Research and Design of Seawolf VI
North Carolina State University
Underwater Robotics Club

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Abstract

Seawolf VI is the sixth in a series of submersible autonomous robots developed by the North Carolina State University Underwater Robotics Club (URC). URC is a group of undergraduate students whose goal is to give students an opportunity to apply their knowledge to solve real world problems, as well as exposing them to new disciplines. Introduced in 2014 but unable to attend competition, Seawolf VI has been finetuned and heavily modified to improve it's performance in the 2015 Robosub Competition, which consists of an underwater obstacle course of vision and acoustic tasks which the robot must navigate autonomously. In this paper we will describe the different components of Seawolf VI and the motivation behind the design.

1 Introduction

Seawolf VI is an autonomous underwater vehicle (AUV) designed by North Carolina State University students to compete in the AUVSI Robosub competition. The competition is held each July in San Diego at TRANSDEC. This competition is a way for our students to come together and apply the skills we learn in class helping each other learn along the way. We must design our AUV to complete an obstacle course using using sensors such as cameras or passive sonar.

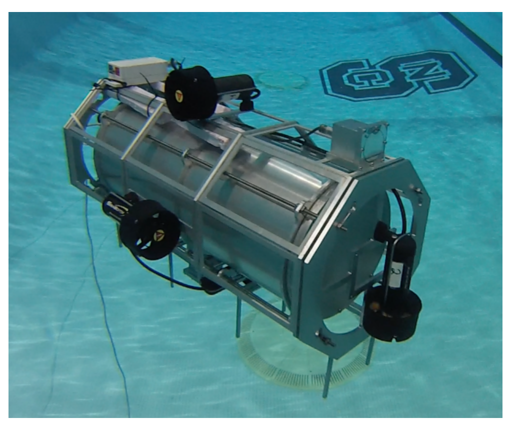

Figure 1: Seawolf VI

2 Design Overview

2.1 Frame

The frame of Seawolf VI was designed in SolidWorks to create a modular system to allow various panels to be swapped out as different peripherals were needed to be mounted. It was created out of machined aluminum with a heavy focus on trying to minimize the weight of the robot.

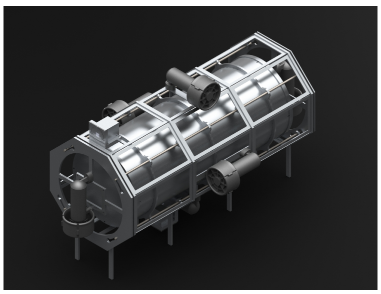

Figure 2: Seawolf SolidWorks Rendering

2.2 Hull

The computer and other electronic hardware is primarily enclosed within our aluminum cylindrical hull. The cylindrical shape was chosen for its capability to resist deformation under pressure. Inside of the hull are two shelves. The top shelf has the computer and electronics attached to it while the bottom shelf holds the batteries. The hull is sealed with two endcaps with the endcap on the rear of the robot holds the pressure transducer as well as several 104 series Fischer Connectors.

2.3 Thrusters

Seawolf VI has six Seabotix DC Brushed Thrusters. They run at 24V which is provided by two 12V sealed lead acid batteries that are connected in series. The thrusters located on port and starboard are used to

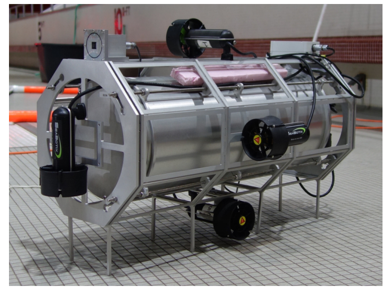

Figure 3: Fully-assembled Frame and Hull

control forward, backward, and yaw rotation. Thrusters located on the bow and stern are used to control depth and pitch movement. The final two thrusters located on the top and bottom of the robot are used to control roll and for movement side to side.

3 Sensors

3.1 Inertial Measurement Unit (IMU)

The Microstrain 3DMGX1 Inertial Measurement Unit measures pitch, yaw, and roll data using a three axis gyro, three axis accelerometer, and three axis magnetometer. It sends the computer this data through a serial interface. The IMU is shown in figure 4.

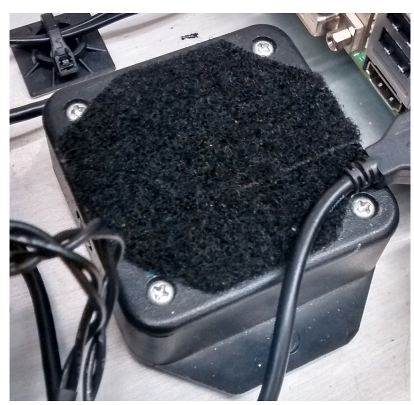

Figure 4: IMU

3.2 Pressure Transducer

The Measurement Specialties US300 analog pressure transducer is used to measure depth. It is mounted through a hole in the hull and connected to the electronics board where the microprocessor reads the sensor value (refer to figure 5).

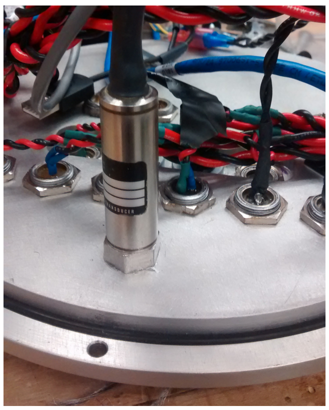

Figure 5: Pressure Transducer

3.3 Cameras

Seawolf VI has two USB HD Microsoft Life-Cam 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 automatically compensate 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.

4 Electronics

Seawolf VI's custom electronics systems are comprised of two boards, stacked with a high-density mezzanine connector between them. These two boards provide power, thruster control, servo control and sensor input for

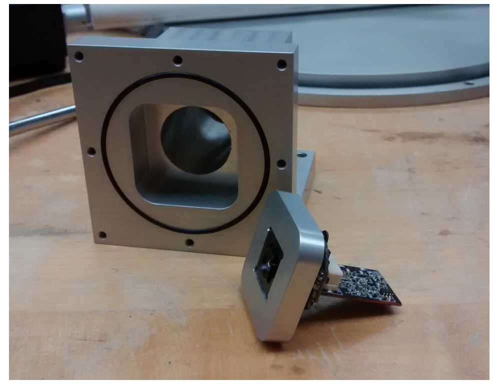

Figure 6: Camera and Enclosure

the craft. This design is a marked improvement from the disarranged multiboard electronic systems used in previous Seawolf designs. The goals of the electronic system in Seawolf VI were to reduce cable clutter and produce a reliable and maintainable design. The custom electronics boards are shown in figure 7.

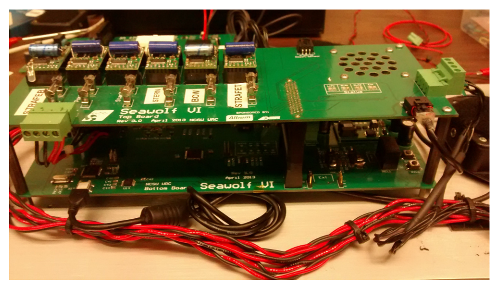

Figure 7: Custom Electronics Boards

4.1 Microprocessor

An Atmel ATxmega32A4 microprocessor on the bottom electronic board interfaces to sensors, servos, and motor controls. The microprocessor communicates to Seawolf VI's computer over a serial connection provided by a FTDI FT4232H USB to serial adapter chip. This chip provides four serial connections over a single USB connection, which provides the serial connection to the IMU (inertial measuring unit).

4.2 Power

Power for electronic systems is split into two isolated domains. In one domain, Sealed LeadAcid (SLA) batteries provide power for thrusters. In the other domain, Lithium Polymer (LiPo) batteries provide power for Seawolf VI's computer and controls. These two power domains are optically coupled and otherwise are entirely isolated. The isolation protects sensitive digital analog electronics used in Seawolf VI's control systems from noise and transients produced by thrusters. Power for the computer and controls is regulated by two 12V switching power supplies capable of providing 72W of power each. Additional regulators provide 9V, 6V, 5V, and 3.3 V for peripherals and electronics. Additional features provided by the electronic systems include automatic low voltage cutoff for the LiPo batteries, low voltage warnings for all batteries, hot-switching to external power to conserve battery life, and a diagnostics and control panel for quick debugging.

Figure 8: Onboard Computer

4.3 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 11. Most of the computer's speed is put toward image processing, which takes advantage of the processors' four cores by processing images from each binocular camera separately. The two LiPo batteries that power the computer will run for about two hours on one charge.

5 Acoustics

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, excluding the UART-to-USB converter, is shown in figure 9, whereby the front-end signal conditioning electronics are most visible.

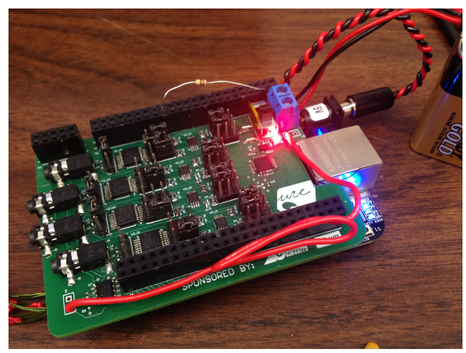

Figure 9: Acoustics Subsystem displaying the front end electronics

5.1 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, 4 channel ADC.

- Breaking out Beaglebone pins in a manner that encourages further testing and experimentation.

Figure 10 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 our acoustics system began with the one thing that was already available to us thanks to previous generations of our team, a set of four HTI 96 Min hydrophones with internal pre-amplifiers. Early tests have characterised that these hydrophones were capable of capturing ultrasonic signals but also that a great deal of high frequency interfecence would couple into our system.

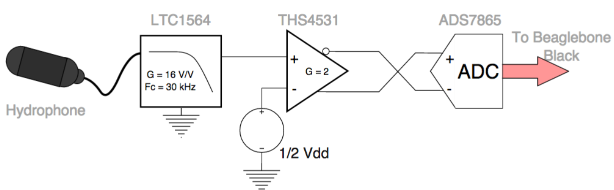

Figure 10: Block diagram showing one out of the four (identical) signal paths from Hydrophone to ADC.

However, we eliminate this noise with the low pass filter that is provided by the LTC1564. We also have digital control of the amplification applied at this stage as well 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 2, 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 12 bit, 4 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.

5.2 BeagleBone Black Software

Following the design of hardware that warrants a clean signal reaching the BBB was the task of creating software that could 1) control the hardware and 2) process data collected by the hardware.

5.3 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 4 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 figure 11 shows the data path within the Beaglebone used to pass usable data to Seawolf.

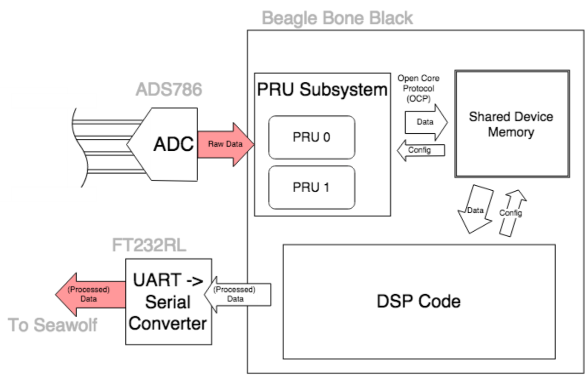

Figure 11: Block diagram showing data flow within the acoustics sub-system

5.4 Processing

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 signal pair of hydrophones, this information yields a single hyperboloid of possible pinger locations in a 3D space. For demonstration purposes, figure 12 shows how this data would look with an array of three hydrophones. To achieve optimum simplicity

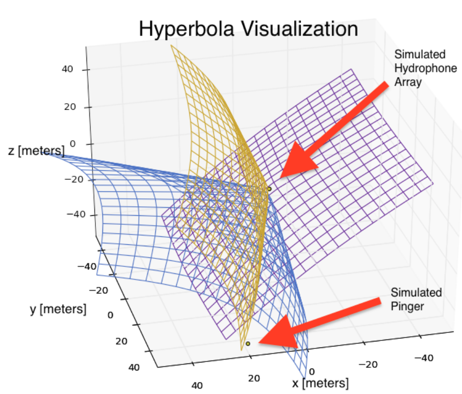

Figure 12: Visual representation of the data generated when an array of 3 hydrophone spaced 6cm apart is used to determine the location of a pinger source that is about 40 meters away from the array.

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.

6 Software

6.1 Libseawolf

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

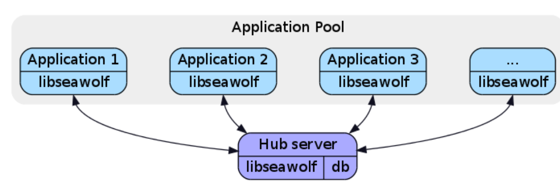

Figure 13: libseawolf Architecture

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, called Seawolfhub, 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, we have written Python language bindings that are used to write some of our applications in Python. An overview of the data flow through Seawolf VI's applications are shown in figure 14.

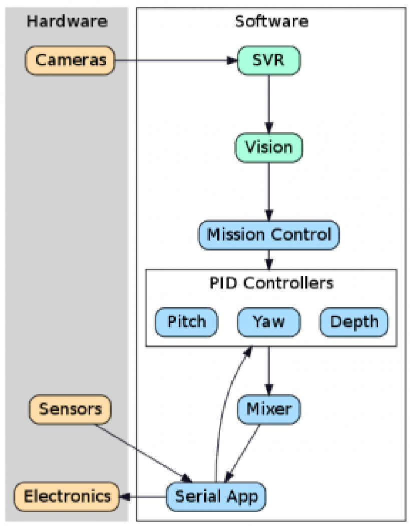

Figure 14: Application data flow

6.2 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.

6.3 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 2015 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, we use a set of OpenCV algorithms including the Canny Edge detector, Hough Transform, and Haar Classification.

6.4 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. Figure 15 shows the logic behind the buoy task, an example of how a mission control task works.

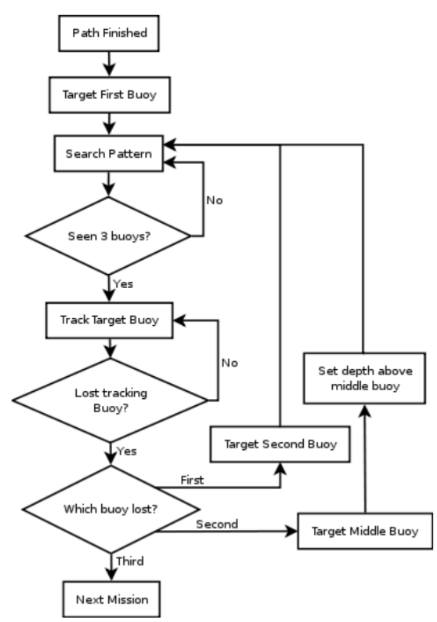

Figure 15: Buoy Mission logic

6.5 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. 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.

6.6 Serial Application

The serial application handles communication to and from the microcontroller and other sensors except for the cameras, which communicate directly to 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.

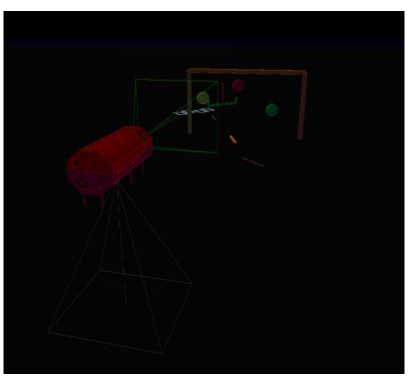

Figure 16: Seawolf Simulator

6.7 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, we 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 our software without the need of a pool.

7 Acknowledgments

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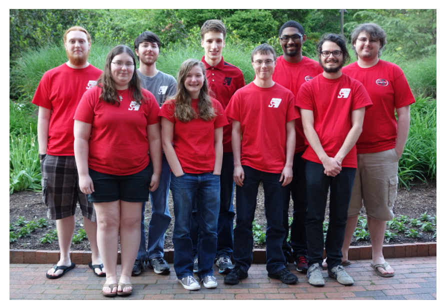

Figure 17: Team Picture

We would also like to extend our sincerest thanks to our corporate sponsors. Without their support our activities would not be possible.

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