University of California, Riverside: Design and Implementation of The Seadragon

Abstract: The Seadragon is an autonomous underwater vehicle (AUV) developed by a team of undergraduate students at the University of California Riverside (UCR). This is the fourth AUV developed at UCR for the AUVSI RoboSub competition. Improved upon a physical foundation built in 2017 and 2018, with refabricated electrical and software systems, the vessel is comprised of an aluminum frame that supports 6 motors and two acrylic tubes carrying computers, sensors, and auxiliary equipment.

I. INTRODUCTION

The University of California, Riverside's RoboSub Project gives students a unique extracurricular engineering experience building an Autonomous Underwater Vehicle (AUV) to learn multidisciplinary skills and practical aspects of engineering not covered in course material. The team is academically diverse, representing students across nearly all engineering disciplines and several physical sciences. UCR RoboSub plans to enter the submarine in the 2019 RoboSub International Competition in July/August.

II. COMPETITION STRATEGY

This year we are attempting the buoy tasks, torpedo tasks, and gate tasks. With the majority of our team graduating last year, this year was dedicated to knowledge transfer and training. As many on our team are new to the project, and there were significant mechanical and electrical developments required before water entry, we limited our scope to increase the flexibility of our testing schedules. Components were designed and thoroughly tested individually while water-test-critical improvements were completed, coming together at the end for systems integrations.

III. DESIGN STRATEGY

This year's submarine is a major overhaul of last year's Seadragon:

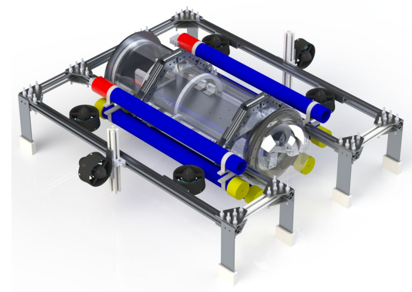

Fig 1. 2018 Design Render

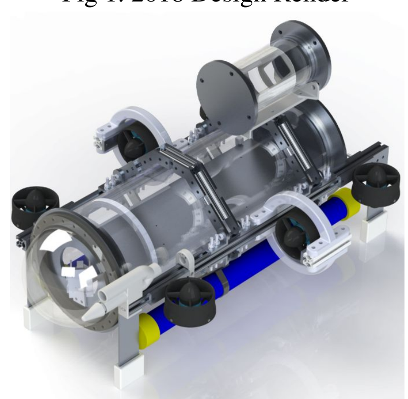

Fig 2. 2019 Design Render

The design changes can be broken into Mechanical, Electrical and Software systems.

A. Mechanical Design

We found the numerous rails of last year's submarine to provide excellent flexibility for components, however the large overall volume limited transportation. Thus, we compacted the submarine and are creating several additional modules towards a goal of "never take off the main endplates". Very few of our mechanical components are off-the-shelf.

1) Frame Modifications

A challenge faced was transporting the submarine due to its high width, so we compacted the submarine by 50%. The thinner structure would increase the forward-thrusters' power consumption and convergence times during rotations, but make it easier to maneuver for obstacles and challenges. To mitigate these drawbacks, circular thruster mounts were designed to allow the forward thrusters to be located either adjacent to the frame or further away, depending on battery and thermal effects. The frame overall was created using stock 8020 T-slot aluminum rail fastened by joints cut from aluminum plate and standard ¼-in bolts.

2) Electronics Chassis

The chassis consists of a large acrylic tube used to house our electronics, and provides the majority of our submarine's buoyancy, with two aluminum endplates creating a watertight seal. The front endplate has a large acrylic dome to house our camera on a pan-tilt mechanism, allowing us to use only one camera to manage forward and bottom views. As we are not attempting the Dropweights task, the camera is set to a static "forward" position.

For the endplates, aluminum was chosen both for its ease of manufacturing and to act as a heat sink when coupled with an aluminum shelf inside the chassis. The endplates feature a double o-ring sealing, with o-rings made from stock cording. The grooves were dimensioned according to published SAE dimensions. [1]

3) Motors and Configuration

The motors and their configuration allow depth, thrust, pitch, roll, and yaw movements. The presence of four depth thrusters allows for simple correctional ability, and the thrust motors along the center of mass also act as yaw motors. The submarine is designed for the center of mass to also be at the geometric center, with the motor centroids positioned accordingly for minimal undesired moments of inertia.

4) Electronics Shelf

The electronics shelf is made from a sheet of aluminum, with several 3D-printed mounts for PCBs, indicators, and other components. As our submarine's main tube provides ~65lbs of buoyancy force, the weight of this shelf helps lower our external ballast requirements. Penetrator bolts from Blue Robotics were used to pass cables through the endplates.

5) Battery Pod

The laborious necessity of removing the main chassis endplates to change batteries, a frequent task during water tests, was quickly realized. An external battery pod was constructed to allow more efficient battery-swapping without going through the main chassis. The battery pod is modeled after the main chassis, with aluminum endplates and a double o-ring sealing, along with penetrator bolts for the cables. Inside the pod is a cylindrical casing designed to keep the batteries along the central axis for laminar wire control.

5) Torpedo System

Our torpedo uses a pneumatic system to project a marker several inches. A standard "powerlet" CO_2 cartridge is enclosed and punctured within an adaptor, attached to a regulator dropping the pressure from ~1000psi to 80pst, attached to a solenoid valve actuated by the electronic controls, connected to a long acrylic tube extending out of the chassis to a torpedo dock at the front of the submarine. The torpedo dock splits the airflow to project two vertically-situated markers forward. The CO_2 holder, regulator, solenoid valve, tubing, and adapters were purchased off-the-shelf, with mounts, markers, and the torpedo dock design and fabricated in-house.

B. Electrical Design

For the 2019 competition we prototyped, designed and tested printed circuit board's (PCB). We unit tested our hardware with our power based components, microcontroller (MCU) boards and the Nvidia Jetson TX2 module board.

1) Hardware components

Our Electrical Design consists of four PCBs, 3 which we designed and 1 that was an off the shelf purchase. The 3 PCBs designed by us include: a MCU/Peripherals power distribution board (PDB), an Arduino Mega Shield, and a Thruster power distribution board. They integrate with Arduino Mega 2560 MCU, STM32 MCU, Computer module board, a Bar30 Pressure sensor, 12V solenoid valve, LED strip, an attitude and heading reference system (AHRS), camera, six electronic speed controllers (ESCs) and their respective thrusters. The design is powered by two 14V lipo Batteries, one of which is stepped down by the Peripherals PDB to power the MCUs and their integrated hardware. The other battery powers connects to the ESCs to power the thrusters.

2) PCB design

a) MCU/Peripherals PDB

This PCB has an array of buck converters that receive a 14V input from a battery and step the voltage down to 5V and 12V to provide peripheral power for the MCUs and other hardware.

b) Arduino Mega shield

This PCB is a shield for the arduino Mega and it controls an LED strip, 12V solenoid, and pressure sensor. The LED strip is used to indicate what the current status of the submarine is. The solenoid is used to launch our torpedoes. The Arduino Mega communicates with the STM32 board using the UART Protocol.

c) Thruster PDB

This PCB is a shield for the STM32 MCU. It distributes power to the thrusters, sends PWM signals to the thrusters and also contains automotive grade MOSFETs that act as our kill switch in conjunction with a magnetic reed switch. The STM32 communicates with the Jetson Tx2 through USB.

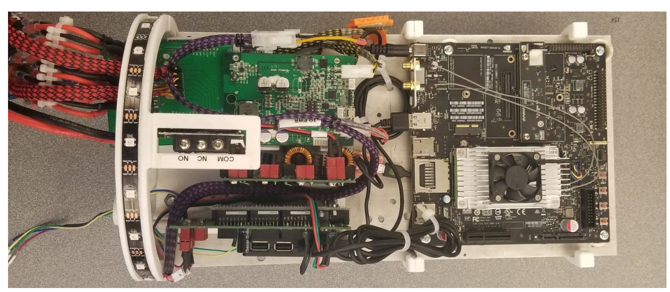

Fig 3. 2019 Electrical System

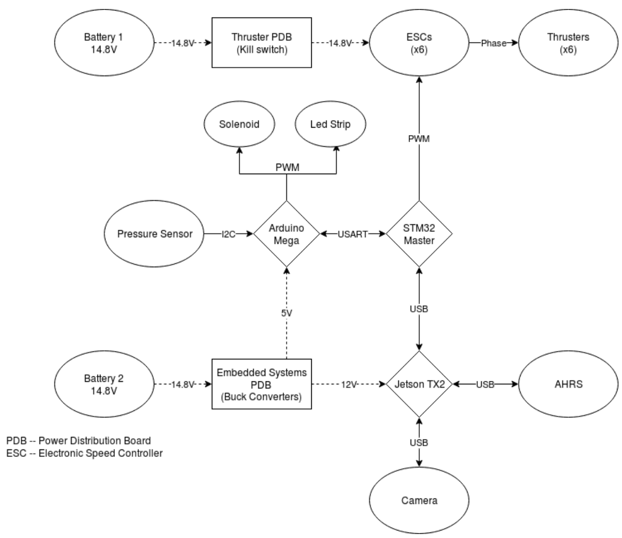

Fig 4. 2019 Electrical System Data Flow

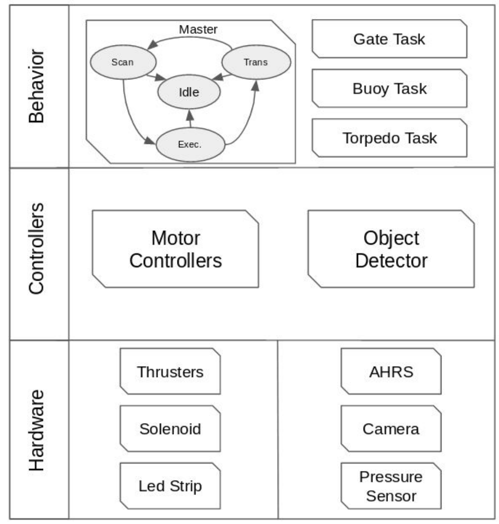

Fig 5. 2019 Software High Level Diagram

C. Software Design

For the 2019 competition, we overhauled our software to include computer vision. We utilized the Robot Operating System (ROS) for message-passing between systems. The software was written in C/C++ and Python.

1) Behavior

The mission planner was implemented as a complex state machine. A master state machine controls which competition task to perform next. This decision is based on information from the computer vision system and previously completed tasks. Once a competition task is enabled it will move through each of its states, performing a simple action in each (move forward, rotate, change depth, or shoot torpedo). Once a task is completed, it sends a message to the master state machine to move on to the next task. Messages between state machines, computer vision, and motor control system are passed via the ROS publisher/subscriber system.

2) Computer Vision

This year the software team focused on implementing computer vision as it is critical in completing most competition tasks. To achieve this, we utilized an existing deep learning model called ssd_mobilenet. We then collected hundreds of images, differing in rotational and translational information, for each object that we wanted to detect. For this year, we trained a deep neural network to recognize the gate and the various vampire images found in the competition. To reduce the training time, we performed Transfer Learning on an existing model. This required us to fine tune the last layer of the network and required less data to train the model. We also performed hard negative mining to reduce the number of false positives from about 27% to less than 5%.

3) Control System

Our submarine utilizes an AHRS (attitude and heading reference system) and depth sensor to provide feedback to the PID controllers. This allows the submarine to maintain it's heading and depth.

IV. EXPERIMENTAL RESULTS

1) Waterproofing: The waterproofing method is broken down into several phases: I) After the frame and chassis improvements are done test for leaks in endcaps attached to acrylic tube.
II) Test electronics connected to penetrators to ensure waterproofing of penetrators connected to electronics. To determine the leak locations of the chassis, paper towels line the inside of the acrylic. When wet, the towels become noticeably darker, indicating a leak.

2) *Water Testing:* In water software testing included the following:
I) Test electronics in chassis with manual control to ensure power distribution boards are working properly.
II) PID tune to ensure motors and on-board computer have correct feedback control.
III) Use created competition obstacles to test mission planning and feedback control.

3) PCB Testing: PCB testing consisted of the following:
I) Unit stress testing of each PCB functionality with border cases to ensure no abnormal behavior and to ensure expected results.
II) Unit tested with long duration periods of time to examine the electronic's durability and susceptibility to the heat generated due to their operation.
III) Multiple Voltage inputs were tested to ensure the power distribution worked as intended.

4) Software Testing
Before water-testing, we used unit tests and the Gazebo simulator and Mock Tests to examine the reliability of the software separate from the mechanical and electrical parts.
Once all unit tests on the state machines passed successfully, they were tested again on the actual submarine.

V. ACKNOWLEDGEMENTS

UCR Robosub could not be possible without the support of UCR faculty, friends, students, and sponsors:

The team would like to thank:

- Martinez and Turek, Inc.
- Industrial Metal Supply
- Electronics Warehouse
- UCR's Department of Electrical and Computer Engineering
- UCR's IEEE Student Chapter
- UCR's ASME Student Chapter
- Dr. Hossny El-Sherief
- Mathaudhu Research Group

VI. REFERENCES

[1] "Cross Section & Groove Design Data." O-Ring Cross Section & O-Ring Groove Design Data. N.p., n.d. Web. 21 June 2017.

Appendix A: Scoring Table

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	40	
Technical Merit (from journal paper)	150	110	
Written Style (from journal paper)	50	50	
Capability for Autonomous Behavior (static judging)	100	88	
Creativity in System Design (static judging)	100	95	
Team Uniform (static judging)	10	5	
Team Video	50	40	
Pre-Qualifying Video	100	0	
Discretionary points (static judging)	40	35	
Total	650	463	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	145	
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	300	
Gate: Pass through 60% section	200		
Gate: Pass through 40% section	400	400	
Gate: Style	+100 (8x max)	400	
Collect Pickup: Crucifix, Garlic	400 / object		
Follow the "Path" (2 total)	100 / segment		
Slay Vampires: Any, Called	300, 600	600	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)		
Drop Garlic: Move Arm	400		
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	2400	
Stake through Heart: Move lever	400		
Stake through Heart: Bonus - Cover Oval, Sm Heart	500		
Expose to Sunlight: Surface in Area	1000		
Expose to Sunlight: Surface with object	400 / object		
Expose to Sunlight: Open coffin	400		
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)		
Random Pinger first task	500		
Random Pinger second task	1500		
Inter-vehicle Communication	1000		
Finish the mission with T minutes (whole + factional)	Tx100		

Appendix B: Component Specifications

Component	Vendor	Model /Type	Specs	Cost (if new)
Buoyancy Control				
Frame	8020 Aluminum Frame			(reusec
Waterproof Housing	Cast Acrylic Tube			(reused)
Waterproof Connectors	Blue Robotics Penetrators			$30
Thrusters	Blue Robotics T100/T200			(reused)
Motor Control	Blue Robotics ESC			(reused)
High Level Control				
Actuators				
Propellers				
Battery	Pulse LiPo	6600 mA-hr		$160
Converter	LM2576SX-ADJ/NOPBCT-ND			$5.72
Regulator				
CPU	Nvidia Jetson TX2			$650
Internal Comm Network	ROS			
External Comm Innterface				
Programming Language 1	Python			
Programming Language 2	C++			
Compass	MyAHRS+			$99
Inertial Measurment Unit (IMU)	MyAHRS+			
Doppler Velocity Log (DVL)				
Camera(s)	Unknown			(reused)
Hydrophones				
Manipulator				
Algorithms: vision	SSD MobileNet Deep Learning			
Algorithms: acoustics				
Algorithms: localization and mapping				
Algorithms: autonomy	State Machines			
Open source software	OpenCV, ROS, ProtoBufs			
Team size (number of people)	25			
HW/SW expertise ratio	20:5			
Testing time: simulation	10			
Testing time: in-water	0			