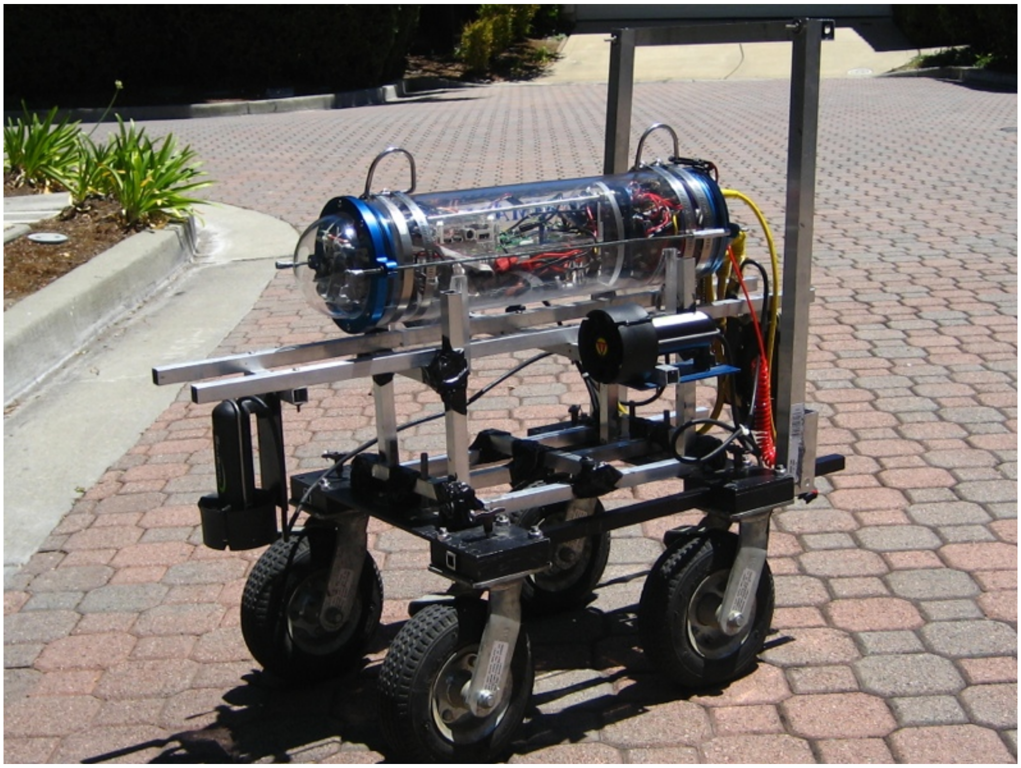
AMADOR VALLEY HIGH SCHOOL

Barracuda Mark X (2011)



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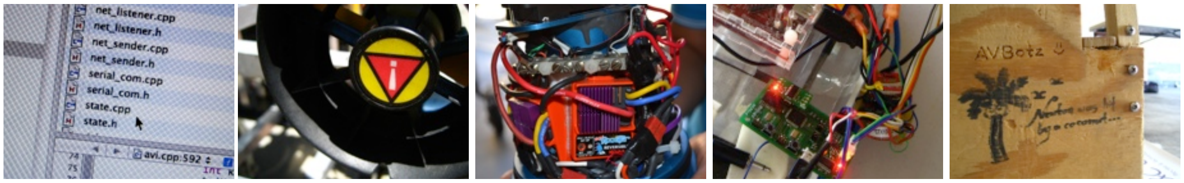
Abstract

The Amador Valley High School Robotics Club has constructed an autonomous underwater vehicle (AUV), named Barracuda Mark X, for the 14th annual AUVSI RoboSub competition.

The internal components of the Barracuda are housed within a single 6” diameter acrylic tube. The vehicle is propelled by two laterally mounted SeaBotix thrusters controlling speed and heading, and two vertically mounted SeaBotix thrusters controlling pitch and depth. A pressure sensor, inertial measurement unit (IMU), two cameras, and a hydrophone array provide navigation and orientation data to the computer: a BeagleBoard, which autonomously controls the vehicle. The computer focuses on high-level mission control and image-processing tasks, while a new custom control board provides low-level control over the thrusters and acts as a liaison with the various sensors.



Last year, the club revamped the hardware and software of the Barracuda, adding a new computer, control board, tether, and thousands of lines of code. This year, the team has focused on teaching the new members about the systems of the Barracuda and adding small refinements. Mechanics has improved transportation and the case; electrical has increased the reliability of the electrical systems and added a new control board; finally, software has ported and debugged code for the new board.

The 2011 Mission (“RoboLove”)

This year, the mission requires the submarine to first navigate through an underwater validation gate in order to demonstrate autonomy. The submarine must then complete a series of tasks, which it can locate by following an orange PVC path on the floor of the pool. First, the AUV must strike two specified buoys out of three buoys (“flowers”). The buoys are colored red, green, and yellow. The AUV must then pass above a green PVC “L” known as Lovers’ Lane. The AUV then must drop two markers (“love letters”) into two designated bins out of a total of four bins. Afterwards, the submarine must approach a 2×2 array of four windows — colored red, green, blue, and yellow — and shoot torpedos (“cupid’s arrows”) through a window of a specified color. Finally, the AUV must determine the position of an acoustic pinger, orient itself above the pinger, lower itself down, and secure a PVC structure (“vase”) near the pinger. Finally, the AUV must survace within a PVC octagon floating on the surface (“sweetie’s house”). Each vehicle has fifteen minutes to complete the mission. Points are awarded upon successful completion of obstacles. In addition, bonus points are awarded based on the amount of unused time, and the weight below the weight limit.

Additional mission details are available on the RoboSub website, <http://robosub.org/>.

Hardware

The Barracuda Mark X consists of a hull, a frame, engines, and several other modular components. All external components are screwed directly into the frame, two square rods running parallel to the tube. The ability to attach components directly onto the tube with any size of screw gives us a greater flexibility in rapidly attaching new components to the frame, without relying on a separate attachment piece, such as ring clamps.

Tube and Frame

The hull of the Barracuda is a 20” long, cast acrylic tube that is 3/16” thick and has a 6” outer diameter. The frame is comprised of two parallel square aluminum rods that are 1/16” thick and are of 3/4” diameter. These run along to the bottom of the tube, and they are affixed to the hull through a series of acrylic cradles cemented to the tube. These cradles have holes through them that the rods of the frame can fit through, and the rods are secured in place by a series of pins on either side of the cradles. Two metal handles are attached to the top of the tube for weight measurement and deployment. Both ends of the tube have anodized aluminum end caps, secured to each other, rather than the tube itself, to alleviate the strain on the hull integrity. These end caps are equipped with compression O-rings to create a watertight seal.

Connector Endplate

All through-hull connectors are made on the rear end plate and use Brad Harrison Waterproof connectors. These connectors are IP67 rated and can handle up to 1000 PSI. The ability to rapidly remove and reattach these connectors without disrupting the watertight seal of the hull adds to the modularity of the design.

Dome Endplate

The front end cap consists of a clear, cast acrylic dome. The acrylic material was chosen for its transparency and its durability. The exceptional visibility it provides is necessary for our cameras to detect physical obstacles, and the dome shape of the endplate gives the cameras an increased field of vision. The flange of the dome is fixed between the front end cap and another metal ring. This assembly is secured by eight screws with compression O-ring.

THRUSTERS

We use Seabotix BTD150 thrusters with built-in shrouds for horizontal thrust and vertical. The power consumption of each thruster is quite low, only drawing 3.3 amps each at full power. This limits the amount of magnetic interference the compass and increases our AUV's battery life. The vertical thrusters control depth and pitch, and are mounted on aluminum bars affixed perpendicularly to the frame. The horizontal thrusters are mounted on an aluminum plate on the horizontal engine bar running perpendicular to the tube. They control the heading or yaw of Barracuda, as well as allowing forward and reverse propulsion.

MARKERS AND DROPPER

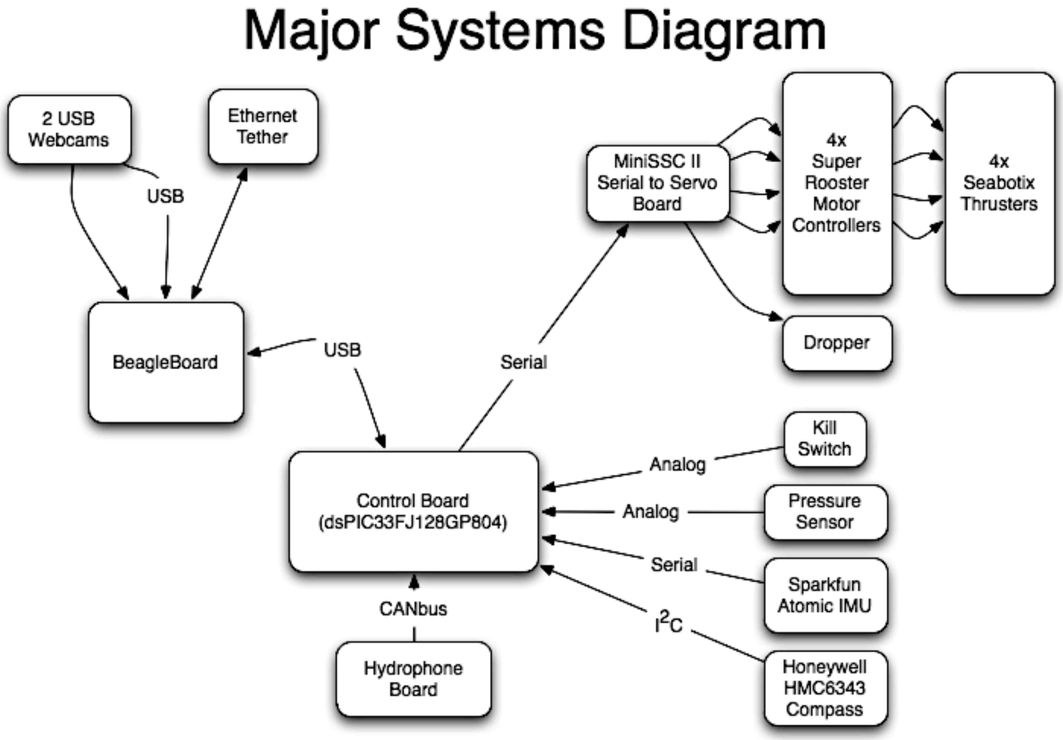
The marker are ¾ inch diameter stainless steel spheres with our school logo (AV) engraved into them. They live in a hollow acrylic tube mounted on the side of the horizontal engine bar. A small waterproof motor with one propeller blade is located to the side of this tube, and the blade prevents the markers from falling out of the hollow tube. The motor will turn when the proper location is detected, turning the propeller and releasing both of the markers.

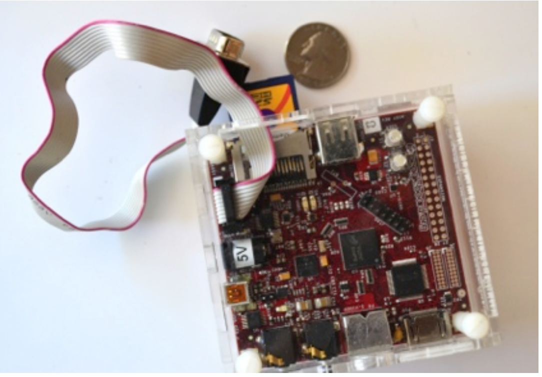
TORPEDOES AND TORPEDO LAUNCHER

The torpedoes are small acrylic bolts labeled with our school logo (AV). The torpedo launcher consists of two canisters of compressed air leading up to two small acrylic tubes, which house the torpedoes themselves. A quick-release valve separates the air canisters from the torpedo bays, and will be closed for the majority of the run. To fire the torpedoes, the vehicle will open the valve electronically, and the compressed air will propel the torpedoes out of the torpedo bays and forward towards the target.

Electrical Subsystems

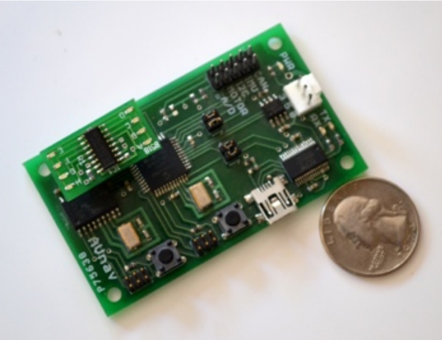
The main tube is partitioned horizontally into two sections by an acrylic rackboard, which extends from the dome to the rear endcap. The BeagleBoard, USB hub, control board, hydrophone board, and power supply are on the top, and the batteries are located in the bottom. Elcon Rack Connectors allow the rackboard and rear endcap to securely attach, transferring data and power to the endcap and to any external peripherals or computers for tethering purposes. This also allows the rack to slide out from the submarine for testing and debugging, if necessary.





COMPUTER (BEAGLEBOARD)

The sub's computer is a BeagleBoard Rev C3. The BeagleBoard runs the Ångström Linux on an Texas Instruments OMAP3530 processor. The BeagleBoard is small, fast, and efficient — it runs on less than 5W of power, allowing it to run off of the main batteries without significantly decreasing Barracuda's battery life. The operating system and mission code are loaded from an onboard 4GB SD card, and the remainder of the input and output is conducted through a single USB port, connected to a hub. Debugging and troubleshooting can be done more easily either over the network.



BATTERIES

The batteries, situated in the center of the rackboard, supply power to Barracuda's thrusters and most of its internal electronics. Two 14.8V Tenergy lithium-polymer battery packs with a combined 12.7 Ah capacity can power the submarine in full operation for over 2 hours, allowing for less frequent charging. The battery packs contain protection circuitry which prevents over-discharging and over-charging of the packs.

Control System

In order to enable the BeagleBoard to focus on higher-level mission and image-processing tasks, we designed a new custom control board to handle low-level control and communications functions. The board uses a Microchip dsPIC33FJ128GP804 because of its low-power 3.3V supply, fast 40 MIPS operation, and high number of communications peripherals. The built-in analog-to-digital converters monitor the status of the kill switch and the pressure sensor. A combination of UART, I^2C, and CANbus configures, monitors, and communicates with the magnetic compass module, passive sonar system, serial-to-servo board, gyroscopes, accelerometers, and the BeagleBoard. An FT232R from FTDI Chip allows the control board to interface with the computer via USB. It appears as a serial port, which can be accessed by the mission software. The control board relays sensor information to the main computer, which processes the information and sends control commands back to the control board. Several PID processes on the control board control the heading, depth, and pitch of the submarine.

A bootloader dynamically downloads updated code from the BeagleBoard upon reset, eliminating the need for a programming device and enabling the team to reprogram the control system remotely over the network. This streamlines and automates the entire development process.

Serial to Servo Board

A Mini SSC board, an off-the-shelf serial-to-servo board made by Scott Edwards Electronics, is mounted to the rear endcap. This board generates PWM signals that operate the Novak motor controllers in response to commands from the control board's UART module.

Tether and Communications

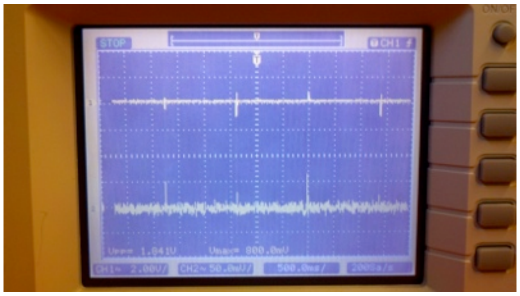
A communications link to the main computer is required to facilitate testing of the vehicle. This is provided by a wireless access point encased within a plastic container, which is manned by a plastic action figure (Captain Smurf). This is attached to the vehicle, which drags it along. The BeagleBoard is connected to the tether via the ethernet port on the USB hub. Through this network connection, we can not only monitor and control the submarine, but also alter the mission code and even reprogram the dsPIC on the control board. Furthermore, the tether, when connected, enables a remote engine kill that replicates the on-board kill switch at the end of the tether. Finally, the tether enables control of the sub from an iPhone cellular device, for demonstration purposes.

NAVIGATION SENSORS

The Barracuda queries a Honeywell HMC6343 3-axis compass module over an I^{2}C bus to measure its absolute heading, while compensating for the hard-iron magnetic distortion caused by the onboard electronics and ferromagnetic materials. However, the presence of constantly changing soft-iron magnetic distortion caused by the motors switching on and off necessitated an alternative method of determining tilt and heading, which is provided by a Sparkfun Atomic Inertial Measurement Unit. The IMU is populated with 3 ST Microelectronics LISY300AL gyroscopes and a Freescale MMA7260Q 3-axis accelerometer. This allows the submarine to determine its orientation independent of the fluctuating magnetic fields in and around the submarine.

CAMERA

The Barracuda uses two 1.3 megapixel Dynex webcams. Using webcams removes the need to have an analog-to-digital converters for video signal. These communicate over a USB 2.0 bus with the computer, which reads and processes the video feed. The downward-facing camera detects the path and bins, while the forward-facing camera detects the start gate, buoys, L structure, and heart cutouts.



PASSIVE SONAR

This year we began the process of redesigning and implementing our passive hydrophone sonar system. The new hydrophone system consists of an array of four RESON TC4013 Miniature Reference Omni-directional hydrophones. The piezoelectric sensor element contained inside the rubber nibble produces an electrical signal on the order of approximately 40mV, which propagates up the coaxial cable. The electrical signal is amplified using an L711JN op-amp to satisfy the minimum 1.8V requirement for the dspblok ad96k42 audio I/O board. After successfully inputting the signal into the dspblok audio I/O board, the analog input signal is filtered and converted from analog to digital. The digital signal representation is then passed to the ADSP-21469 processor on the dspblok 21469 where the signal representation is processed to determine the time difference on arrival (TDOA) for each signal received. The TDOA is then transmitted via a UART connection to the BeagleBoard. As we continue to improve the hydrophone system, our goal is to move from TDOA signal analysis to a more robust phase difference on arrival method which will improve the system accuracy and reduce the sensor spacing requirement from approximately 1 square feet to less than 10 square centimeters.

Software

The BeagleBoard runs Autonomous Vehicle Intelligence, which we develop in-house. AVI manages the entire sub by reading input from configuration files, sensors, and cameras and sending commands to the motors and lights. It also contains many intelligent algorithms for target location, color identification, and edge detection.

The shift from Windows XP to Ångström Linux last year required a ground-up rewrite of AVI. So while we called last year's version AVI 5, it was really a 1.0 release at heart. Therefore, this year, AVI has been evolved and refined to smooth out the kinks and bugs we introduced last year. AVI 6 runs faster, more efficiently, and smarter than its predecessor.

CLASS DESIGN

Rather than use strings to communicate between various classes, AVI 6 implements a class design in which a single mission controller class encapsulates all positional variables. This design allows the software to flexibly and quickly change desired heading and depth and provide feedback to the control board.

FEEDBACK CONTROL

Used at least indirectly by almost every high-level control process on the vehicle, the feedback control allows the vehicle to adapt itself to changing external situations. This process implements a general Proportional-Integral-Derivative control loop, which can be run on any number of feedback inputs. Every feedback mechanism used by the system simply has to supply a configuration, an input value, and a set point. The feedback control process then produces a value from −1 to 1, indicating to the vehicle how it needs to change to reach the set point. The feedback control is used to control not only heading, depth, and pitch, which are handled by the control system PIC, but also for some of the high-level navigation tasks. The control loop itself includes several features, including derivative filtration (important for sensors that have noise spikes occasionally) and mechanisms to help prevent integral windup.

SPEED CONTROL

The control board sends motor commands to the a microcontroller on the serial to servo board. The board uses a simple serial protocol for communication and provides an interface to the motors; the PIC on the board has eight PWM servo outputs, which drive the Novak speed controllers and the marker-dropper.

ORIENTATION MEASUREMENT

The control system combines the high-bias but low-noise integrated rotation data from the IMU's gyroscopes and the low-bias, high-noise data from the accelerometers and magnetometers on the Honeywell compass module using several Kalman filters, which estimate the current orientation based on knowledge of the previous known position of the AUV, the current sensor measurements, and knowledge of the dynamics of the AUV.

MISSION CONTROL

The mission control class contains the information on the state and current objective for the completion of the mission. Mission state is coordinated using shared variables, which other classes check to determine their behavior. Once the controller has determined that one portion of the mission has been completed, it updates the mission state variable, and the other classes adapt their behavior to the new mission state.

OPTICAL ANALYSIS

The BeagleBoard reads video streams from the two Dynex webcams using Video4Linux. But to make the navigation processes possible, it is necessary to have robust and effective optical analysis algorithms in place. First, we use the Mathematica software to model the filters and tweak settings. Then, we implement these custom filters with the OpenCV library. This allows us to develop highly efficient optical processing algorithms quickly and easily.

BEGINNING THE MISSION

Once the mission process is initiated, the process waits for the kill switch to be inserted. After insertion, the vehicle dives to mission depth and continues straight through the validation gate. During this time the optical processing code begins to search for the buoys ("flowers"). Based on the order of colors specified in the configuration file, it checks the forward camera for the presence of a circle of the first color within the image. The center of this circle is computed, and its distance from the center of the field of view computed. Any deviation causes a command to be sent to the control PIC to correct for the deviation. When a successful collision is detected (signaled by the sudden disappearance of the enlarged circle), the submarine then searches for and targets the buoy of the second color in the same way.

Afterwards, all image processing is focused on locating the L structure (Lovers' Lane).

Following the Path

With a second web camera facing directly downwards, we are able to switch between input sources to view the orange path that outlines the course. Our algorithms in OpenCV allow the computer to quickly filter out the orange color of the path, and apply Hough transformation to find the coordinates and slopes of the path relative to the orientation of the submarine. The vision processing unit can then adjust the desired heading based on the coordinates that we calculate in our code.

Edge Detection

The first step in finding the bins is finding the edges. First, to cut down on noise, we normalize the image. Then, we use the Sobel operator to find the edges. The results are run through an intensity threshold, which provides a black and white image which has a higher contrast is more suitable for the Hough transform and also uses less CPU power to process.

Hough Transform

For target recognition, we use a process known as the Hough transform. The goal of this process is to find a geometric description of lines within images, including possibly disjoint (dashed) lines, which makes it ideal for recognizing the edges produced by the target. The ideal output of a Hough transform on the box target image is a grid of 2 lines overlapping 2 other lines at right angles.

Dropping Love Letters in the Bins

While continuing to travel straight, the vehicle searches for the orange path and the target bins. When one of the bins is located the vehicle will attempt to station itself directly over the center of the target, using the center of mass image processing algorithm. Once the vehicle is positioned properly over the center of the bin, it drops both markers and proceeds toward the window.

Firing Cupid's Arrows through the Hearts

The vehicle resumes processing forward vision once the markers have been dropped. It then searches for an intense red object, which would indicate the presence of the heart cutouts. Once the cutout is found, the vehicle slows down and orients itself in front of the heart of a specified color. The vehicle uses the size and distortion of the heart to determine its placement and orientation relative to the heart. Once it is properly aligned, the vehicle will fire its torpedoes.

Navigating to the Sweetie's House

After completing the marker drop, the computer signals the systems to begin analysis of the audio data. The dspblok polls the hydrophones through the analog-to-digital converter at a constant interval, and fills a buffer. Once the buffer is full, it runs many algorithms on the data in the buffer to filter out the noise, check for erroneous readings, and finally, check if a ping was received. If a ping was received, the board sends the location of the pinger as a vector to the BeagleBoard via serial. The BeagleBoard uses this data to navigate to the pinger.

Retrieving the Flower Vase and Surfacing in your Sweetie's House

Once the vehicle is positioned above the pinger, signified by a directional vector with very small X and Y components, it proceeds to secure the structure ("vase") by lowering the grabber onto it. After the structure is secured, the vehicle will surface. Once the pressure sensor detects that the AUV is at the surface, it will shut off the motors and complete the mission.

Conclusion

The advancements made this year will allow our AUV, Barracuda Mark X, to face the new challenges presented by the 14th annual AUVSI Robosub Competition. We hope that these changes will make our submarine a much more competitive entry, and the transition of this year's team to the next in a much smoother process.

Acknowledgements

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