University of Southern California AUV Technical Design Report

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Abstract

The Autonomous Underwater Vehicle Design Team from the University of Southern California has moved forward with an unconventional vehicle design meant to modularity and constant improvement. The autonomous vehicle, named Turtle I, is made with a central hull, containing the main electronic components, which connects with external thrusters, “pods”, and other additions mounted on an external octagonal aluminum skeleton through waterproof connectors. Turtle I is controlled by a Jetson TX2 which receives information from cameras, movement and sound sensors to locate itself within the course and plan a route to follow. These components communicate through electronics and code made mostly in-house, bringing features such as power regulation, thruster control, auto-stabilization and computer vision together in one, compact package. The vehicle’s usage of external pods allowed for constant innovation and improvement. While Turtle I was initially only able to roughly navigate in set paths, the addition of pods and other mounted modular devices now allows it to locate pingers, drop objects, sense pressure and shutdown on the command of a diver. The team goal at Robosub 2019 will be to qualify for the semifinal round and complete two obstacles using the technologies previously outlined.

Introduction

This report aims to outline the work of over 30 graduate and undergraduate students from the University of Southern California from various majors towards a working competitive vehicle. This includes financial, administrative, design and testing work done by engineering, business and science students from various backgrounds. Not only is it necessary for our main computer onboard to tell the motors where to move, there is work done by all team to insure the computer is housed in a safe and sturdy structure, that it receives the right power and inputs from the electrical systems, that its communication protocols allow it to control all of its outputs and that it is fully funded and affiliated to the university. The following sections will outline what those goals are, how the team has designed the vehicle to meet our requirements and what has been done to ensure those goals can be achieved. Beginning with our competition strategy, we will outline what we wish to achieve at this years Robosub and the design, production and experimental results that will allow us to do so.

Competition Strategy

Following the 2018 competition one of the main goals for this year's competition was to add many of the subsystems that would allow the Turtle I to complete more tasks.

Due to the limited time we had to prepare for the competition, we decided to have the submarine ready for a subset of the competition tasks. These subsystems include computer vision-based navigation, dropping a marker, depth sensors, pinger localization and a killswitch. Each part that we added introduced added complexity to the design of the Turtle I and increased the complexity of troubleshooting any problems that arose.

In order to organize the team better we split into different sub teams to work on the different components of the sub, namely Mechanical, Electrical, Software and Embedded Systems. A majority of the time went into developing the different hardware and software components that would allow us to achieve the competition goals mentioned above. Integration of the components into the sub was done on a rolling basis whenever a new component was finished. Members from different sub teams would work together to make sure the integration of a new subsystem went as smoothly as possible. The Turtle I was tested in a pool about every 2-3 weeks. The complexity of organizing these in pool tests as well as the physical location of the pool restricted in water testing time more than we would have liked.

Vehicle Design

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 Mechanical Design

The primary objectives of USCTurtle's mechanical design are to maintain a high degree of inherent stability and to maximize options for future expansion. USCTurtle's main hull is constructed of 3 major components: a domed lid, a cylindrical central body and a bottom wet connector plate. The placement of the domed lid and heavy bottom plate result in a high center of buoyancy and low center of gravity. This combination means that USCTurtle is very resistant to unwanted changes in the pitch and roll axes and is quick to recover to a stable, upright position.

Surrounding USCTurtle's main hull is an octagonal ring of mounting frames. Each frame is equipped with slots on each edge as well as an octagonal slot pattern in the center. This allows for maximal flexibility both in terms of position as well as orientation. Throughout USCTurtle's development, this flexibility has been invaluable as we reorganized our external components in response to the integration of new subsystems.

Due to budgetary and time constraints, as well as a strong desire to retain a mature platform to allow for continued electrical and software development, much of USCTurtle remains similar to our 2018 entry. Much of this year's work has focussed on improving reliability and ease of use. To this end, new external enclosures have been fabricated. Instead of securing end caps with screws, the new enclosures utilise a latch system which not only makes opening and closing them tool-less, but also eliminates thread deterioration issues we experienced previously. The internal layout of USCTurtle has also been enhanced with a new modular computer stack for our Nvidia Jetson. The stack has freed up space for a bottom facing camera and also helped to organise wiring allowing for a simplified removal process allowing components to be replaced or repaired more easily.

3.2 Software Design

For the software side of the USCTurtle we decided to guide our submarine using computer vision. We collected images of replicas of the competition obstacle and trained a computer vision model using YOLOv3. We used this as a basis for our navigation. Navigation consisted of writing scripts using computer vision data to be able to guide the submarine to a specific location in the real world. We used the locations of objects in camera footage to calculate the number of degrees that the sub had to turn. This information was fed into a PID loop which allows us to navigate towards certain targets. This is done with a forward camera to be able to navigate forwards towards an object as well as with a downwards facing camera to be able to hover over an object.

3.3 Electrical Design

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. An updated third iteration of this board had addressed issues of grounding and reliability inside the submarine.

The electrical team has now ensured that a PWM driver, an I2C board, ESCs, an IMU, the TX2 onboard and various microprocessors all have a reliable source of power and connect to a common ground without an issue.

Furthermore, the electrical team took on a project to incorporate hydrophones into the vehicle's navigation systems. This required extensive research, designing, prototyping and testing. Utilizing a triangular array of three hydrophones, each with a customized PCB to filter and remove noise from frequencies outside the expected pinger range, the team learned to find a bearing to follow towards a pinger releasing a set frequency. The information from each of the hydrophones goes to a microprocessor which utilizes the phase difference between these three signals to determine the angle from which the waves are coming from. Depending on further software integration, this system should allow the vehicle to find distant obstacles that would otherwise go unnoticed by our cameras.

Experimental Results

Over the years of the USCTurtle's development, numerous tests were performed to evaluate the structural integrity, neutral buoyancy, motor control, electrical reliability, 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 testing, it was revealed that due to the replacement of the external enclosures, USCTurtle's natural pitch angle and buoyancy had changed. To correct this issue, additional testing with different weights and configuration of ballast was done in order to bring USCTurtle back to its near-neutrally buoyant and upright state.

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.

Continuous testing was done later on the self-stabilization software using a PID control loop, proving to be the hardest part of getting the submarine to navigate in accordance to our plans. After noting issues with the integration of IMU data and timing of caller function, the PID code was made more stable and usable by the software team to keep the vehicle on its course.

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.

Acknowledgements

A great thank you to the previous team leads that pushed this vehicle to what it is today, with Matt Vera, Kiera Salvo and Jamie Smith as outgoing president, mechanical lead and embedded systems lead respectively. When reading this report it is important to remember that no part of Turtle I was done in isolation, the whole team needs continuous communication in order to complete its goals.

References

M. Vera et al, “USC Turtle Design, Build, and Operation,” AUV Design Team, University of Southern California, Los Angeles: 2018

Oppenheim, A. and Schafer, R. (2010). *Discrete-time signal processing*. Upper Saddle River [N.J.]: Prentice Hall.

Appendix

Appendix A: Expectations

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	30	
Technical Merit (from journal paper)	150	90	
Written Style (from journal paper)	50	40	
Capability for Autonomous Behavior (static judging)	100	70	
Creativity in System Design (static judging)	100	80	
Team Uniform (static judging)	10	8	
Team Video	50	40	
Pre-Qualifying Video	100	0	
Discretionary points (static judging)	40	5	
Totals	650	363	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	75	
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	0	
Gate: Pass through 60% section	200	200	
Gate: Pass through 40% section	400	0	
Gate: Style	+100 (8x max)	0	
Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the “Path” (2 total)	100 / segment	100	
Slay Vampires: Any, Called	300, 600	300	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	0	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	0	
Stake through Heart: Move lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	0	

Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	0	
Random Pinger second task	1500	0	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	Tx100	0	

Appendix B: Component Specifications

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	N/A	Depth controlled by thruster		
Frame	Custom	N/A	Al 6061, each panel ~7”x4.5”	
Main Hull	Custom	N/A	Acrylic tube, 9” ID, .5” wall Acrylic dome lid	
External Enclosures	Custom	N/A	Acrylic tube, 3.5” ID, .25” wall Al 6061 end caps	
Waterproof connectors				
Thrusters	Blue Robotics	T100		
Motor Controller	Blue Robotics	Basic ESC		
Battery	Battery Space	High Power Li-Po Battery	14.8v, 10Ah	
Converter				
Regulator				
CPU	Nvidia	Jetson TX2		
Carrier Board	Colorado Engineering	X-Carrier		

IMU	X-IO Technologies	X-IMU		
Camera	Blue Robotic	Low-Light HD USB Camera		