Amador Valley High School

Barracuda Mark XII (2013)

Kevin Chen *(leader)*, Aditya Sinha, Brody West, Pierson Connors, Albert Lee, Alex Korshak, Eric Pianin, Glynn Williams, Gordon Su, Jonathan Yip, Karan Samel, Luke Shimanuki, Siddhartha Desai, Swayam Suri, Yashwanth Nannapanini

Abstract

Students from Amador Valley High School have developed Barracuda XII, an autonomous underwater vehicle, for the 16th annual International RoboSub Competition. With a completely redesigned hull and electrical system, Barracuda XII presents a more stable platform upon which mission software can be built. This year's improvements include a longer hull, faster main computer, 720p cameras, a digital-signal-processing board, and robust, parallelized image processing algorithms. Barracuda's sensors include an inertial measurement unit (IMU), a pressure sensor, two cameras, and four hydrophones. With all these improvements, typical battery life for Barracuda remains the six to ten hours.

The Team

In 1999, students from Amador Valley High School began competing at the AUVSI International RoboSub Competition, then known as the AUV Competition. This year, the 15 members of our team span all experience levels, from incoming freshmen to graduated seniors. All stages, from development to manufacturing to testing, are carried out entirely by students. With no technical advisors, the team must rely on self-education. The leadership of the team devised a series of lectures to familiarize new members with mechanical, electrical, and software engineering concepts, allowing team members to understand how Barracuda works without taking college-level classes.

In addition, the team has increased its community outreach this year by teaching robotics to middle-school students at Harvest Park Middle School, and by presenting to the public at the Alameda County Fair. The team hopes to increase interest in engineering among young children through this outreach.

The RoboSub 2013 Mission

AUVSI Foundation created this student competition in 1998 to increase interest in unmanned systems. The competition, now in its 16th year, is designed to simulate real-world tasks for autonomous submarines. These tasks include navigation, object recognition, object manipulation, passive sonar, and torpedo firing. In addition, vehicle weight and team presentation skills factor into the scoring system.

Mechanical

Recently acquired CAD software, along with easy access to a laser cutter and a 3-D printer, has completely changed the way our mechanical team creates designs. This enables higher precision and faster iteration than our team could achieve in the past. This year, the mechanical team redesigned the hull, internal rack, and grabbers in a major overhaul of Barracuda. All three components were modeled in SolidWorks.

Hull

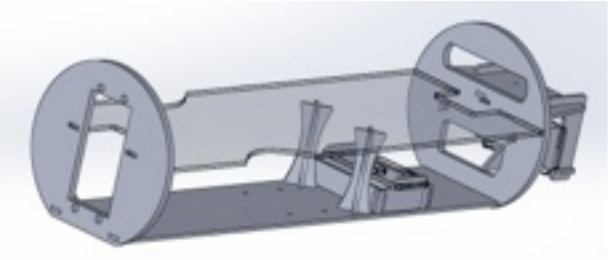
A 24 inch (60.9 cm) long by 6 inch (15.2 cm) outer diameter clear acrylic tube houses Barracuda's electronics. By making the tube longer, but not wider, the internal space can be increased while maintaining compatibility with existing components. The tube of the sub rests on a frame of 1-inch (2.5-cm) square tubular aluminum bars, which attach the tube to two high-density polyethylene (HDPE) panels. The side panels act as a hard point off which the majority of components are mounted, such as the thrusters and grabbers. The use of large side panels allows for much more freedom in the mounting of external parts, increasing the extensibility of Barracuda. These side panels also have handles that assist both in the moving of the sub and in the mounting of the lifting harness.

End Caps

To maintain a seal on either end of the main tube, Barracuda uses anodized aluminum end caps. Both the front and rear end caps use a single rubber O-ring which compresses against the interior of the hull to create a watertight seal. The front end cap houses a clear acrylic dome in which the forward-facing camera and IMU reside. The use of a clear dome provides many advantages: it provides extra space for the cameras and allows for a larger field of view. The rear end cap contains all signal and power I/O. To accomplish this, it has 11 Brad Harrison connectors, each containing four to eight pins. These connectors are IP68-rated and can handle up to 1000 PSI, which is the equivalent of about 231 feet (70 m) of water. The ability to attach and detach these connectors rapidly without disrupting the watertight seal adds to Barracuda's modularity. The end caps are pulled together on the longitudinal axis of the hull by turnbuckles and threaded rods. The use of turnbuckles instead of latches alleviates much of the torsional stress on the sidewall of the main tube that could be caused by closing the latches.

Thrusters

Barracuda uses four Seabotix BTD150 thrusters connected to the rear end cap for propulsion. At full power, each thruster draws 4.5 amps of power and provides 21.6 Newtons of force. Two thrusters, mounted on aluminum plates at the front and back of the submarine, control depth and pitch. Two additional thrusters are mounted on the side panels with aluminum L-brackets, one thruster per HDPE side panel. These thrusters control speed and heading. Strafe thrusters were omitted in this year's redesign due to cost restrictions.



Internal Rack

The internal rack is a two-story acrylic structure that houses most of the electronics. The main computer and the control board are on the top shelf while the batteries, the downward facing camera, and the power supply are on the bottom shelf. The circular end plates on both sides of the rack have indentations for the shelves to slot into, which redistributes the weight of the shelves into the end plates, and simplifies the assembly of the rack. At the front end of the rack, there is a platform for the IMU and a mount for the forward facing camera, which is also made of laser-cut acrylic. The rear of the shelf has a TE Elcon drawer connector that allows the electronic components in the rack to connect easily with those in the back end cap. There is surplus space on both the top and the bottom shelf to accommodate future expansion.

Grabbers

We used CAD tools and a laser cutter to create most of the grabber. Without the accuracy and the precision of the laser cutter, creating something as small and complex as our current grabber would not be possible. The grabber uses a passive grab, active release design. Barracuda will descend onto the structure, which will enter the gates of the grabber. The grabber's latch will shut beneath the structure, keeping it from falling out of the grabber. To release the structure, the sub will rotate the obstruction that keeps the latch in place. We designed a rack and pinion system to rotate all of the obstructions at once, which allows us to use only one servo on each side of the AUV. The grabber's components are sandwiched between two plates to provide additional support for the acrylic, and holes in these two plates provide a place for the components to slide into. This ensures that assembly is simple, repeatable, and most important, accurate. We have four grabber assemblies on Barracuda, two on each side. This reduces the precision needed to pick up the PVC structure.

Electrical

Batteries

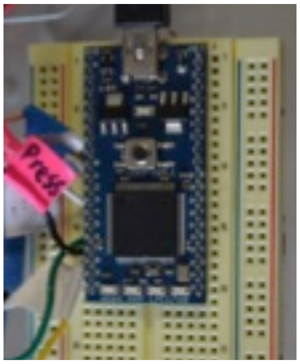
Barracuda runs on two 14.8-V four-cell lithium-polymer batteries connected in parallel. Their total energy capacity is about 150 Wh, which allows the sub to run for six to ten hours, depending on the tasks being executed. Thunder Power RC batteries were chosen for their ability to provide large amounts of burst current, which accommodates the inrush current of powering on the thrusters. Using two batteries at a time makes them hot-swappable, which is useful for saving time during testing because the computers do not need to be shut down to change the batteries.

Power Supply

Besides the motors, which operate at 14.8 V, all of Barracuda's electrical systems run on 5 V. To power these devices, Barracuda uses a switch-mode power supply based on the National Semiconductor LMZ12010 Simple Switcher, which was selected for its shielded inductor internal to the switching IC. An undervoltage lock-out system turns off the power supply when the battery voltage drops below 12 V, thereby turning off the motor controller. Low-ESR tantalum and ceramic output capacitors reduce ripple.

Main Computer (ODROID-X)

The Hardkernel ODROID-X is Barracuda's main computer. It runs on 10 watts of power and has a quad-core, 1.4-GHz Samsung Exynos4412 processor and 1 GB of RAM. It handles image processing and mission planning, and communicates with the mbed and cameras through USB. We replaced the BeagleBoard because the ODROID-X is 10 times faster at integer arithmetic, which is important for image processing.



Control Board (mbed LPC1768)

Barracuda's control board utilizes the mbed LPC1768, which has a 32-bit, 96-MHz ARM Cortex-M3 processor. The mbed has 512 KB of flash memory and 32 KB of user-program-accessible RAM. It has a multitude of interfaces, which add versatility and extensibility to Barracuda. The mbed is used for for low-level tasks such as sending motor commands to the servo controller, processing data from the Inertial Measurement Unit (IMU), reading the pressure sensor, and determining pinger location from the timestamps of our four hydrophones. These functions allow the main computer to concentrate on high-level processing. This year, we transferred the mbed from a breadboard to a printed circuit board for reliability reasons. We also added several features to the control system, including a leak detector, a battery voltage detector, and a temperature sensor.

Motor and Servo Controller

Barracuda's serial to servo controller is the 12-channel Pololu Mini Maestro. It receives serial commands from the control board and outputs pulse-width modulation (PWM) to the four motor controllers and servos operating the droppers.

Motor Drivers (Novak Super Roosters)

Barracuda's four Novak Super Roosters change the voltages applied to the thrusters according to PWM input from the servo motor controller. The high currents being switched by the motor drivers generate significant heat. To supplement the heatsinks of these drivers, they are arranged around the rear aluminum end cap to dissipate heat into the water.

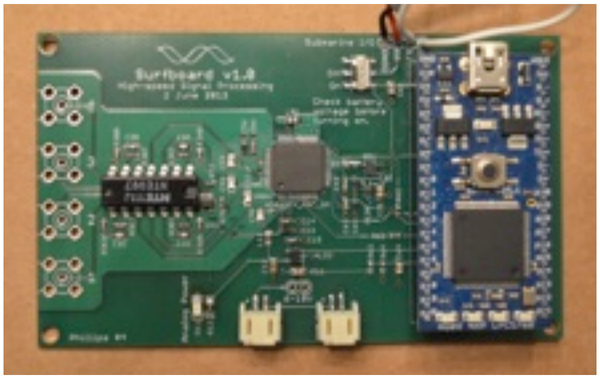
Wi-Fi Tether

Barracuda's Wi-Fi tether contains a wireless access point and a battery pack, both stored in a floating, waterproof Pelican case. The access point is wired to the main computer via the rear end cap. Used during testing to upload code to the main computer and the control board, the tether saves time by allowing operators to monitor and debug the software while the vehicle is in the water.

Navigation Sensors (Inertial Measurement Unit, Pressure Sensor)

Barracuda's IMU is the 9DOF Razor from SparkFun Electronics. It has nine degrees of freedom with its triple-axis magnetometer, triple-axis gyroscope, and triple-axis accelerometer. Barracuda does not use the magnetometers in the IMU because their performance is affected by the changing magnetic field created by the thrusters. Instead, the accelerometers and gyroscopes are used to determine pitch and relative heading.

Barracuda's pressure sensor is the Ashcroft Model K1 Pressure Transducer/Transmitter. It translates the pressure of the water into voltage readings which are linearly converted to depth by the control mbed.



Signal Processing Board

Barracuda uses four Reson TC4013 hydrophones to capture audio from the pinger. Surfboard, a custom digital-signal-processing board, determines the pinger's location. Incoming signals are amplified through a four-channel op-amp with low-pass filters. Then, they are passed to the Texas Instruments ADS1274 analog-to-digital converter to be digitized at a sample rate of 105 kHz. The ADS1274 was selected for its fast conversion time and ease of use. An mbed LPC1768 processes the signals and sends the timestamp of each pulse to the control mbed inside the submarine.

Digital and analog circuitry are isolated to prevent high-speed digital noise from entering sensitive analog circuitry. Analog circuitry is powered from small lithium-polymer batteries near the board to avoid switching noise.

Cameras (Logitech c525 Webcam)

Barracuda uses the Logitech c525 720p Webcam, which is an upgrade from the 240p camera that we used last year. The higher resolution gives us the option of oversampling to reduce noise that can interfere with image processing. The other major change was in the focal lengths of our cameras. Our old cameras had a fixed focal length too short to see the bins clearly, while the submarine's new Logitech c525 cameras automatically focus anything farther than seven centimeters from their lenses.

Software

SparkFun 9DOF Razor Firmware

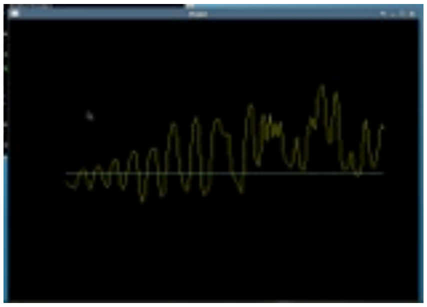
We maintain an open-source fork of the SparkFun 9DOF Razor production test firmware which increases the output rate from 10 Hz to 100 Hz. This is achieved by caching readings from the magnetometers because they can only be polled at 10 Hz.

AVNavControl

AVNavControl runs on the mbed LPC1768. The program is responsible for gathering and processing data from the IMU, pressure sensor, kill switch, and hydrophone board. It relays information, such as the current heading and depth, to the ODROID-X via USB. AVNavControl also sets the submarine's desired heading and depth as requested by the ODROID-X.

Control Systems

AVNavControl uses three PID controllers to control the heading, pitch, and depth of the submarine. Heading is determined by integrating readings from the gyroscope. Pitch is



calculated by fusing data from the accelerometers and gyroscope with an extended Kalman filter. Depth is found by mapping readings from the pressure sensor with a linear regression. This year, we wrote a program that plots the error history of the controller in real time so that we can better tune the PID controllers.

Motor Control

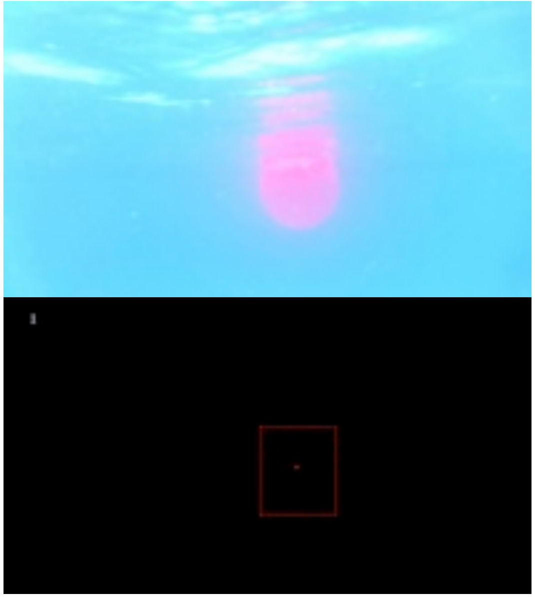
To achieve the desired heading, pitch, and depth, AVNavControl interprets the outputs of the PID controllers. The output of the heading controller is combined with the desired forward and backward power to calculate speeds for the left and right thrusters. The outputs of depth and pitch controllers are combined to calculate speeds for the downward-facing thrusters. These thruster speeds are continuously sent to the motor controller.

Extensive Vehicular Automaton (EVA)

EVA runs on the ODROID-X and is responsible for mission control and vision processing.

Mission Control

EVA is responsible for executing each task in the mission and ensuring that each task is carried out correctly. After each task is complete, it can choose the next task based on the options given to it in a configuration file and its current state. EVA is also able to re-sequence its mission based on which tasks are likely to complete successfully. For example, after passing through the validation gate, EVA can either decide to follow the path or proceed on to buoys based on what the cameras see.



Vision Processing

EVA uses Video4Linux2 drivers to capture images from the cameras and OpenCV libraries for its common image processing algorithms. Images undergo a pipeline that contains the following processing steps: conversion from the YUV color space to RGB, color enhancement, and thresholding. Further processing, such as edge detection or image matching, depends on the requirements of the current task.

The largest change to vision this year is the addition of blob detection. Blob detection labels contiguous regions to prevent small areas of colored noise from reducing reliability. The software team implemented the algorithm described in “A linear-time component-labelling algorithm using contour tracing technique” by Chang, et al (2003).

Logging

EVA uses a suite of custom output functions that save all messages from each run in timestamped logs. When a task that requires vision is in progress, both the raw and processed images are saved at a predetermined interval in the same directory as the log. Preserving and organizing mission data enables the software team to analyze runs in order to debug and make changes as necessary.

Multithreading

EVA implements a custom thread pool to leverage the full potential of the quad-core processor and to offset the performance penalty imposed by the larger images of the new cameras. Each image is split into four sections, and each portion is processed by a separate thread. Auxiliary duties, such as receiving images from the camera, are also handled by different threads so that the main thread can remain dedicated to completing the mission.

Modular Design

One of the main goals considered while designing EVA was modularity. Each task in the mission is given its own class, and none of these classes can communicate with each other. Class instantiation and cleanup is handled by the main class. Moreover, communication with peripherals, such as the cameras and control board, is separated from the tasks. This loose coupling ensures that the each task can be altered or replaced altogether without affecting other tasks.

Surfboard

Surfboard runs on a second mbed LPC1768 and processes the digital signal from the ADC to locate the pinger. Direct memory access is used to receive the signal, allowing the mbed to transfer data using less processing power and reserving resources for other processes. To find the pinger, Barracuda uses an IIR band-pass filter on all four channels to attenuate the frequencies that could not have been transmitted by the pinger. Next, the filtered waves are analyzed to find the start of the wave in each channel. The relative time that the wave starts in each channel is transmitted to the control mbed, which uses time difference on arrival (TDOA) to calculate the location of the pinger with respect to the submarine.

Conclusion

The redesign completed this year will allow Barracuda Mark XII to face the significant new challenges presented by the organizers of the 16th RoboSub Competition. With increased documentation, we hope that the team will retain more organizational knowledge as members graduate. As of June 30, Barracuda has seen over 50 hours of in-water testing.

Acknowledgement

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