University of Southern California AUV: USCTurtle Design, Build, and Operation

President: Matthew Vera
Mechanical: Ethan Geipel
Electrical: Andrea Luna
Software: Iordanis Fostiropoulos

Abstract

This journal characterizes the design and build of the USCTurtle, an autonomous underwater vehicle (AUV) constructed by USC AUV for the purpose of competing in the 2018 Robosub Competition. The USCTurtle was built over a period of two years and utilizes no legacy hardware from previous USC team designs. The USCTurtle has successfully navigated a test pool through both manual and autonomous controls.

1.0 Introduction

The University of Southern California Autonomous Underwater Vehicle Team's foremost objective for the 2017-2018 academic year was to create a submarine that could reliably navigate complex environments with both manual and autonomous capabilities. To this end, 35 undergraduate and graduate students—distributed amongst mechanical, electrical, and software subteams—met at least two nights per week over the course of two years, designing, prototyping, testing, and revising both core and ancillary systems. The creation of the USCTurtle both provided students an opportunity to develop technical engineering skills and introduced a new set of unique designs from which future AUV designers may draw.

2.0 Competition Strategy

In 2016, the USC team experienced a comprehensive system failure that destroyed existing hardware and, by extension, rendered existing software obsolete. Since then, its primary goal has been to create a reliable submarine capable of successfully navigating vision-based obstacles autonomously.

In preparation for the 2018 Robosub competition, the team designers focused on reliability, rather than system complexity. Goals for the first year of work included 1) designing a hull that was naturally stable, non-inverting, and watertight, and 2) implementing a safe and well distributed electrical infrastructure able to properly power and control the submarine's motors, on-board computer, and sensors.

More recently, projects centered on ensuring the submarine's on-board computer could recognize elements in its environment, maintain a steady position while rotating to examine its surroundings, properly access its sensors' data, make decisions based on those surroundings, and correctly translate its desired direction into motion. All tests throughout the last year were conducted with a strong focus on assessing the submarine's ability to recognize and navigate its environment autonomously.

While resources were directed primarily towards improving core functionality, some subsystems were designed and prototyped to perform precision tasks featured in the Robosub competition such as grabbing a small item, recognizing specific frequencies in the water, and shooting a torpedo. However, because of time constraints imposed by the development and implementation of the AUV's electrical systems, these projects were not integrated into the current design.

3.0 Design Creativity

The USCTurtle has been, from conception to competition, uniquely designed. The most creative elements of its design include its main hull, frame layout, and the arrangement of the electrical components on the interior of the submarine.

3.1 Inherent Stability

Upon inspection, it is clear that the saucer-like profile of the USCTurtle does not conform to traditional AUV designs. The main hull is composed of a small cylindrical cavity capped by an acrylic dome, and an array of mounting frames surround the hull octagonally. The mounting frame pattern is drawn from the octagonal layouts used in previous USC designs.

One benefit from this unique cylinder-and-dome design is that it prevents the AUV from inverting, or otherwise changing its orientation. The buoyancy and positioning of the dome provide stability in the water, and the weight of the battery pods and wet connectors beneath the submarine ensure that the vehicle will always return to its nominal resting position. This natural stability eliminates the need for additional, overly-complex sensors and software to keep track of orientation, as is often necessary for traditional AUVs.

3.2 Low-Cost Field of View

The positioning of the dome vertically above the mounting frames offers another advantage: field of view. Independent camera pods can be cumbersome because they increase submarine complexity, and front-facing, horizontally-mounted cameras in cylindrical AUVs require that the submarine turns in its entirety to expand its field of view. In the USCTurtle however, the primary camera rests in the dome and is able to see above the ring of frames at all times. With the use of a stepper motor, the camera can rotate about its vertical axis without limitation—this enables it to analyze its surroundings in any direction while the submarine itself does not move. The stepper motor records the change in angle between true front and the direction it decides to move, quantifying the direction of intended motion for the submarine motors.

3.3 External Modularity

The octagonal ring of aluminum frames gives the design modularity, leaving room for additional motors, competition components, or auxiliary pods to be added, removed, and reoriented as needed. The frames themselves are all identical, each equipped with an octagonal mounting ring in the middle; this allows for any pods, motors, or other external components to be mounted in virtually any orientation. Both the unique layout and the functional design of the frames have been useful to accommodate the frequent changes that come with continuous development and testing. Within the course of this year alone, the motors, battery pods, and other mounted components have been attached in seven different orientations.

3.4 Internal Modularity

As the USCTurtle developed, the complexity of the electrical system increased quickly, necessitating an efficient organizational structure that could still accommodate change. The mechanical team sought to implement a modular system similar to the external mounting frames, and designed a circular pattern of poles that sit flush with the walls of the hull.

Panels large enough to house each electrical component were designed such that they could be easily mounted on, removed from, or shifted around these poles. The panels surround the center bottom of the main cylinder, where all wet connectors enter the hull, creating clear paths between external wires and all electrical subsystems. This system was produced entirely in-house: the panels were 3D printed and the poles were made on a lathe. Because of the convenient manufacturing methods, when necessary, panels could be custom designed for the specific electrical component they held. Fortunately, the green octagonal layout contributed further to the USCTurtle's chelonian theme.

3.5 Custom Boards

The flexibility to change and relocate electrical units became useful during the customization of essential components like the power board, motor rotation driver, and speed motor controllers. The power board was custom designed to properly distribute power generated by the batteries to specific subsystems. One battery controls the power flow to the logic components inside the submarine, while the other battery powers the motors exclusively. The power board also houses a killswitch to instantly shut down the submarine in the event of an emergency. The motor rotation driver was custom designed to balance the speed controllers and collectively drive the motors as needed.

4.0 Experimental Results

Over the two years of the USCTurtle's development, numerous tests were performed to evaluate the structural integrity, neutral buoyancy, motor control, and autonomy of the submarine.

4.1 Watertightness

During the first year of building the USCTurtle, experiments focused on ensuring that the hull would not allow water to leak in and damage electrical components. Verifying the structural integrity of the design during these early developmental stages was paramount. Testing performed in August 2017 confirmed a flaw in the hull—the water's high chlorine content had dissolved a small divot out of the hull's adaptor, introducing a leak into the main cylinder. Supplemental rubber was applied to the divot, and after submerging the hull and applying lateral and axial forces, the USCTurtle was determined to be fully waterproof and testing continued.

4.2 Weight Distribution

During these watertightness tests, it was observed that the vehicle tended to pitch backwards when placed in the water; this was because the external component distribution was uneven. To solve this issue, a series of weights were attached to the unweighted frames to achieve balance. After testing the pitch of the submarine with additional weights, it was discovered that though it was symmetrically-loaded, additional weights needed to be added to establish neutral buoyancy. Further testing helped calibrate the weight distribution until neutral buoyancy was attained.

4.3 Motor Control

After verifying structural integrity and balance, more performance-based evaluations were conducted. An experiment was performed to determine the necessary level of thrust supplied to the motors to achieve reasonable speeds without compromising the Inertial Measurement Unit (IMU)'s calibration, while avoiding unnecessary stress on the electrical components. By transforming the submarine into a remote-control unit where power supplied to the motors was a independent variable, the software team was able to observe, record, and implement the optimal thrust for each specific motor. This test also contributed to the decision behind the layout of the motors: four vertical and two horizontal. It was observed that setting the motors in this particular orientation best supported the IMU in maintaining stability.

4.4 Computer Vision

A concurrent set of tests was performed by the software team to calibrate the submarine's computer vision. Underwater images and videos were taken—from various angles—of objects expected to be used in the competition, like gates, buoys, and dice. These images were used as the basis of a library of elements the program would learn to recognize. Using these and other videos to simulate live navigation in the water, the software team was able to test the ability of the program to understand its environment and make decisions based on those observations.

5.0 Acknowledgements

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