seawolf VI operation, but also reprint any of the six electrical system PCBs with upgraded firmware and/or hardware functionality over the course of next year. This way, functional testing of Seawolf and development of new electronic systems can occur at the same time without interfering with each other.

C. *Acoustics*

1. Acoustics Overview

The acoustics sub-system consists of a BeagleBone Black (BBB) microcomputer, front-end signal conditioning electronics, and a UART-to-USB converter circuit for serial communication with the robot. The exposed system while mounted on top of the sensor board is shown in Fig, 13, whereby the front- end signal conditioning electronics are most visible.

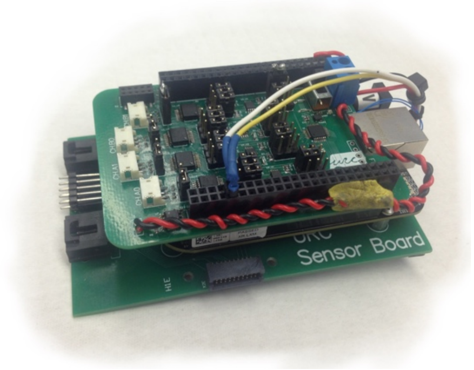

Fig. 12. Acoustics Subsystem displaying the front end electronics

2. Front End Electronics

The front end electronics board performs the following functions:

- Distributing power amongst the acoustics sub-system.
- Connecting hydrophones to the BeagleBone Black via a series of signal conditioning electronics and a 2MHz throughput, dual sampling, four channel ADC.
- Breaking out BeagleBone pins in a manner that encourages further testing and experimentation.

Fig.14 is a block diagram showing the signal path for one of the four identical channels on the ADC. The goal of this particular signal path configuration is to guide an isolated hydrophone signal to the BBB with as much fidelity that is practical. The design of acoustics system began with the one thing that was already available to the URC thanks to previous generations of the team: a set of four HTI 96 Min hydrophones with internal pre-amplifiers. Early tests have characterized that these hydrophones were capable of capturing ultrasonic signals but also that a great deal of high frequency interference would couple into the system.

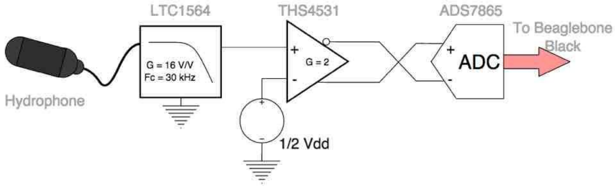

Fig. 13. Block diagram showing one out of the four identical signal paths from hydrophone to ADC

However, this noise is eliminated with a low pass filter that is provided by the LTC1564. Acoustics also has digital control of the amplification applied at this stage within the range of 1V/V to 16V/V. The next stage of the circuit is then a THS4531 differential amplifier, which proceeds to convert the single ended hydrophone signal to a differential one. This helps provide a signal that is recommended per the ADC's spec, double the total working voltage range, and it gives us another opportunity to increase the analog gain of the circuit as much as needed. The diagram shows the differential amplifier configured to have a gain of 2V/V, which is appropriate when maintaining operation of the acoustics system even when Seawolf is physically close to the pinger.

The final stage of the hardware circuit is an ADS7865 analog-to-digital converter (ADC), which is a 12bit, four channel, simultaneous (dual) sampling ADC with a maximum throughput of 2MHz. Current hardware/software on the BBB is capable of driving this ADC at 1.6MHz throughput, which comes equates to 400KHz per channel. At this sampling rate, acoustics is capable of sampling a 40KHz competition pinger and yielding an accurate measure of time delay of arrival.

3. BeagleBone Black Software

Following the design of hardware that warrants a clean signal reaching the BBB was the task of creating software that could control the hardware and process data collected by the hardware.

4. Hardware Interface

While the BBB has a 1 Ghz single core processor, it still was a significant challenge to discover IO that was fast enough to support the sampling of four simultaneous channels of analog data of a signal that could be up to 40KHz. Some of the options that the BeagleBone Black offers for controlling IO are just too slow for the application at hand. Through research and testing, it was apparent that using the BBB's built-in 200MHz microcontrollers could support control of the 2MHz throughput ADC used in this project. The block diagram in Fig. 15 shows the data path within the BeagleBone used to pass usable data to Seawolf.

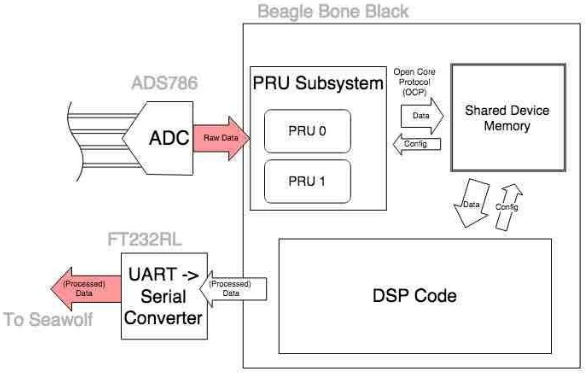

Fig. 14. Block diagram showing data flow within the acoustics sub-system

Additionally, acoustics supports a separate debugging interface accessible by a 115200 BAUD UART terminal on the BeagleBone itself. This interface has all the capabilities one would have when communicating with another computer over the secure shell (SSH) protocol.

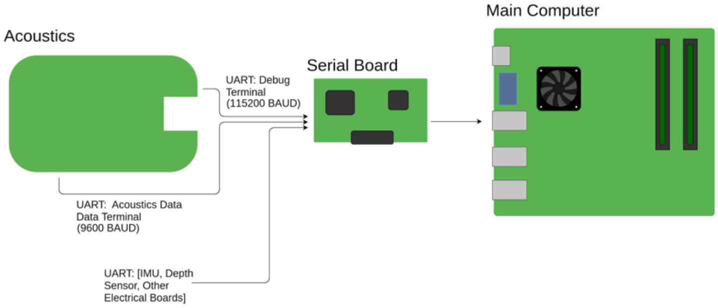

Fig. 15. Diagram showing how acoustics fits in with the existing electronics

The method used to estimate the pinger location involves measuring the time delay of arrival (TDOA) of a pinger signal amongst a physical array of hydrophone elements. Amongst any single pair of hydrophones, this information yields a single hyperboloid of possible pinger locations in a 3D space. For demonstration purposes, Fig. 17 shows how this data would look with an array of three hydrophones. To achieve optimum simplicity and usability, Seawolf also has the option to use two pairs of hydrophones independently. How the two pairs of hydrophones physically get placed can vary depending what advantages are to be desired, but the current recommendation is to have one pair in the front of Seawolf, and another pair on the bottom of Seawolf. The front pair may be oriented such that Seawolf can determine how far left or right the pinger is from its axis of forward travel. The bottom array may then be oriented such that Seawolf can determine whether or not it it directly over top of the pinger during a surfacing event.

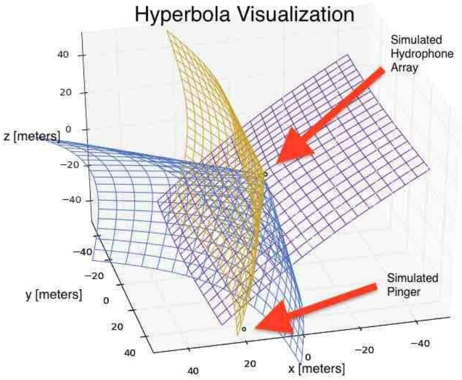

Fig. 16. Visual representation of the data generated when an array of three hydrophones spaced 6cm apart is used to determine the location of a pinger source that is about 40 meters away from the array.

5. *Challenges and Improvements*

One of the most challenging aspects of the URC acoustics system is actually manufacturing the hardware. The PCB containing all signal conditioning electronics is very high density due to the requirement of having it fit in the footprint of a BeagleBone Black microcomputer. While soldering this board by hand is very low cost, it is in the URC team's best interest to invest in learning how use a stencil and reflow oven in any future reprinting of the board. This is especially necessary when considering the high pin count of the acoustics board, which effectively increases the chance of at least one very difficult to debug cold solder joint occurring on the board. Also the team should experiment with large acoustic arrays on the order of hundreds of 22KHz wavelengths and use a peak detection method rather than a phase detection method. The current phase detection method is limited by the size of the hydrophones and the bracket holding them, which unfortunately allows Seawolf to use phase detection at a maximum frequency of 32KHz, though the competition pinger can go up to 40KHz. The current work around for this is to switch to a peak detection method if the pinger frequency is greater than 32KHz, but this method lends itself to high inaccuracies with such a small hydrophone array.

D. *Software*

1. *Libseawolf*

Seawolf's software is organized into many independent applications which each execute in a separate process. They can be run independently, making for a highly modular design. To allow these applications to communicate, Seawolf uses a custom inter-process communication (IPC) library called libseawolf.

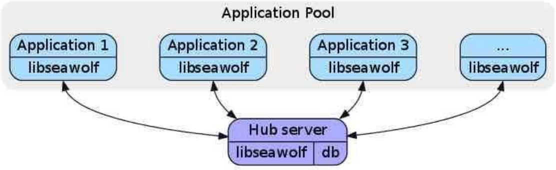

Fig. 17. Libseawolf architecture

Libseawolf was developed in 2008 by the team and has since become a stable independent library. Libseawolf allows applications to seamlessly set and access shared variables, send notifications, and wait for events to complete. Each application talks directly with a central server, calledseawolf-hub, using TCP/IP, which allows components of the system to be distributed across multiple machines, or even written in different languages. Although libseawolf is written in C, The URC has written Python language bindings that are used to write some of their applications in Python. An overview of the data flow through Seawolf VI's applications is shown in figure 18.

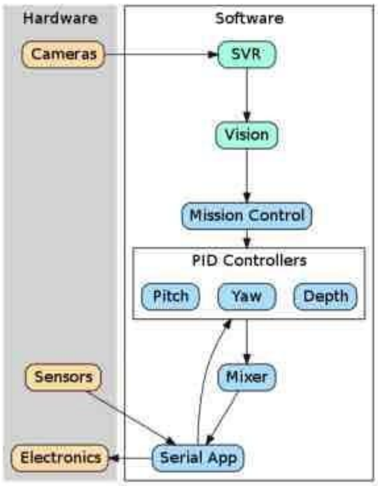

Fig. 18. Application data flow chart

3. Seawolf Video Router (SVR)

Seawolf VI features a streaming video router called SVR (Seawolf Video Router). SVR allows for efficient handling of multiple video stream sources, and allows for the creation of live debug video streams which can be monitored remotely over a network connection to Seawolf VI. Without SVR, viewing these streams would mean using the X11 protocol, which is slow at transferring large images.

4. *Vision Processing*

The vision application takes images from SVR and interprets them by looking for objects. Examples of objects include buoys, the gate, and a path marker. For the 2016 competition, Seawolf can also identify bins and the hedge object. Mission control requests vision to look for a particular object, and vision will respond each time it sees that object. To recognize these objects, Seawolf uses a set of OpenCV algorithms including adaptive thresholding[2], the Canny Edge detector[1], and the Hough Transform.

5. *Mission Control*

Seawolf 's mission control subsystem utilizes vision and sensor data in order to make all the decisions necessary to complete tasks. When a mission is completed, mission control progresses onto the next linearly. Each mission has its own logic code that navigates the robot and positions it for the next task. These navigation commands are given to the PID controller subsystem, which controls the values to be set to each thruster.

6. *Proportional, Integral, Derivative (PID) Control*

The PID controller applications are responsible for setting thruster values based on a desired heading dictated by mission control. PID is a common control loop algorithm which uses three terms: proportional, integral and derivative; hence the name PID. Seawolf VI has four PID controllers, yaw, depth, pitch, and roll movements of the robot. The output of each of the PID controllers must be mixed together into actual thruster values, which range from -1 to 1. This is the job of the mixer application. The final thruster values are then given to the serial application.

By choice, all of Seawolf's degrees of control (yaw, depth, pitch, and roll) are actually dominated by the P and D terms, and the I term is almost never used at all. This was derived out of the URC's manual tuning process, which favors smooth panning movements with almost no oscillations if possible. During extensive testing, it has been recognized that robots in the underwater domain fight a lot of inertia, and as a result, the I term tends to accumulate fast and dissipate slowly despite attempts to apply anti-windup techniques commonly used in other robotic applications.

7. *Serial Application*

The serial application handles communication to and from the microcontroller and other sensors except for the cameras, which communicate directly to the SVR. The serial application goes through each serial interfaces and deduces which device it is connected to. It then starts the correct driver for each serial device.

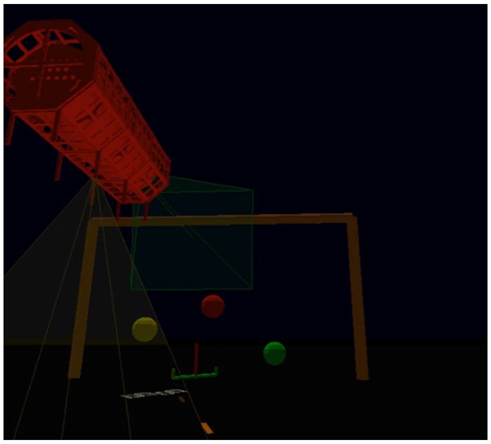

Fig. 19. Seawolf simulator

8. Simulator

A major barrier to getting mission control working correctly is the amount of testing time it takes. Testing usually requires long amounts of time in the water. Even simple problems with mission control can be hard to test out of water. To alleviate this barrier, the URC wrote a robot simulator in Python using OpenGL. By replacing applications that interact with the environment, the simulator allows us to test the remainder of Seawolf's software without the need of a pool.

9. *Problems and Improvements*

The URC would like to improve improve the software user interface in the future of the URC program. Currently, the modular software backend is very useful, but it is very difficult to create consistent workflows and adapt to various situations quickly when there is no front-end interface to give the user insight as to what is going on in the backend. Additionally, the URC vision system is very difficult for new members to modify. It is recommended that future vision developers try to write new code that emulates a processing pipeline, where discrete vision processing methods developed by past members of the team get treated as re-orderable steps a larger program. In effect, this could allow new member to experiment with how the order of various processing steps matter, or this could open up opportunities to grab novel techniques developed older vision programs for use in a new one.

IV. EXPERIMENTAL RESULTS

In general, the team accomplishes testing in two domains, whereas one domain is purely in the lab or in simulation, and the other domain is in water with the full system. Over the course for the 2015-2016 school year and summer, and as of the writing of this journal paper, Seawolf VI has accumulated 12 hours of functional testing in the water as well +54 hours of testing in the lab. The large proportion of lab testing stems design and development of an entirely new electronics system, which needed to be extensively tested, debugged in between in-water tests.

One huge challenge of the URC robotics program is figuring out how to test certain subsystems effectively in the lab. This is difficult, because the lab has totally different visual and physical characteristics than the water. The URC has found that the only effective way to test their vision processing code early is to "pretend" the robot is in water by feeding it previously recorded footage while monitoring the robot's thruster output values. The URC also leverages the use a custom 3D Seawolf simulator, as mentioned in the software section above.

As part of performing in-water functional tests, the URC team has gained some knowledge about how the robot works and its maximum capabilities. Experimentation with the new power system configuration has determined that Seawolf VI can float idly on the surface with computer power for up to 3 hours with a single battery, or (if tuned for the proper buoyancy), it can operate underneath the surface for 30 - 60 minutes on dual batteries. The URC team has also performed isolated tests in order to gage the fidelity of the acoustics system in the past. One form of standardized measurement the team team is working on developing is a measure of the speed of sound in water. Fig. 20 below shows how the team constructed a large, 3.5ft hydrophone array in order to measure the propagation time of an acoustic pulse on the order of 700 microseconds.

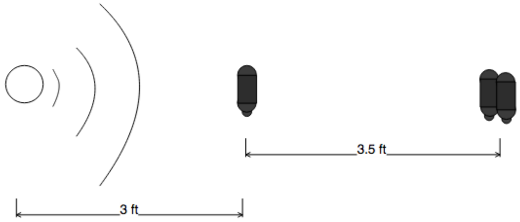

Fig. 20. Large hydrophone array example

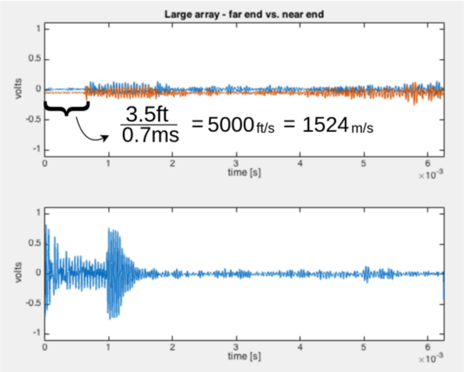

Fig. 21. Large hydrophone data

This yields a calculated speed of sound of 1524m/s in water, which is only 2.8% from the wikipedia reported constant of 1482m/s. The URC team should not only work in the future to develop its own calibration protocol based on this experiment, but also develop isolated test for other sensors on the robot, such as the IMU and depth sensor.

V. ACKNOWLEDGMENTS

The Underwater Robotics Club at North Carolina State University, would like to thank Dr. John Muth, who has generously provided the team with lab space and access to university resources. The club would also like to thank the NCSU ECE department staff, especially Stefanie Peterson, Melanie Whittington, and Heather Daughtridge for their support, and the NCSU Aquatic Center for use of their dive well for testing the robot.

The students in the URC would also like to extend their sincerest thanks to their corporate sponsors. Without their support the URC's activities would not be possible.

Sponsors:

Gold	ATI Industrial Automation, MECHA, NC Space Grant, Altium
Silver	American Society of Mechanical Engineers: Eastern North Carolina Section, SparkFun Electronics, XIMEA
Bronze	Advanced Circuits, Intel, JW Fishers, DigiKey, LeddarTech, RootBSD, SolidWorks

VI. REFERENCES

[1] Feature Detection. (n.d.). Retrieved June 17, 2016, from http://docs.opencv.org/2.4/modules/imgproc/doc/feature_detection.html

[2] Miscellaneous Image Transformations. (n.d.). Retrieved June 17, 2016, fromhttp://docs.opencv.org/2.4/modules/imgproc/doc/miscellaneous_transformations.html

Appendix

VII. OUTREACH

In 2012, as many members were graduating, the club recognized the need to grow their membership but ran into a problem: There were plenty of engineering students, but not enough that were also interested in joining an academic club with no course credit attached. The club knew how valuable of an experience building a robot for RoboSub is so they decided to start sharing that with the NCSU Community.

The first event in the Fall 2012 was "Engineering College Connections." There the club was able to recruit several freshmen to join the club. After talking to all of the freshmen they realized that they had all participated in some sort of competitive STEM club in the past such as *FIRST* Robotics Competition (FRC), Science Olympiad, or Technology Student Association (TSA).

Many of the competitive STEM events that the students had come from have an outreach component and those students wanted to continue giving back to the community. They encouraged the whole Underwater Robotics Club to also volunteer to help at workshops, competitions, and demonstrations. This led to a tradition of the URC spreading their passion for robotics by volunteering whenever its members can.

A. *Outreach at North Carolina State University*

The Underwater Robotics Club's outreach began at North Carolina State University and they have continued volunteering there since. The group sets up tables at many events throughout the academic year including:

- NCSU Open House
- College of Engineering Open house
- Engineering Welcome Back Bash
- Engineering College Connections
- Collaboration with IEEE, ASME, Engineering council, TEECA, and other STEM clubs on campus for presentations, fun activities, and info sessions
- Speak to Robotics classes about underwater robotics and help the students that choose to build a ROV for their final project

At these events the club will not only talk about robotics, but will discuss what it's like to be a student at NCSU with prospective students and freshmen. The club also volunteers to help out professors by providing real world examples of where content would be applied.

B. *K-12 Educational Outreach*

As more members volunteered, the club got more attention. A lot of public schools contacted us to come speak to their classes and set up tables at their science fairs, so the club took Seawolf out to visit the students. Other educational places also contacted the club like museums, summer camps, and homeschool groups. Here is a list of the events the club has gone to:

- Present about robotics and bring Seawolf to elementary schools, middle schools, and high schools
- Teach homeschoolers about robotics
- Bring Seawolf to summer camps and talk about robotics/engineering
- Have a booth at various museum events including Robot Rumble as a part of the NC Science Festival
- Travel to talk about UUVs and Seaperch to Computer Science and ROTC students at a high school on NC's coast

C. *Outreach with competitive STEM organizations*

They also volunteer at many STEM competitions throughout North Carolina and mentor several groups of middle and high school students.

- Judge and referee at *FIRST* LEGO League Competitions
- Judge and referee at local and state level VEX Robotics Competitions
- Judge at state level TSA competitions
- Referee, inspect robots, run the field, help with team queueing, and provide technical support at official and off season *FRC* events.
- Coordinate, run, and score events at regional and state level science Olympiad competitions
- Mentor six *FRC* teams
- Coach one all-girl FRC team
- Assist with North Carolina SeaPerch training
- SeaPerch Demonstrations
- Teach workshops for FRC

D. *Impact on the Members and Community*

The members of the Underwater Robotics Club at NCSU have had many opportunities to work on soft skills that working toward their degree wouldn't teach them.

They practice a lot of public speaking while presenting to their peers, children, teenagers, and other adults in the community. They also get to practice their cooperation and teamwork skills with many different groups of other volunteers when helping out at local STEM competitions. This gives members the skills that many of their future employers will be looking for.

The club and its members have volunteered over 4,200 hours in the last 4 years. In this time, the URC has reached approximately 40,000 K-12 and college students as well as many other people throughout their community.

This year alone the URC have over doubled Their hours volunteered in 2012 with 1,674 hours total. In that time, it is estimated that 15,000 people have been reached by the club's efforts. In Fig. 22 the growth of the club's outreach is clear.

E. Plans for the Future

The Underwater Robotics Club at NCSU plans to continue growing their outreach efforts. The following are their goals for the next few years:

- Continue helping to grow SeaPerch in NC
- Reach out to more local FRC teams
- Establish connections with local STEM teachers so the club can come talk about robotics to their classes and help with engineering activities
- Connect with more professional organizations and companies to build professional relationships and work together on presentations

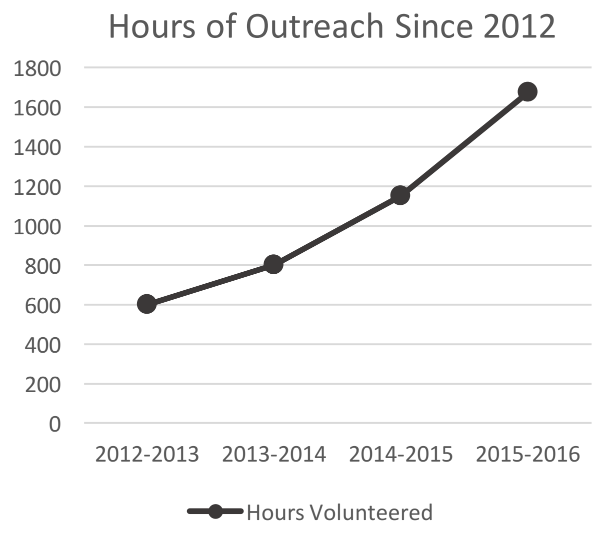

Fig. 22. Graph showing hours of outreach since 2012