Amador Valley HS RoboSub Team: Development of Barracuda Mark XIV

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Abstract—The Amador Valley High School Robotics Team, or AVBotz, is a diverse group of students with a common goal: to refine Barracuda Mark XIV and learn about robotics in the process. This year, the main electrical changes include an improved hydrophone system with dedicated components and a more powerful computer. Software emphasis was placed on vision-processing, replacing previously problematic classes, and modifying various algorithms in accordance to prior testing experiences. Mechanical has focused on developing a grabbing mechanism and producing copies of competition props. Public relations, a new subdivision this year, has organized several outreach and fundraising events.

I. INTRODUCTION

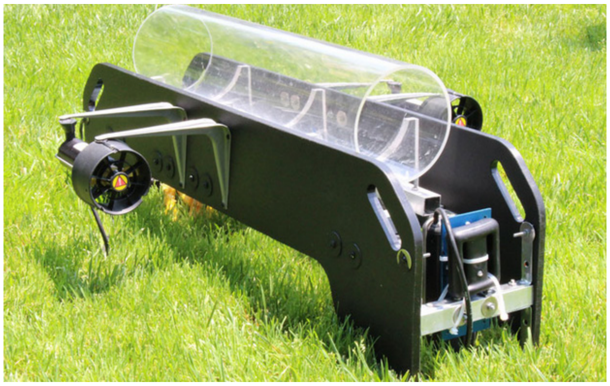
This year, the AVBotz team has made alterations to the way we've traditionally done things. We've doubled membership from the original fifteen to the current twenty-eight, created a public relations division to focus on community outreach, and increased the number of weekly meetings.

Other things haven't changed. The team still meets with Harvest Park Middle School students to teach robotics and computer programming, demonstrates Barracuda to the general public at the Alameda County Fair, and offers lectures on mechanical, electrical, and software concepts to all Amador Valley High School students. Every step of the development process, from initial blueprinting to production, is handled completely by team members with no help from technical advisors. We continue to uphold the team's legacy of excellence that started sixteen years ago.

AVBotz is one of more than thirty teams, ranging from high-school to collegiate levels, that compete at RoboSub. Each team builds an autonomous submarine that aims to complete a set of challenges, including navigation, object recognition, object manipulation, passive sonar, and torpedo firing. Task completion, vehicle weight, and presentation skills all factor into the scoring system.

II. MECHANICAL

Mechanical is responsible for all of the structural components of the submarine. Its goal is to improve the capabilities of the sub's hardware and to help maintain the sub in its working capacity. To do this, mechanical uses many tools, including SolidWorks CAD, 3D-printers, CNC machines, and laser-cutters.



A. *Hull*

The submarine's hull is a two-foot acrylic tube with an outer diameter of six inches. Electrical components, such as the cameras and ODROID, are housed in this watertight container on an acrylic rack. A frame of one-inch thick aluminum bars secures the tube to the two side panels, which are made of High-Density Polyethylene (HDPE) and provide structural support for the entire sub. Two sets of handles at the front and back of the sub were cut into the side panels to make the sub easier to carry. The side motors are connected to the side-panels via L-brackets, while the other two motors (located at the front and back) are attached to the aluminum bars. The frame also provides a mounting place for other external components, such as the dropper.

B. *Thrusters*

Barracuda uses four Seabotix BTD-150 thrusters. Two forward-facing motors are located on the side panels and are attached via aluminum L-brackets; they control the sub's horizontal propulsion (forwards and backwards only). The other two motors face downward and are located on the front and back, attached to the framework; they direct the depth and pitch. Each thruster is connected to a port in the back of the submarine, which routes signals from the Super Roosters (our motor drivers) to the thrusters. Each of the thrusters draws a max of 4.5 amperes of current and exert 21.6 Newtons of force.

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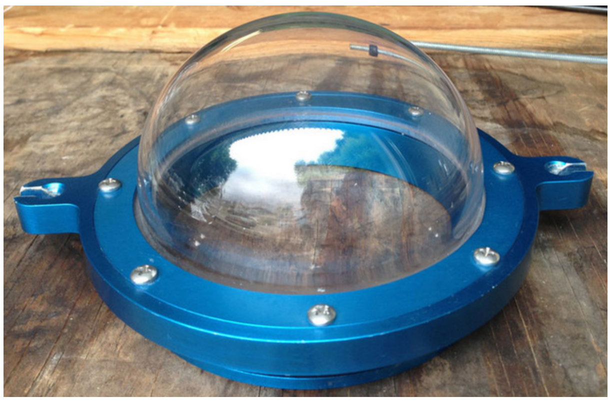
C. *Endcaps*

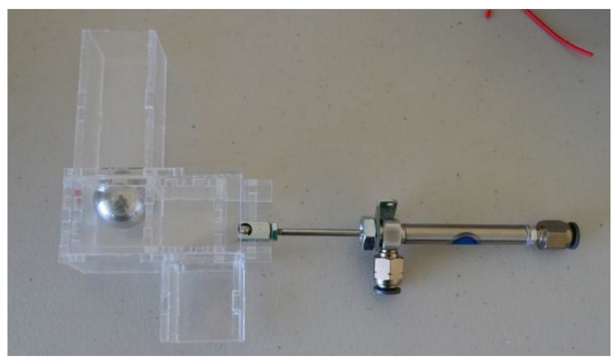
Barracuda has two anodized aluminum end caps, one at each end of the main acrylic tube. The front end cap (pictured on the next page) is an aluminum ring around a clear acrylic dome that houses the IMU and the forward-facing camera. The inside face of the rear end cap connects to many of the main electrical components, and the outside face houses a set of 11 Brad Harrison connectors that handles all of the submarine's signal and power I/O and allows us to connect components such as the pneumatic dropper and the motors to the electrical components inside the hull. The connectors are rated IP-68 and can be quickly attached and detached without disrupting the watertight seal. Both end caps have rubber O-rings fitted into grooves along their circumference, creating a watertight seal when the end caps are in place. Uniform pressure is applied to the hull via two turnbuckles and two threaded rods that are mounted on opposite sides of the end caps. This design reduces torsional stress on the tube and provides additional structural integrity.



D. *Pneumatics*

Last year, we implemented a pneumatic system in the submarine. Currently, this system only powers our dropper, but our goal is to use it to run all of the auxiliary components, such as the planned torpedo launcher and grabber. Our air supply is contained in a 15 cubic inch air tank located at the back of the submarine, with a pressure of 125 psi. A waterproof Otterbox on the underside of the submarine houses other pneumatic components. Air flows from the air tank to the pressure regulator, which decreases the pressure from 125 psi to a working pressure of 30 psi. The regulator connects to a solenoid valve, which directs air to the pneumatic cylinder that runs the dropper.

The dropper is an external mechanical structure made of laser-cut acrylic. There are two main parts: one is a container screwed onto an aluminum tube (part of the submarine's structural support) located in the middle section of the sub's bottom, while the other is a sliding acrylic piston attached to a pneumatic double-acting cylinder that works by direct control. The cylinder is controlled by a twelve volt, 4/2 way solenoid valve. The dropper is loaded with two one-inch diameter stainless steel ball bearings from the top tube, which leads to the acrylic piston. The pneumatic cylinder pushes the piston forward, and a hole in the bottom of the piston aligns with the bottom tube. The ball bearing falls from a hole in the bottom of the dropper, and the pneumatic cylinder retracts, allowing the second ball bearing to drop into the piston. This design allows us to drop two markers with only one pneumatic cylinder and dropper.



E. *Kill Switch*

In the past, Barracuda's kill switch was a waterproof button. This switch required two hands to operate and floated freely in the water, which made it both inconvenient and difficult to operate. This year, we switched to a Carling Technologies W series sealed rocker switch, which can be operated with one hand. The switch is IP-68 certified and is housed in a custom 3D-printed case filled with epoxy to waterproof the surrounding cables. It is attached near the back of the submarine, next to one of the handles on the side panel, for easy access.

III. ELECTRICAL

The electrical subdivision is responsible for maintaining and developing Barracuda's internal and external electronics. This year, electrical focused on developing hardware for the passive sonar system. To do this, we added a dedicated digital signal processor (DSP), a custom amplifier, and a custom filtration system.

A. *Batteries*

Barracuda's primary power source is two Thunder Power RC 14.8 V Lithium Polymer batteries connected in parallel. We chose these batteries because of their high energy capacity, small size, and ability to provide large amounts of burst current. The energy capacity of the batteries is 150 Wh, which allows our sub to run for up to five hours of continuous water-testing. The ability of the batteries to supply large quantities of burst current accommodates the inrush current of powering the thrusters. Using two batteries makes them hot-swappable, which allows us to save time while testing, since the electronics do not need to be powered off when changing the batteries.

B. *Power Supply*

Besides the motors, which run off of 14.8 V, all of Barracuda's internal electronics run exclusively on 5V. To accommodate this, we have a custom PCB with a buck converter based on the TI LMZ12010 simple switcher. We chose the LMZ 12010 because it can drive up to a 10A load, which gives us ample clearance for expansion. The LMZ12010 also contains an undervoltage lockout system which turns off the motor controller if battery voltage falls below 12V. We included low-ESR tantalum and ceramic capacitors to reduce ripple.

C. *Main Computer*

Barracuda's main computer is the Hardkernel ODROID-X2. The ODROID-X2 is a development board based on the Samsung Exynos Prime 1.7GHz ARM Cortex-A9 Quad Core processor with 2GB of RAM. The ODROID-X2 handles Barracuda's vision-processing and mission-planning programs, and it communicates with the mbed and the cameras through USB. We chose the ODROID-X2 because it has an excellent price-performance ratio and uses just 10 watts of power, which contributes to Barracuda's long battery life.

D. *Control Board*

Barracuda's control board is based on the mbed LPC1768, a microcontroller with a 32-bit ARM Cortex-M3 core running at 96MHz. It includes 512KB FLASH and 32KB of user-accessible RAM. The mbed also has many useful interfacing capabilities, including Ethernet, CAN, SPI, I2C, ADC, DAC, and PWM. Barracuda uses the mbed to handle low-level tasks, such as motor-control and processing data from our various sensors. A SparkFun Logic Level Converter is used to ensure proper communication between the mbed and the motor controller.

E. *Servo and Motor Control*

Barracuda's servo controller is the 12-channel Pololu Mini Maestro. The Pololu receives serial signals from the mbed and outputs pulse-width modulation (PWM) signals to the motor drivers to control motor speed.

F. *Motor Drivers*

Barracuda's motor drivers are four Novak Super Roosters. The Super Roosters adjust the voltage applied to the thrusters based on PWM input from the servo controller. To mitigate the heat generated by the Super Roosters, they are arranged around the rear aluminum end cap to dissipate heat into the water.

G. *Wi-Fi Tether*

Barracuda's WiFi tether contains a Netgear router and a rechargeable battery pack in a waterproof Pelican case. The access point is wired to the main computer via an ethernet cable that passes through the rear endcap. The tether allows us to upload code to the main computer and control board during testing, allowing us to save time by having the operators debug while the vehicle is still in the water.

H. *Navigation Sensors*

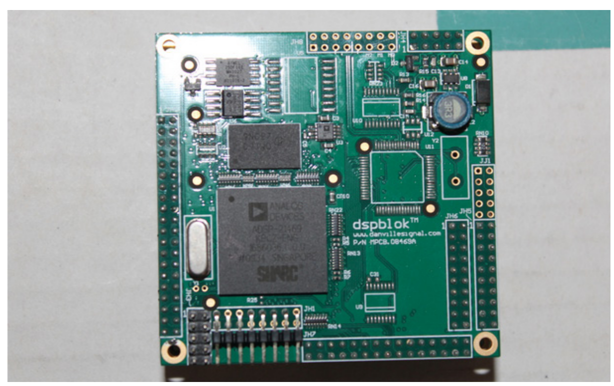
Barracuda uses the 9DOF Razor IMU. It gives the sub nine degrees of freedom with its triple-axis accelerometer, triple-axis gyroscope, and triple-axis magnetometer. However, the magnetometer is not utilized due to changing magnetic fields induced by the thrusters. Instead, the accelerometer and gyroscope are used to determine heading.

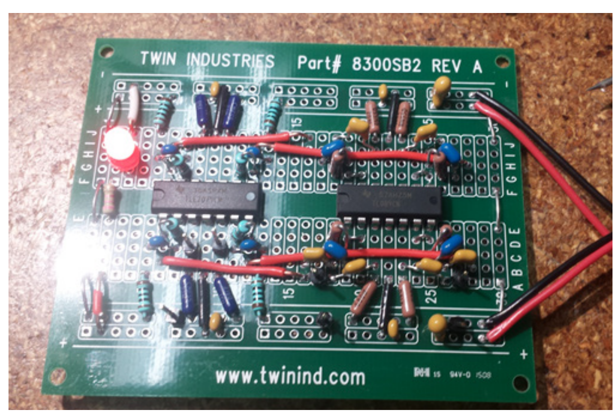
Barracuda's pressure sensor is the Ashcroft Model K1 Pressure Transducer/Transmitter. It converts pressure readings from the water into voltage. These voltage readings are linearly converted to depth on the mbed.

I. *Hydrophone Signal Processing*

Barracuda uses four Teledyne Reson TC4013 Hydrophones to capture audio from the pinger. The Danville Signal dspblok 21469 serves as Barracuda's DSP. This year, we built a custom amplifier and filtration system to condition the signals before being processed on the DSP. Barracuda's op-amp is built around the Texas Instruments TLE2074CN and results in a gain of 40 dB. After amplification, the signal is passed through a high-pass filter designed around the Texas Instruments TLO84CN. The high-pass filter has a cutoff of about 10 kHz and helps to filter out any noise not generated by the pinger. The DSP processes the amplified signal and sends Time Difference of Arrival (TDOA) data to the main computer.

The amplifier is isolated from the rest of the electronics to prevent any high-speed digital noise from entering the analog circuitry. The amplifier is powered by small 9V batteries near the board to avoid switching noise.



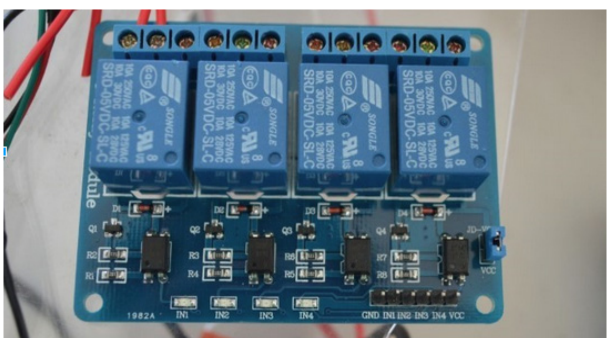


J. *Cameras*

For visual input, Barracuda uses front-facing and downward-facing 720p Logitech c525 webcams. The high resolution of the cameras gives us the option of oversampling to reduce visual noise, which can interfere with our vision-processing. The Logitech c525 cameras automatically focus anything farther than seven centimeters from their lenses.

K. *Actuator Control*

Barracuda uses a SainSmart 4-channel Relay Module to control its pneumatic solenoids. The module receives signals from the mbed and switches 14.8V from the batteries to power the solenoids. A 4-channel relay gives us the capacity to add more external peripherals in the future.



IV. SOFTWARE

The software subdivision is responsible for building and maintaining all programmable elements of the auv. Its goal is to create a robust yet flexible system capable of performing a myriad of diverse tasks and actions. To do this, the software subdivision designs and improves algorithms to manage various aspects of the submarine, including mission control, image processing, navigation, and multilateration.

A. *Extensive Vehicular Automaton (EVA)*

EVA runs on the Odroid-X2. EVA connects directly to the mbed, dspblok, and cameras to control all aspects of the submarine. It is responsible for vision, mission control, multilateration, and other high-level functions.

Mission Control

EVA contains a set of independent modules for the various competition tasks. Each module is initialized, but only one is selected at a time. In each cycle, the selected module is executed until it either finishes or quits. EVA selects the next module from a list based on the submarine's position, nearby detected objects, and time remaining in the run.

Image-Processing

EVA is connected to 2 cameras: one pointing forwards and one pointing down. Each image is run through an enhancement filter to intensify features that stand out in the water. The process for each task is described below:

Guide: The image is thresholded for orange to separate the path from the rest of the ground. Canny edge detection and Hough line transform are used to calculate the angle the path is pointing.

Flux Capacitor: The image is split up into subsections, each assigned values for the likelihood that each buoy is within its area. This figure is calculated by an algorithm based on the colors of the contained pixels. The region with the greatest probability is selected for each color (red, green, and yellow).

Time Portal: The center of the gate is determined by calculating the average position of yellow pixels in the image. Proximity to the gate is determined by calculating the standard deviation of the horizontal position of yellow pixels.

Refuel: To locate the bins, the image is thresholded to find the black sections of the bins. A blob detection algorithm finds the location of each visible bin. To detect the image inside each bin, EVA uses Fast Library for Approximate Nearest Neighbors (FLANN) to compare features found in the image with those found in sample images.

Logging

EVA records comprehensive logs from its runs, including the current state, both raw and processed images, and text data from each task. This simplifies debugging by showing us exactly what happened and why, and it allows us to perform extra tests on the images to adjust for future runs.

Hydrophones

In order to determine the location of the pinger, EVA receives Time Difference of Arrival (TDOA) data from NALU. Using these differences it constructs three hyperboloids and calculates their intersection by solving a linear system.

Multi-threading

Because the Odroid-X2 has a quad-core processor, EVA tries to multithread its algorithms whenever possible. To manage the allocation of threads, EVA uses an open-source threadpool by AVBotz alumnus Jeff Chen. By splitting processing four ways, calculations can be performed four times as fast. This is particularly useful for fast image-processing.

B. *AVNavControl*

AVNavControl is a low-level controller that runs on the mbed. It relays sensor data to EVA and executes EVA's decisions by physically interfacing with the motors. The separation of hardware-interfacing and mission control allows EVA to focus on higher-level functions.

State

There are four components of the submarine's state: power, heading, depth, and pitch. With the exception of power, each of these is determined in real time with sensor data. Depth depends on pressure sensor data, heading depends on gyroscope data, and pitch depends on both the gyroscope data and the accelerometer data run through a Kalman filter.

Motor Control

AVNavControl integrates three proportional-integral-derivative (PID) systems to control the bearings of the submarine. It receives instructions from EVA in the form of desired values for state variables, then it applies the appropriate PID controller to approach the desired value without overshoot.

Modes

AVNavControl has multiple modes in order to allow it to perform different tasks depending on the situation. The standard mode accepts signals to control the state. Additionally, a debugging mode allows the calibration of the IMU, direct access to peripherals, or PID tuning. This year, AVNavControl can switch modes through a serial message without a restart. This saves time because we no longer need physical access to the mbed in order to perform these tasks.

C. *Nautical Autonomous Linear Ultracomputator (NALU)*

NALU, named after the Hawaiian word for "wave," runs on the dspblok and interfaces between EVA and four hydrophones located outside of the main hull. Using analog data from each hydrophone, it detects the signal emitted from the pinger and calculates the time difference of arrival (TDOA). This data is sent to EVA for multilateration. This year, new software was written to run on Analog Devices' ADSP-21469 on the dspblok to read from the analog to digital converter and to determine the TDOA.

Time Difference of Arrival (TDOA)

The dspblok receives amplified signals from the hydrophones at 96 thousand samples per second. NALU detects the time (measured in samples) at which the ping reaches each hydrophone and calculates the time difference of arrival.

Serial Interface

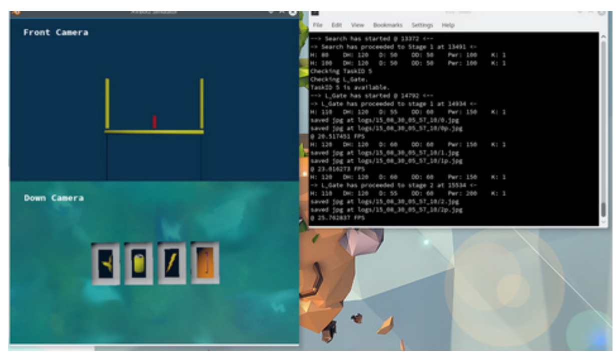
Using the TDOA data, NALU creates a three-byte message containing the time differences, followed by a three-byte tail. This is transmitted through an RS232 interface and converted to USB to connect to EVA.

D. *Extra Tools*

By developing extra tools, we have managed to make our testing much more efficient.

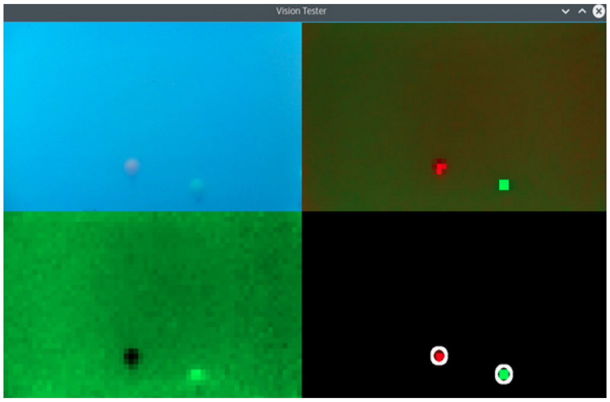
Simulator

Designed in the free and open-source 3D-modeling software Blender, our simulator provides a virtual testing ground that can be used in conjunction with EVA to test new code in a real time environment. Given that the simulator can be operated on each individual team member's computer, this allows for work to be conducted on multiple tasks concurrently. By doing so, the simulator enables members to implement unique ideas on a smaller scale before we as a team can collaborate to come up with the most practical and efficient solution. In addition, the simulator allows for more efficient use of our time by allowing us to fix and debug time-consuming errors before running pool tests.



Vision Tester

Our homegrown vision-analysis program allows us to test computer-vision algorithms more easily by isolating image-processing from the rest of EVA. It separates image-processing into multiple components and displays the output of each step. This allows us to quickly develop new computer-vision algorithms and test them on the fly. The vision tester is pictured on the following page.



Manual Aquatic Robot Vehicle Interactive Navigator (MARVIN)

MARVIN is a python library that creates a serial interface to the mbed and simplifies the transmission of common instructions. In conjunction with the python shell, it provides a simple command line interface to manually control the submarine. Additionally, it can easily be used by other scripts to enable other forms of control.

Remote Robot Digital Director (R2D2)

R2D2 combines the MARVIN library and CWiiD to enable the use of a Nintendo WiiMote to send commands to AVNavControl. This allows us to intuitively control the submarine with a familiar and user-friendly controller.

V. ACKNOWLEDGEMENTS

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