Autonomous Underwater Vehicles Team at Berkeley (AUVs) RoboSub 2019: *Project Blue*

Abstract

Blue is Autonomous Underwater Vehicle Team at Berkeley's (AUVs) first entry into the RoboSub competition. The submarine robot is a culmination of all that the team has learned in the past three years of its existence. *Blue's* systems were designed in late 2018 and constructed in early 2019 by a team of all undergraduate students attending the University of California, Berkeley. *Blue* is an entirely student-built robot that was designed uniquely for as a test bed for student learning with the opportunity to expand its capabilities in the future. *Blue* features a stereoscopic vision system, data cataloging abilities, and a robotic arm. *Blue* is designed to complete image recognition tasks and manipulate objects with a robotic arm.

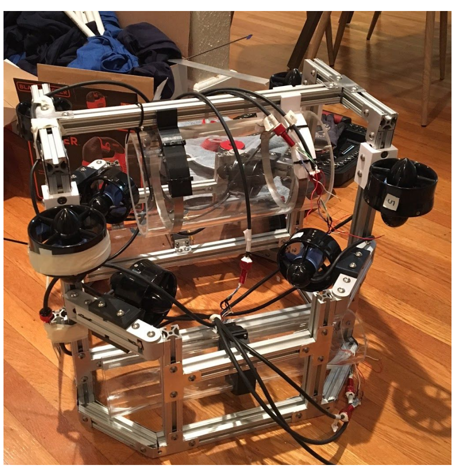

Image 1: *Blue* under construction

Competition Strategy

As a first-year entry, *Blue's* main objective is to complete a series of gate tasks. Following the path and placing objects at the garlic drop were selected as secondary tasks. An additional goal for this competition includes collecting vehicle telemetry via a USB thumbdrive. AUVs has partnered with a GPU analytics plaftorm to enable students to inspect and identify areas for improvement during competition.

In completing the gate tasks, the robot is equipped with a forward facing stereoscopic camera and CPU that uses a series of filtering and color balancing techniques, developed in-house, to translate visual data into vehicle movements. This same system can be repurposed for use on the path tasks. Objects in the garlic drop can be released from the sub's mechanical arm.

Accomplishing these tasks requires a functional and well designed robot sub. *Blue*'s design was created with electrical, propulsion, and equipment requirements in mind. As the team's knowledge base of these systems grew over time, the chassis was redesigned a total of two times up until the RoboSub 2019 competition. This caused significant delays which prompted the team to create a total of two submarine vehicles prior to the 2019 RoboSub competition (*SmolBot* and *Blue*). *SmolBot* served the team as a test platform and *Blue* as our RoboSub 2019 entry.

Vehicle Design

Electrical Documentation

Blue's electrical systems are separated into three main, air-sealed capsules. Two 3-inch tubes serve as flat-cell lithium polymer battery bays for the sub's power supply. These tubes contain thermal sensors and voltage monitors that alert the system when power is low. The sub is wired in a 6 cells in series and 2 groups in parallel (6S 2P). A third 6-inch tube contains the subs power distribution, electronic speed controllers, cameras, central processing unit (CPU), microcontrollers, and accessories. Organization of these tubes and their contents is provided in *figure 1 and 2*. The robot's "kill-switch" utilizes a non-latching hall-effect sensor to disable the robot in the presence of a strong magnetic field.

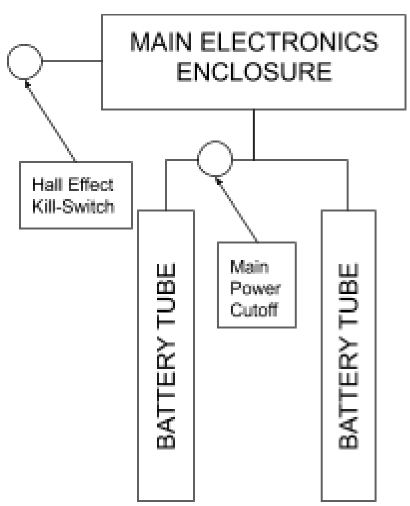

Figure 1: Tube layout

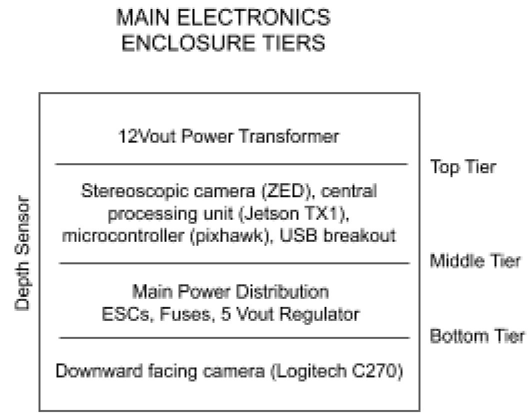

Figure 2: electronics tiers in main housing

Blue's power systems were designed to provide power to 8 T200 thrusters, logic systems, and accessories. Power to all components is provided by a student designed power distribution, which provides a 30A fused path for each electronic speed controller (ESC), and features a 12V and 5V power rail. Battery power is stepped down by a top-mounted transformer down to 12V for the CPU, manipulators, and lights. 12V is then stepped down again to 5V for USB powered components and cameras.

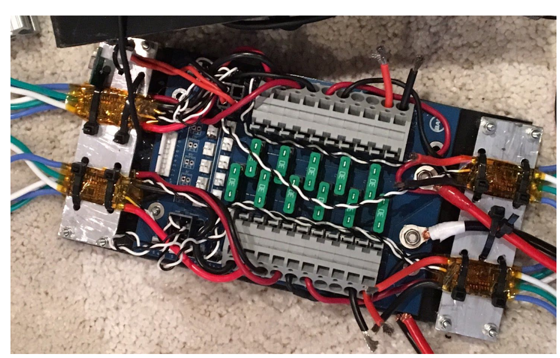

Image 2: *Blue's* power distribution

Blue's CPU is an NVIDIA Jetson TX1 mounted to a CTI Orbity Board

Carrier. The Orbity Board connects to a USB hub, which interfaces with a ZED stereoscopic camera, Logitech C270 webcam, USB thumb drive for telemetry, and a Pixhawk 1 flight controller for motor control. All of these devices exceed the power that the Jetson can provide, meaning that the USB breakout must accept an external power input.

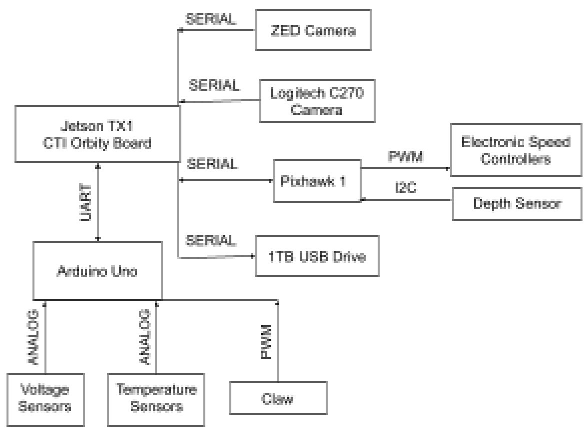

Figure 3: Wiring Schematic

Chassis Documentation

Blue's chassis is composed of 80/20 extruded aluminum framing. The structure is bolted together with aluminum sheet brackets and stainless steel hardware. Development of the chassis required a small frame that provides a clear sight for forward and downward facing cameras. 3D printed motor mounts were created for vertical and horizontal thrusters, as well as for the main electronics tube mounts.

Propulsion Documentation

Blue's propulsion system consists of eight BlueRobotics T200 thrusters: four supply vectored thrust (at 45º angles) and two enable vertical movement. The thrusters are shrouded within the frame in order to ensure that they do not get damaged during transportation and mission completion. This also significantly reduces the probability of the vehicle getting snagged on various objects while performing tasks in the water.

The T200 thrusters were chosen for their compact, lightweight, inexpensive, and waterproof qualities. Seabotix BTD150 thrusters were included in the vehicle's initial design; however, the T200 thrusters were chosen to ensure that the vehicle remains compact and well within the size and weight bonus point requirements. The vectored thrust design also enables the vehicle to move with greater precision in all directions compared to direct drive.

Software Documentation

One of the largest project teams at AUVS at Berkeley, the software team researches and develops advanced perception and control algorithms for the vehicle. The following section details the construction of the team's software stack along with its integration with electrical and structural components.

Perception

The most important part of any autonomous system is its ability to collect feedback from surroundings so it makes informed, intelligent actions. Our dedicated Perception project team develops advanced computer vision algorithms with Principal Component Analysis (PCA) and other filtering techniques to produce accurate underwater identifications. Additionally, the project team also is in charge of researching the implementation of future technologies like acoustic positioning and Simultaneous Localization and Mapping (SLAM). The work is simplified with the OpenCV library, but our computer vision pipeline is still developed and customized in-house through repeated iterations of performance evaluations through sample competition footage generously donated by other teams.

Often, our software goes above and beyond what is necessary to ensure task completion. For example, our gate detection solution, which originally could be completed using only HSV filtering, uses a well-developed pipeline including PCA and color balancing which comes out to what we hope will be a competitive algorithm.

For identification tasks, the project team will either use its Oriented Fast and Rotated Brief (ORB) or Scale-invariant Feature Transform (SIFT) classifier, both of which are very accurate and fast classifiers as proven through testing, but the exact classifier to be used will be determined at competition after reviewing test run results. In the future, the team hopes to fully utilize its TensorFlow classification neural network modeled after a MobileNet architecture developed by its machine learning research group to develop faster, more accurate classifiers.

Control Systems

The Control Systems team develops handlers that transforms robot operating system (ROS) topic outputs into robot actuator movements. As architects of the larger data pipeline that takes in sensor readings and outputs thruster commands, they are in charge of planning for the fusion of data from multiple sensors and even multiple thruster outputs for safe vehicle operation.

Our control system is made up of an Nvidia Jetson TX1, which is where our perception and control system code is stored and run, a Pixhawk 1, which is our flight controller which evaluates thruster outputs into vehicle actuations, and a connected suite of sensors which helps the vehicle make informed actions.

The control system is currently a PWM output based system that modifies all 6 DOF: pitch, roll, yaw, thrust, forward, and lateral motion. We use a PIDF controller to maintain our heading at our intended setpoint. This is used in combination with the Pixhawk Stabilize mode to ensure pitch and roll are 0 at all times. Finally, the translational motion is done through approximate velocity control with a fallback to time and vision based control. We are using the onboard Pixhawk IMU, but this IMU has a lot of internal error and so our velocity integration contains a lot of noise. As a result, when we can no longer rely on the velocity from the IMU, we defer to time-based control till we see our next vision target.

This is all encapsulated in a custom Python library that puts the Control System in a State Machine. We have a driver program that allows us to test from CLI in a REPL loop and internally use the same thing to change states for different tasks. This provides a safer developing experience which allows any developer on our team, even those with no command line experience, to write fail-safe code and prevent the unexpected execution of uncontrollable vehicle maneuvers.

Experimental Results

AUVs prioritized testing that would assist in control systems integration and provide evidence of structural sufficiency in mechanical design.

Materials testing

Vital components such as the sub's motor mounts and main tube mounts are made from 3D printed PLA filament. Shear tests were performed on vulnerable areas to ensure the material can handle stresses in use.

Dry Bench Testing (20 hours)

Early on, AUVs constructed a test sub, *SmolBot,* before the competition robot chassis could be completed. This provided ample time for students to develop an understanding of vital robot systems and test control code as the competition bot was designed simultaneously. *SmolBot* was successful as it enabled hands-on experimentation with competition grade control and propulsion electronics..

Small Tub Testing (4 hours)

SmolBot, AUV's test sub was submerged in a small tub of water within a hydrology laboratory at UC Berkeley. Control teams were able to determine how values translated to movement and vehicle speed. Mechanical teams also acquired an understanding of underwater mechanics such as weight balancing and buoyancy principles

Acknowledgements

It takes a great effort to make this competition and endeavour possible. AUVs at Berkeley would like to thank the following individuals / sponsors:

- Negassi Hadgu and Dr. Variano at the University of California, Berkeley
- Dr. Hannah Stuart and Dr. Dennis Lieu at the University of California, Berkeley
- UC Berkeley & College of Engineering
- Engineering Student Services (UCB)
- Engineering Student Council (UCB)
- OmniSci (Formerly MapD)
- Bay Area Circuits (BAC)
- AUVs at Berkeley Members

Appendix A: Expectations

Subjective Measures			
	Maximum Points	Expected Points	Points Scored
Utility of team website	50	30	
Technical Merit (from journal paper)	50	35	
Capability for Autonomous Behavior (static judging)	100	50	
Creativity in System Design (static judging)	100	70	
Team Uniform (static judging)	10	9	
Team Video	50	30	
Pre-Qualifying Video	100	0	
Discretionary points (Static Judging)	40	10	
Total	650	234	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	68	
Marker / Torpedo over weight or size by <10%	Minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	100	
Gate: Coin Flip	300	250	
Gate: Pass through 60% section	200	100	
Gate: Pass through 40% section	400	300	
Gate: Style	+100 (8x max)	100	
Collect pickup: Crucifix, Garlic	400 / object	0	
Follow the “path” (2 total)	100 / segment	200	
Slay Vampires: Any, Called	300, 600	0	
Drop Garlic: Open, closed	700, 1000 / marker (2+pickup)	300	

Drop Garlic: Move arm	400	0	
Stake through heart: Open oval, corner 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+fractional)	Tx100	0	

Appendix B: Component Specifications

Component	Vendor	Model / Type	Specs	Cost (if new)
Buoyancy Control	Target Ace	n/a n/a	Pool Noodle ½ Bolt	5 20
Frame	G.A. Wirth Ace	80/20 Framing n/a	Includes hardware Brackets	453.58 24
Waterproof housing	Blue Robotics	6” Tube 3” Tube (2)	Includes potting and flanges	1,217.74
Waterproof connectors	Blue Robotics	M10 Penetrator	48 total	150
Thrusters	Blue Robotics	T200	8 total	1,715.16
Motor Control	Blue Robotics	Basic ESC	8 total	See Above
High Level Control	mRo	Pixhawk 1	Essential kit	199.90
Actuators	n/a			
Propellers	Blue Robotics	CW/CCW	Included w/ T200s	n/a
Battery	HobbyKing	Zippy 3s	2 sets (4 ea)	240
Converter	Amazon	Uxcell	24V to 12V	32.99
Regulator	Amazon	DROK	12V to 5V	8.99
CPU	Arrow Electronics CTi	Jetson TX1 Orbity Carrier	n/a	350.94 191.81
Internal Comm Network	n/a			

External Comm Interface	n/a	n/a	Personal Laptop	n/a
Programming Language 1	Python (OpenCV)			
Programming Language 2	Robot Operating System (ROS)			
Compass	Built into Pixhawk 1			
Internal Measurement Unit	Built into Pixhawk 1			
Doppler Velocity Log (DVL)	n/a			
Camera (s)	ZED Amazon	ZED C270	Stereoscopic Camera Webcam	503 40
Hydrophones	n/a			
Manipulators	Blue Robotics	Newton Gripper	n/a	372.83
Team Size (number of people)	40 (Students only)			
HW/SW expertise ratio	1:1			
Testing time: simulation	20 hours			
Testing time: in water	4 hours			

Appendix C: Outreach Activities

1) Sharing software code via GitHub

   Leveraging the size and motivation of the software group, we tackle problems by trying many different approaches, and evaluating the best solution. The result is a finely-tuned software stack which performs through deliberate real-world actuations, which are the result of data being passed through many layers of the software pipeline.

   This year being our first, we aim to build our resource library as quickly as possible, so that our team remains as agile as possible at competition to accommodate different situations. All of the code we develop, regardless of whether it is used or not, is saved on our public GitHub page, as one of the ways we give back to the RoboSub community for helping us get started. We hope that future teams will find our repository useful for getting themselves started as well.

2) Community workshops and info-sessions

   Through their involvement in AUVs, members learn and apply what they learn in community engagement opportunities. AUV's computer vision team hosted a machine vision workshop at CalHacks 2019: a community event in Berkeley focused on exposing college-level students to tech problem solving challenges. Members explained how underwater images were processed to provide meaningful information and then led an activity where participants detect a piece of paper with their web cameras.

   AUVs also has the opportunity to partner with the local tech start-up environment, hosting a community workshop with OmniSci. Students who attended had the opportunity to see how GPU accelerated data analysis is transforming big data analytics in the near future.

3) Science, Technology, Engineering and Math Advocacy

   At AUV's core is a mission to create the problem solving leaders of tomorrow and the team participates in events that align with this purpose. For the past three years, AUVs was present at the UCB SWE Mini University where youth interested in engineering and the sciences can see how students can get involved in fun projects outside the classroom. AUVs also participated in CalDay 2019, a day open to the public full of educational events. The team demonstrated our test sub *SmolBot* and answered any questions participants were curious to ask.