USCR AUVSI TECHNICAL REPORT, July 2010

**University of Southern California Competition Robotics (USCR)**

# SeaBee III

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## ABSTRACT

*The new SeaBee III is an autonomous underwater vehicle (AUV) designed and built by undergraduate and graduate engineering students from the University of Southern California. This year's vehicle incorporates a variety of improvements over last year's vehicle including a new software platform, upgraded electronics, and new mechanical components. The SeaBee III will enter its second competition in the 13th Annual International AUV Competition hosted by AUVSI and ONR.*

## 1. INTRODUCTION

USCR's consistent and active participation in the AUVSI competitions reflects dedication to furthering robotics research at USC and around the world. The team hopes to improve upon its 6th place finish last year, 6th place finish in 2006 and 2007, and 15th place finish in 2008. The improved SeaBee III includes many new features that will help us achieve our goals, such as a single hull layout and a liquid cooling system. The electronics and software architecture have also been redesigned to accomplish more of the competition tasks.

## 2. MECHANICAL DESIGN

The mechanical design of SeaBee III stems from a desire to make the team's AUV more compact and lightweight. The single-hull design with an internal rack system was developed to enable easy removal and access to electronics. In addition, connections are established by using waterproof connectors from the end cap to external components such as the compass, SONAR, marker droppers, cameras, thrusters and the bump sensor.

### *2.1. Hull*

The hull for Seabee III is constructed out of 3/16” thick T6061 anodized aluminum. The enclosure employs a cylindrical design measuring 7.5” in diameter and 13” in length. It shields the internal electrical systems from water damage with a watertight design. In the hull cap design, the mechanical team members covered the cap with waterproof Fischer Connectors allowing access to the electrical systems from components outside of the hull. The new SeaBee III can be seen in Figure 1.


Figure 1. SeaBee III Assembly

### *2.2. External Frame*

Using ¼" thick T6061 anodized aluminum, the mechanical team created a lightweight, hydrodynamic frame that could support the weight of the hull. The frame measures 24" x 12.5" x 16.5". There are two mount bars on top and four on the bottom for competition specific components. The side rails, can be used to mount our flotation system. We wanted to make the external frame flexible for future modular upgrades, so we placed auxiliary ports on the end cap.

### *2.3. Internal Frame*

In order to mount all of our electronics inside of the hull, we utilized a custom designed internal frame attached to our end cap, which can slide in and out of the hull on Teflon rails. This frame is machined from aluminum and is designed around our electronics, ensuring a secure mounting platform for every device that is installed in the SeaBee III. We used CAD software to model all of the electronic components and ensure that they would both fit into the hull when it was completed. We aimed to maximize and efficiently use space within the hull. The rendering in Figure 3 below demonstrates the utility of this design.

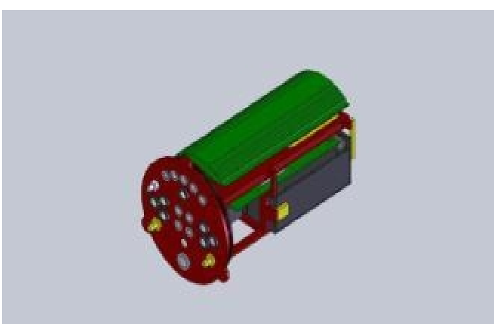

Figure 3. Internal Assembly

### *2.4. Cooling System*

Because of the SeaBee III's dual core processor and a number of other highly thermally demanding elements, it is necessary to provide a cooling system to prevent damage to the electronics. To that end, we designed a unique water-cooling system consisting of two cooling blocks, an external radiator and a circulation pump. The primary cooling block is mounted to the standard XTX heat-spreader to cool our CPU while the second smaller cooling block pulls heat away from the motor-driver H-bridges. The radiator is designed to be both light and effective, consisting of a series of copper pipes attached securely to the end cap and extending just between the hull and the external frame.

### *2.5. Motors/Thrusters*

The SeaBee III uses six (6) SeaBotix BTD150 thrusters – the same propulsion mechanisms used by our previous AUVs. These thrusters are arranged in three main groups, horizontal for forwards and backwards movement, vertical for depth, and two strafing to enable five degrees of control.

### *2.6. Marker Dropper*

The marker dropper mechanism was constructed using linear actuators. This design features a compact frame and a robust releasing structure that is quick, accurate, and reliable. The dropper is connected to the SeaBee III internal electronics using a 4-pin connector on the end cap. When the control signals activate the relays, the two solenoids on the marker dropper release a marker which is held in place with two spring-loaded arms.

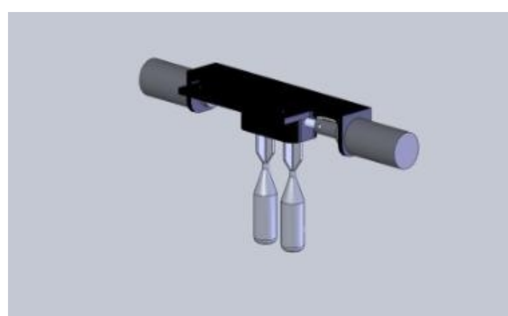

Figure 4. Marker Dropper

The markers are shaped like mini-torpedoes with angled fin tails to induce a spin during the descent. This shape ensures a highly hydrodynamic marker that will fall in a more streamlined way than that of a spherical marker.

### *2.7. Grabber*

The grabber mechanism is the component of the SeaBee III that is used to pick up the counselor in the recovery phase. SeaBee III's grabber, shown below, is an attachment on the bottom made of aluminum. It is lined with several small acrylic teeth that push the PVC briefcase into one of the slots. With this revision of the grabber we have incorporated a retractable design. The grabber is able to slide within the constraints of the robot when it is not in the pool to maintain SeaBee III's compact design. When the SeaBee III sits on the counselor, the slots will open up allowing the PVC pipe to fall into place. The slot levers are controlled by small torsion springs that close the slots after the counselor is in place. The SeaBee III can then breach with the counselor secured by the grabber.

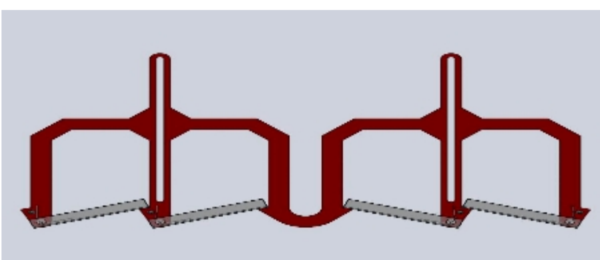

Figure 5. Grabber Mechanism

This design provides the SeaBee III with room for errors when picking up the PVC counselor due to its size and placement on the robot. No matter what the orientation of the AUV is, if one part of the counselor is on any of the 8 slots of the grabber, the counselor will be secured.

### *2.8. Manual Control Case (Flo-Case)*

In past competitions, team members realized the impracticality of each person carrying different testing equipment to the practice side of the pool. Sometimes, cables are left in the booth, wasting practice run time. In addition, a team member would have to hold up umbrellas to block sunlight glare onto laptop screens.

To combat these difficulties, the team decided to create an all-inclusive testing platform for the SeaBee III. This manual control case, called the Flo-Case, is shown on Figure 6 below. The case allows for direct data monitoring and video feed from the submarine and contains a laptop, monitor, keyboard, router, USB ports, power supplies, gauges, and networking equipment. This device will provide convenient on-site testing and debugging of the software. This case will also serve as storage for spare parts.

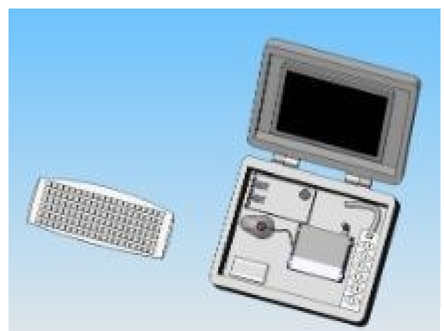

Figure 6. Manual Control Case

### *2.9. Shooter*

The SeaBee III shooter incorporates a slingshot-powered design to fire a pool toy torpedo (Toypedo) through the window. For accuracy and space constraints this model only fires one toypedo when triggered. Due to the projectile's shape and buoyancy, the toypedo is capable of firing straight for 8ft. We chose the Toypedo itself as the projectile for a number of reasons. The Toypedo developed by Swim Ways has a hydrodynamic design combining a streamlined fin-stabilized shape with a rubber material. It measures 1” in diameter and 5” in length. The Toypedo is especially useful for us because it was designed to be neutrally buoyant, with a specific gravity between .95 and 1.05 relative to water. It also required no modifications for the competition and is cheap and dispensable.

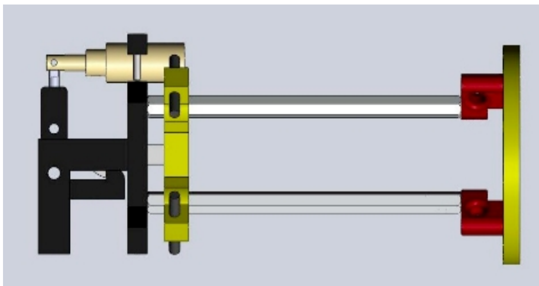

Figure 7. Shooter

## 3. ELECTRICAL DESIGN

The goal of the electrical team for SeaBee III was to design and integrate all electronics into a cohesive structure that interacts with software. To this end, electrical team members worked on different projects, each requiring the development of a printed circuit boards (PCB).

Eagle X11 software was used to create circuit schematics, and to place and route components on a board for fabrication. After ordering all the necessary integrated circuits and electronic parts from Digi-Key, we soldered the connections onto the PCBs fabricated by our sponsor, Advanced Circuits. The following sections below discuss each electrical subsystem of SeaBee III:

### *3.1. Computing*

The computing and processing systems of the SeaBee III resemble the cerebral cortex of the brain. SeaBee III runs a custom processor with two XTX Computer on Modules (COMs) for all major path planning and intelligent decisions. The carrier board developed by our electrical team this year is shown in Figure 8. The two processing modules are networked together using an Ethernet switch. Together, the processor and network make up a small Beowulf Class I cluster to evenly share computational loads.

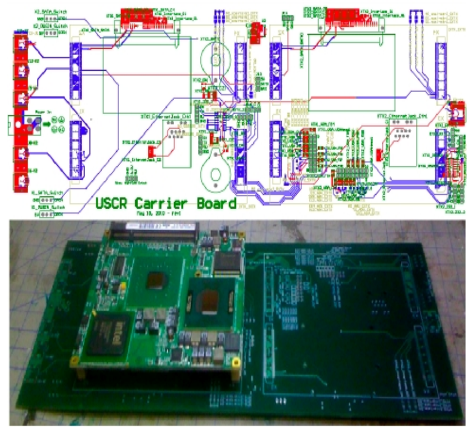


Figure 8. Custom Carrier Board

Each processing module is connected to a 250 GB SATA hard drive and interfaces to VGA, USB, and Ethernet. These large capacity drives supports large amounts of on-board computing power and allow us to use the submarine as our main development workstation. Each computer contains four (4) USB connectors, providing interface for the cameras and USART buses to establish communication with our I/O chip and SONAR system.

### *3.2. Battery Management*

SeaBee III runs on 12 Lithium Polymer cells from MaxAmps that provide 10,000 mAh each. The electrical team members put together the 3.7-volt cells into two (2) battery packs of 6 cells each. The two battery packs supply 22.2 volts to power the submarine. As an interface with the lithium polymer batteries on the SeaBee III, the battery board will monitor battery life and charging cycles using an ATMEGA 406 microcontroller. A built-in

Coulomb counting system in the microcontroller and extra differential Operational Amplifiers enable the team to identify the amount of battery power remaining. This information, visually outputted on the LEDs, is crucial in that it ensures consistent and reliable battery power during testing and the competition run.

### *3.3. Power Regulation and Management*

The Power Board controls and interfaces all power, control, and sensor interfaces for the submarine other than the cameras, which are controlled by the Carrier board. This board ensures proper interfacing to two USCR custom-built lithium-polymer battery packs. In addition, the SeaBee III's power board manages power conditioning needed to convert voltage to acceptable levels for the computers, integrated circuit sensors, pump, and cameras.

Besides power regulation, nine motor drivers on the board control six thrusters, two marker droppers and an auxiliary motor for future expansion. These motor drivers are then controlled by an eight-core Parallax Propeller microcontroller. The Propeller not only controls the motor commands but also talks serially to numerous sensors including battery management, accelerometer, gyroscope, analog to digital converters, pressure sensors, and the compass.

### *3.4. Sensors*

The SeaBee III has an impressive array of sensors to provide input to the main computers including internal and external pressure sensors, an HMC6343 digital compass with pitch and roll detection, a high speed accelerometer, three (3) internal temperature sensors, an active SONAR system, current monitoring for each of the five (5) motors and four (4) Internet Protocol (IP) cameras.

The team decided to use IP cameras to provide a high resolution and more responsive vision system. Two cameras are facing forward, while the other two face downward. The IP cameras are directly connected to the computing cluster via a USB network hub.

Our newest addition to SeaBee's sensor array is the Xsens MTi Inertial Measurement Unit (IMU). This device is composed of multiple accelerometers and gyroscopes which allow it to measure acceleration, both angular and linear, and magnetic field. These measurements allow for the capability to very accurately get an idea of the physical orientation of the robot in terms of relative spatial position and against absolute measurements like compass heading. Previously we had only used a compass which was sufficient for rough estimates but proved unreliable and lead to technical issues such as magnetic interference from thrusters. The IMU interfaces much more simply and gives more varied and accurate data. It is much less affected by noisy magnetic fields than our previous compass which makes localization a much easier and more reliable task.

The SeaBee III's sensor array is monitored by a Propeller microcontroller, named the BeeSTEM. In addition to reading and forwarding sensor data to the main computer module via USB, the BeeSTEM is responsible for executing the SeaBee III's main PID control loops and maintaining the AUV's depth, heading, and speed. This offloading of our PID loops to the BeeSTEM ensures that our main computer is free for more complex tasks such as vision processing and mission planning. The BeeSTEM responds to commands given by the main computer module, manipulating the SeaBee III's movement as our Mission Planning module sees fit.

***3.6 Actuation Control***

Our team utilizes a PID (partial integral derivative) controller to determine the thrust needed to bring the system from it's actual position to a desired position. The desired position is sent from the COM modules and the vision algorithms running within. After the system receives a new command, a separate control loop reads the sensors to find the current position and does it's best to achieve the ideal orientation. This approach takes a significant amount of tuning but has proven highly reliable in the past.

***3.7 Active SONAR Array***

After various attempts at developing sonar capabilities we have decided on an active sonar system. Rather than trying to passively filter and process sonar as we did in the past, we decided to do all of our signal processing using the Cheetah SPI Host Adapter. This device has a sampling rate over 40MHz and easily interfaces with our XTX computers to process incoming digitized signals. Now rather than try to do stripped-down geometric phase angle calculations, we implement a Fast Fourier Transform (FFT) to determine the phase difference of two incoming hydrophone signals using three Reson TC4013 Hydrophones. The new system has the added benefit of requiring a much smaller PCB since the only components we need are Analog-to-Digital converters for the hydrophone and input and outputs for the hydrophones and Cheetah respectively.

This new sonar layout is very simulation friendly since the only real device that needs to be approximated is the input signal. In the past we had to try to simulate a large amount of circuitry which did not always behave as we expected. This ease of testing has allowed us to develop more effective signal processing algorithms this year.

Figure 9. Reson TC4013 Hydrophone

***3.8. Killswitch***

The new SeaBee III uses the same magnetic Killswitch that our previous submarine used - a magnetic sensor and a cylindrical enclosure on top of the submarine to start or kill the SeaBee III.. However, we have made mechanical improvements to ensure it works even more reliably. The Killswitch, illustrated in Figure 10 below, looks like a handle and can be rotated to turn the submarine on or off using static magnets. In addition, the on or off status will be displayed to the outside world using green and red LEDs and an LCD screen for custom output determined by the main computers.

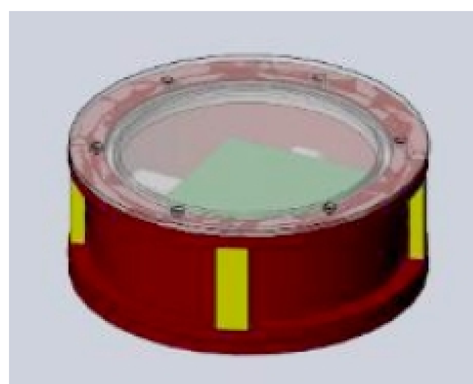

Figure 10. Magnetic Killswitch

## 4. SOFTWARE

***4.1. Architecture***

The new SeaBee III takes advantage of a completely new software platform. The ZeroC

Internet Communications Engine that was utilized by previous versions of SeaBee was replaced with the open-source Robot Operating System (ROS) from Willow Garage. The transition to ROS simplified the low level software implementation, while still allowing us to take advantage of many of the control schemes we had developed over the past several years. ROS has also improved the SeaBee III's performance. For example, we are now able to encode our camera images as Theora at a resolution of 640x480 while using less than 10% of our available processing power — a significant improvement over previous implementations. Our ROS software hierarchy can be seen in Figure 11.

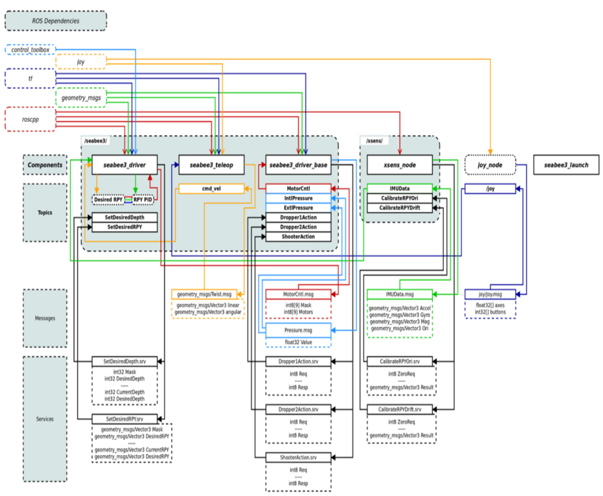

Figure 11. ROS Software Hierarchy

### *4.2. Graphical User Interface (GUI)*

The SeaBee III GUI, seen in Figure 12, uses a Qt interface to display the submarine's telemetry and sensor data. The GUI also enables user control over the desired position of the submarine, including the SeaBee III's depth, heading and speed. In addition, data published by various software modules are displayed in a centralized location. These processed data include a localization map indicating the approximate position of the SeaBee III as well as object recognition results returned by our vision system. The SeaBee III GUI runs on our control box and uses ROS to listen for updates to sensor and processed data, updating the GUI correspondingly.

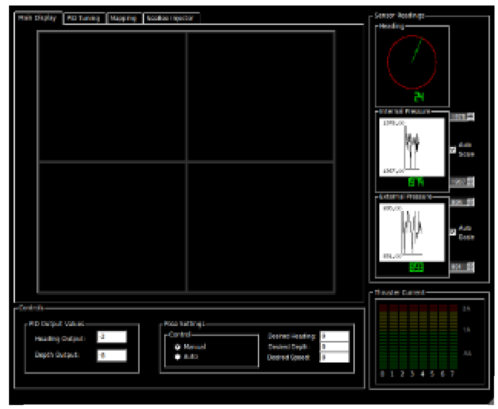

Figure 12. Graphical User Interface

### *4.3. Image Recognition and Vision System*

SeaBee III utilizes a well-developed vision platform to help accomplish the competition tasks. The Saliency Neuromorphic Vision Toolkit, provided by the iLab at USC, and the Open Source Computer Vision Library (OpenCV), provided by Intel, are incorporated into the vision code running SeaBee III. The library, written in C and C++, runs on Linux operating system (Ubuntu).

#### *4.3.1 Contour Recognizer*

Using the OpenCV vision library, the Contour Recognizer identifies closed contours in camera images. It analyzes the approximate shape of the contours to identify competition course obstacles such as pipelines and bins, and then publishes its findings through ROS. The Contour Recognizer has the advantage of not basing its analysis on the colors in the image, which can vary drastically depending on time and the environment.

*4.3.2. Buoy Recognition*

The Buoy Recognizer uses OpenCV as the base library to perform its Vision based calculations to identify the Buoy amongst other suspended objects when traveling underwater. It primarily works on the concept of template matching, and once when a template image is provided to the module, it then scans through the frames received from ROS and tries to identify the Buoy.

To make the template comparison more accurate and helpful for the main navigation module, it has a sub-module called the "Confidence Module", which does an image 'rotation and compare' algorithm on 5 differently rotated angles of the image and provides us with an final average of all the modules on a percentage scale for easier understanding.

*4.3.3. Pipe Recognition*

The Pipe Recognizer runs on a rectangle-finding algorithm that sets the Region Of Interest (ROI) to the size of the entire image. In order to filter noise and group the camera image into large, consistent areas, the image is down-sampled, then up-sampled. Each color channel is then traversed separately. For each channel, the image is first converted to grayscale, which is searched at multiple thresholds using the Canny Edge Detection algorithm. Canny will account for shading and a simple contrast check. The edges are then expanded so that close regions can merge together, causing output of fewer yet more useful large regions. Within these large regions, the rectangles are detected using 4 vertices that will be convex.

Figure 13 illustrates the contours of rectangles viewed at various angles and distorted. Comparably, Figure 14 shows how the algorithm locates the outer and inner contours of the bins in the AUVSI competition.

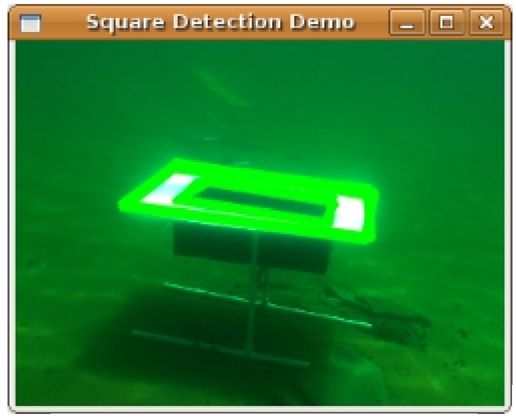


Figure 13. Actual Camera Image

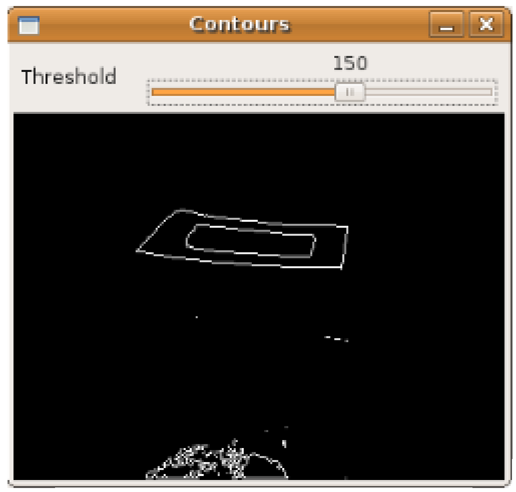


Figure 14. Contour Recognition

4.3.4. Color Segmenter

The Color Segmenter module does a color filter algorithm (color value range based color segmentation) on the image received through ROS, helping us to further distinguish objects i the environment. One innovative feature of our color segmenter is the ability to detect and highlight objects of the same color while leaving the rest of the image in greyscale.

### *4.4. Localization*

The Localization module provides an approximation of the submarine's location in the competition pool. This data is used to provide general waypoints that the submarine should follow in order to navigate the competition obstacle course. The localization module is tightly integrated with the modules detailed in the following two sections.

### *4.5 Control & Navigation*

#### *4.5.1. Automated navigation*

Balancing and control are implemented using the proportional-integral-derivative (PID) mechanism. The method allows for modifying the hull by attaching whatever mission-specific mechanism necessary without rebalancing. Moreover, PID enables error correction to deliver fast and accurate control of speed, position and orientation in the three dimensional underwater environment.

This module gathers input from the various Image Recognition and Vision Systems stated above, thereby making its decision on what path to take and which direction to move to. The communication solely takes place thru' ROS, where this modules gathers all the input it needs and makes its decisions based on that.

#### *4.5.2. XBOX 360 Controller Based Manual Navigation*

The XBOX 360 controller module is primarily a test bed module which has helped us to tweak and configure our Seabee with ease for the Mechanical and the Electrical team to carry out their testing when none of the Vision Systems nor the Localization modules are run. When started, this module helps us to calibrate the XBOX 360 controller thus enabling us to have an error free manual navigation. This XBox 360 controller is a major improvement over the cumbersome keyboard interface used in the past.

### *4.6. Mission Planning*

The Mission Planning module manages mission progress and directs the SeaBee III's actions. Operations flow logically from one competition task, or 'state,' to the next. Messages from each of the other modules are processed by mission planning, which determines an appropriate course of action for the AUV based upon completed tasks and proximity to known objects in the pool. Using the ROS architecture, we were able to develop a complex mission planning scheme that was easy to maintain and use.

### *4.7. Internal Temperature and Pressure detection*

Every time we plan to have a test to run the Seabee, several parameters had to be checked manually to confirm that Seabee is in perfect running condition to carry out our tests. This was one of the heavily time consuming processes that we had to perform every time and was very cumbersome to perform as its prone to manual measurement and read errors. As a result of this, we developed a module which reports us about the Internal Temperature and the Pressure inside the Hull for continuous monitoring. This module coupled with an high-end mobile phone which does an SSH into Seabee has given us the mobility that we wanted to perform these cumbersome tasks with ease.

### *4.7. Simulator*

This year we developed a fully featured 3D simulator for our submarine using the Ogre 3D C++ libraries. The SeaBee simulator is complete with underwater and above water caustic effects, depth fog, surface ripples, and a mock course setup that our submarine can navigate. Screenshots from our simulator are shown in Figures 15 and 16.

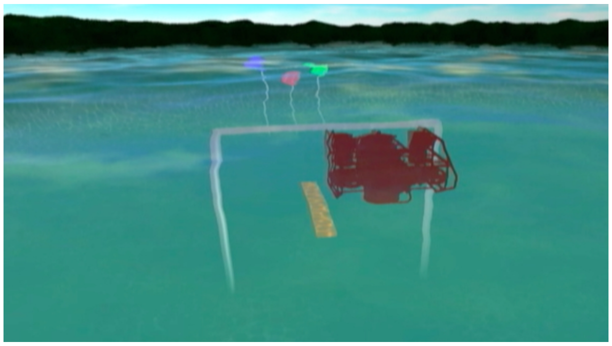

Figure 15. Above water view of SeaBee III in our simulator during a simulated run.

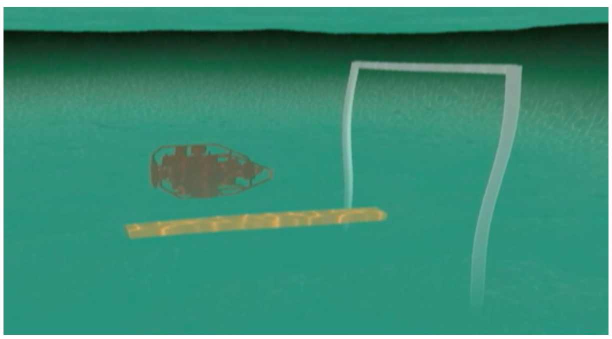

Figure 16. Underwater view of SeaBee III in our simulator during a simulated run.

## 5. FUTURE WORK

While the SeaBee III is currently designed to achieve a pre-defined set of objectives, the team is dedicated to developing projects that are adaptable to accomplish a broad range of tasks in various environments. As our existing underwater platforms have proven their effectiveness in the competitions, we also strive to use the AUVs for marine research.

As a mark of the team's expansion and progress, USCR has begun development of an Unmanned Aerial Vehicle (UAV). This helicopter-like apparatus will include a plethora of inertia-sensing equipment along with GPS, range-finders and vision-based navigation systems.

Most importantly, the key to the organizations future success lies in the team members. As a result, USCR has established training programs for its new members. These training sessions are held during the first month of the semester and focus on developing fundamental skills frequently used for electrical, software and mechanical projects.

## 6. ACKNOWLEDGMENTS

Generous support from USC, iLab, industry, and academia allow USCR to continue being an integral part of student research and involvement in the Viterbi School of Engineering.

As a student run organization, this endeavor was made possible by: Fischer, Digi-Key, Advanced Circuits, Max Amps, ORE Offshore and the USC Viterbi School of Engieering.

Special thanks goes to both the USC Viterbi School of Engineering and the USC College of Letters Arts and Sciences Machine Shop, without whom we would not have our SeaBee AUVs at all. The Viterbi School of Engineering provided us with research funding. Don, our machinist, and his team in the shop have proven themselves to be one of our most valuable resources.