Bruin Underwater Robotics 2025 Technical Design Report

University of California, Los Angeles (Bruin Underwater Robotics)

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***Abstract*—The 2024-2025 season marks Bruin Underwater Robotics (BUR)'s second year competing in Robosub, as well as designing autonomous robots in general. Our goal for this year was to use the lessons we learned in our rookie year to create *Endurance*, a more robust vehicle.**

Much effort has been taken to reprioritize and narrow the scope of our competition goals. As such, we have decided to focus on the core features needed for autonomous behavior, with navigation and localization being our main goals for this season. To fulfill these goals we have implemented a simple, yet modular, design for our AUV. We have made this decision for the hopes of utilizing the same vehicle for systems and controls testing for future seasons. This, along with development of a virtual simulation platform, will allow us to perform systems-level testing while designing future AUVs.

I. Competition Strategy

Last year (2024) was our first year competing in Robosub, as well as our first time designing a non-teleoperated underwater vehicle. Although we were proud of what we accomplished as a first-year team, we made many design decisions that ultimately limited what our bot could do. We wanted to do better.

This year, we rebuilt our robot from the ground-up. We had two main goals for our redesign: (i) alleviate many of the pain points in our previous design, and (ii) create a robot durable enough to last for years to come. Our focus on durability arose not just out of a desire to conserve parts and reduce failures, but also from a longer-term project planning perspective. A major challenge for our team has historically been our inability to do substantial underwater testing until the robot is fully manufactured. Now, by building our new , we can ensure that our dive-ops and software subteams will have a solid and reliable testing platform for use going forward.

A. Course Strategy

Learning from our previous season, our strategy focuses on navigational tasks (Gate, Slalom, and Surfacing) as our main priority. These tasks require that our AUV is capable of basic maneuvering and localization, which are fundamental to achieving any task in the Robosub competition. Our robot utilizes an internal IMU and an external pressure sensor to determine its position and orientation. In addition, a Zedd Mini stereo camera is used for localization with respect to the pool environment. Making these operations our main priority ensures that both our robot and team are capable of performing the basic steps that are necessary for further tasks.

The next set of tasks that we aim to complete are Bin and Torpedoes. From our previous experience in the competition venue, we expect that we can use our computer vision systems to identify and map the task locations. Further using computer vision, the AUV will properly orient itself to our intended target and, based on the task at hand, release markers or deploy torpedoes.

B. Project Strategy

A lesson we learned from our Robosub debut is the importance of early and consistent system level testing. Due to the design cycle of our AUV, full system testing was impossible until both the physical robot was fully manufactured. As a result, even when our software team had systems ready to test, we were left incapable of verifying its capabilities. To remedy this issue, our strategy tackles the problem through two fronts: (i) designing a durable and reliable AUV that can be used season-to-season and (ii) developing

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an AUV simulation platform. By implementing both of these changes, our team will become capable of both physical and virtual testing from early in the competition season.

II. Design Strategy

A. Chassis

The main priorities when designing the chassis of our autonomous underwater vehicle (AUV) for this year's competition were durability and optimization. While competing last year in our debut into RoboSub, our team ran into unforeseen issues with our AUV being hard to maintain and set up during competition. That experience influenced us to go for a sturdier, more reliable design this year, along with making the robot easier to take apart and rebuild if necessary. Another motivation for our further emphasis on durability was to have a ready AUV for next year so that in-pool software testing can occur during the design and build phases of our next AUV.

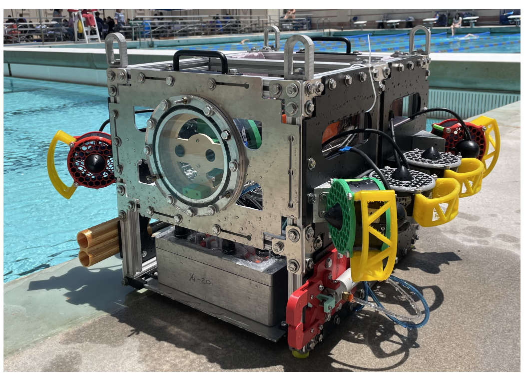

Fig. 1: *Endurance*, the competition AUV for Bruin Underwater Robotics.

1) Frame: In the pursuit of durability, our AUV is made of an aluminum t-bar frame with high-density polyethylene panels (HDPE) and aluminum brackets, making the main shell of our AUV extremely rigid. To account for this rigidity in structure, the frame was designed with lots of internal space for different potential additions. External attachment points were also left on the HDPE panels to allow for the addition of any unforeseen components needed on the outside of the AUV as well.

2) Slide-Out Panels and Buoyancy: Accessibility of our AUV's battery and pneumatic boxes was another one of our main concerns with this rigid frame design. Therefore, we attached our battery and pneumatic boxes to aluminum panels with 3D-printed rails that allow them to slide within the aluminum t-bar frame, giving us easy access to both boxes without requiring a large disassembly of the AUV. Estimating our center of buoyancy was also a huge consideration when designing our AUV and influenced where our battery and pneumatic boxes would lie compared to the electronics bay.

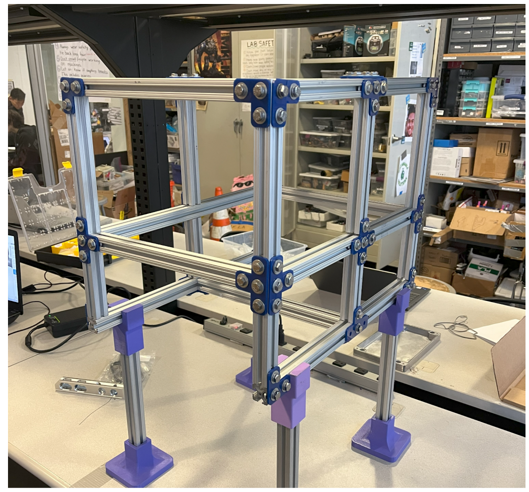

Fig. 2: Aluminum profile extrusion comprises the bulk of *Endurance*'s frame.

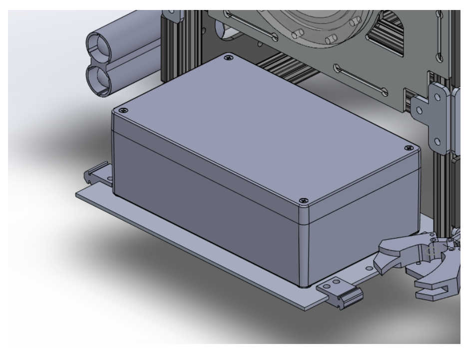

Fig. 3: Conceptual draft of slide-out panels.

3) Cable Management: Lastly, during last year's competition, our team received feedback on our lack of cable management for our previous AUV. In response to this, extra care was put into designing different parts of our AUV's chassis to allow for more cable routing opportunities. Cable management in general was also made to be a priority when assembling our AUV as we tried to avoid excess wires sticking out of the chassis frame.

4) Electronics Bay: Similar to our last design we decided to reuse our tube and flange electronics bay, we found this design offered a more efficient and adjustable system than a welded hull. However, last year we had used plastic clamps around the middle of our electronics bay, which had worn and cracked and did not stabilize our E-bay as we had hoped. To remedy this, we mounted the E-bay by its flange directly onto the frame using large aluminum plates. These plates created a rigid structure that gave us a secure, consistent mounting point.

5) Hardware Mounting: To mount our electrical devices within the electronics bay, we used a series of parallel vertical plates. This method offers a much more efficient packing system than our former triangular shelf system and allows us to move critical components closer together and off the bottom of our electronics bay. All of our cables still route outside the electronics bay through one of our acrylic end caps and are sealed using cord grips.

B. Dive Operations

1) Pneumatics: Similar to last year, this year we decided to use pneumatics to operate the torpedoes, arm, and dropper. Our system consists of a paintball air tank connected to four solenoid valves that control the flow of air to the 4 actuators. To ensure that the system was safe a vented ball valve, 2 relief valves, and a pressure regulator, which kept the operating pressure below the maximum pressure rating of the individual components, were implemented into the system.

The solenoids were housed in an aluminum box. In order to get the tubing into the box a large square was cut out using a plasma cutter to which a clear acrylic plate, with 12 holes for the core grips, was epoxied onto.

2) Torpedo: The torpedo design consists of a double barrel holder, with two 3D printed torpedos. These 3D printed torpedoes were printed with 80% infill to achieve neutral buoyancy (so the density of the torpedo and the water are roughly equal). The barrel can hold two linear pneumatic actuators and has guiding rails. Additionally, the torpedo has knobs to slide along the rails as it is actuated out to ensure the straightness of the torpedo launch.

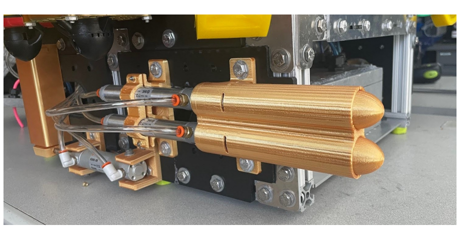

Fig. 4: Torpedo subassembly.

3) Arm: The arm design features a two bar linkage system driven by a linear pneumatic actuator. It was designed to pick up several different components and hold on to them as the robot moved through the water. The main goals when designing the arm were replicability of motion and strength of the system. A large surface area and specific linkage geometry were used to achieve a consistent closing sequence. In order to achieve strength in the system the arm and all of the subsequent mounting brackets were 3-D printed at 80% infill. In addition the linkages are mounted through the claws to better protect and house them.

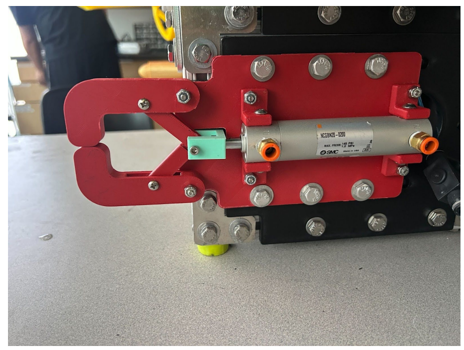

Fig. 5: Arm subassembly.

4) Dropper: This year, we decided to attempt a new task by including a dropper mechanism. This sub assembly consists of a release mechanism by a pneumatic actuator, two dropper items shaped like torpedoes, and a 3D printed housing. These dropper items are made of aluminum to ensure that they would sink (due to density properties), and they were designed in a way in which they can be manufactured from a rectangular piece of stock and using a CNC milling machine and a lathe. Lastly, to meet certain requirements, a sticker with the BUR logo was added to the dropper items.

C. Hardware

1) Battery Board: The electronics are powered by two 14.8V 7.2Ah LiPo batteries, with a 3.3V buck

Fig. 6: Manufactured marker with BUR logo.

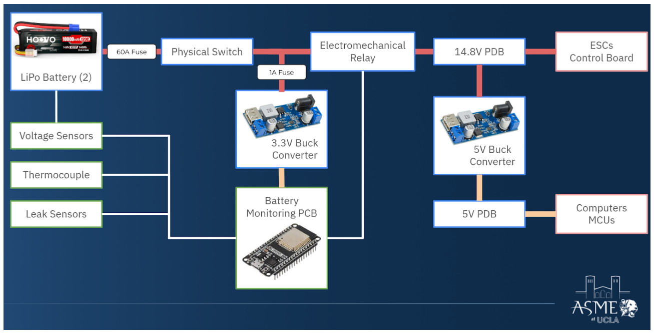

Fig. 7: AUV power system diagram.

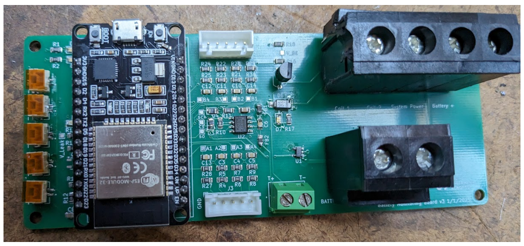

Fig. 8: Early version of battery monitoring PCB. Dive-ready version still in development.

converter used to power the battery-monitoring system. The custom battery board monitors the voltage of each cell and will automatically cut power in the case of overcurrent, undervoltage, leak detection, or dangerously high temperatures. This year, the board was redesigned to rely on a physical relay and a power MOSFET (accommodates higher current and can easily be replaced), to draw power from the main batteries instead of a dedicated 11V battery (simplifies pre-dive procedures), and to use screw terminals instead of soldered connections (increases safety and modularity). Several prototypes of this board have been created, though a pool-ready version is still in development.

2) Control Board: The custom Control PCB is mounted on an Arduino Due to interface with the eight thruster ESCs and the four pnuematic solenoids. This board was modified from last year's design to accommodate a 4th solenoid.

D. Software

Much of our onboard software stack remains unchanged from last year, minus minor tweaks to our controls subsystem to fit our new robot. Instead, a major focus this year was on simulation. During the 2024 season, our software team was unable to test major subsystems for most of the year while the robot was under construction, leading to a rush to complete certain subsystems before the end of the year. This

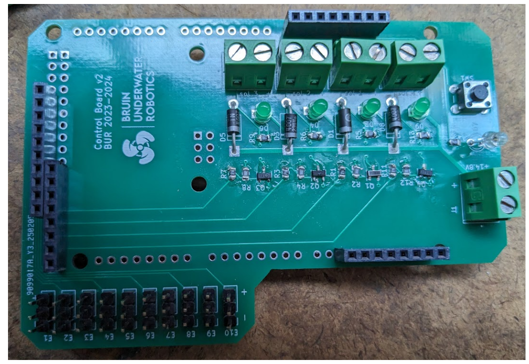

Fig. 9: Control PCB shield for an Arduino Due.

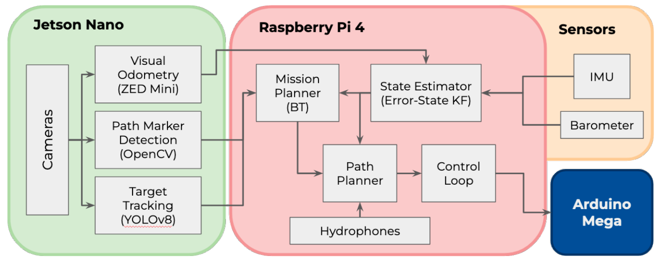

Fig. 10: Overall software architecture remains unchanged from 2024 season.

year, we sought to address this challenge by using simulation in two ways: (i) simulated rendering of competition elements and objectives to train our computer vision component, and (ii) physical simulation of the robot and robot motion to test our controls and motion planning subsystems.

1) Rendering: We created an HDRP (High Definition Render Pipeline) environment in Unity 2022.3 to facilitate the generation of synthetic data for training purposes. Unity 2022.3 was chosen for its compatibility with the Unity Perception Package, which significantly streamlined the process of generating large quantities of annotated bounding box data in a JSON format. Additionally, the built-in water system that was introduced in the 2022 version allowed for the creation of realistic, free, and easy-to-implement water effects, removing the need for custom shaders or third-party assets [1]. To populate the simulated environment with detailed 3D models, custom assets were created in Blender. Blender was chosen over other modeling software because its lightweight nature places less demand on the computer, which is beneficial during the asset creation process for our project. It also provided robust tools for designing high-quality models, which were then imported into Unity with minimal compatibility issues. After generating the data, we used a simple Python script to convert the JSON files from the Perception Package into YOLOv5-readable .txt files, which enabled seamless integration into the model training pipeline.

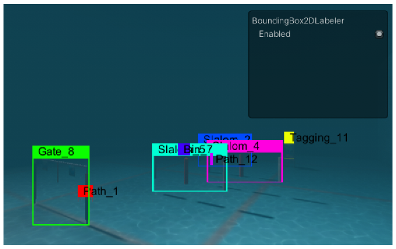

Fig. 11: Frame of simulated environment with bounding boxes.

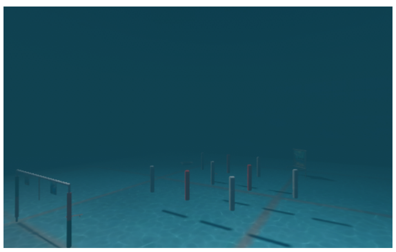

Fig. 12: Frame of simulated environment without bounding boxes.

2) Physical Simulation: Similar to our chassis subteam, one of our primary software goals this year was to establish a software "base" that could be used as a foundation for future development in the years to come. For software, our aim was, specifically, to create a simulation environment that could be used for testing of our controls and planning subsystems virtually.

For simulation, we used the Gazebo Garden simulation suite. In particular, we used the Hydrodynamics plugin to simulate the movement of our robot underwater; namely, the plugin models the effects of buoyancy, drag, and ocean currents on our robot using a system of second-order differential equations with respect to the robot's x/y/z position [2].

Within the simulation, we specified the locations and directions of all six thrusters (relative to center of mass), representing the rest of the robot as a rectangular box for simplicity. For control, we used the same software stack presented in the above diagram, except with two changes:

1) We replaced our usual state estimator with the position output from Gazebo itself.
2) We used a custom ROS node to map the output of our thruster manager (part of our control loop) into Gazebo thruster commands.

Although we were not able to finish our simulation in time to use it before pool testing began, we intend to utilize it more this summer to help us prepare for competition. More generally, we are excited for the possibilities that having this capability might open up for us in the future.

III. Testing Strategy

A. Mechanical

1) Buoyancy: One of our main priorities when testing the chassis of the AUV was calculating the center of buoyancy. Center of buoyancy calculations, as well as center of mass calculations, were done on the CAD of our AUV to allow for a better understanding of where design adjustments would need to be made. Further tuning of the center of buoyancy was done once we began pool testing our AUV and could see the effects from a real-life environment and unaccounted buoyancy values.

2) Endcap: Ensuring that the endcaps and o-rings made a water-tight seal on our electronics bay was another one of our main priorities during testing. Initial Solidworks simulation tests were done on the endcaps of our electronics bay to determine how much internal pressure they could withstand. In-lab tests were then done in a large bucket of water with a vacuum seal. These were done to confirm the o-ring seals on the endcaps were working properly before moving to pool tests. Once those in-lab tests were successful, we began official pool tests and were able to perform depth tests on the AUV up to 15 feet with no leaks.

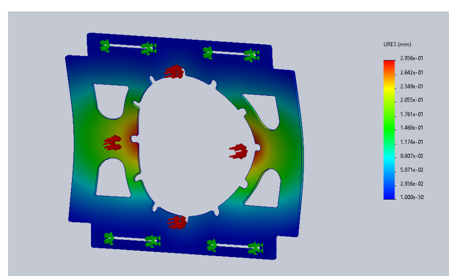

Fig. 13: Solidworks FEA analysis of Endcap mounting piece.

3) Pneumatics Bay: To test if the pneumatics box with the epoxy solution was waterproof, we ran several vacuum leak tests. During the test pneumatics tubes were inserted into each core grip and the box was closed. An air compressor was then attached to the box to create a vacuum and replicate the pressure differential as if the box were underwater. We sprinkled water droplets onto the acrylic/aluminum interface, looked for water getting into the box, and listened for any possible gaps in the epoxy or any faulty components. We ran this test several times until no air leaks were occurring. This test was much quicker and simpler to conduct than going to an actual pool to test the pneumatics box.

4) Torpedo: Several torpedo designs were proposed consisting of different nose and fin shapes. For each design, CFD analysis was performed to analyze the velocity profile and drag coefficient. The simulation was performed in a way where the torpedo would remain stationary and the fluid (water) would move towards the torpedo. This simulation would behave similarly to a torpedo being shot into still water. One torpedo design appeared to have the best results and was selected as a final design. Additionally, changing the nose shape of the torpedo was found to not affect results by too much. However, discrepancy between the physical and theoretical torpedo may differ due to the nature of FDM 3D printing [3].

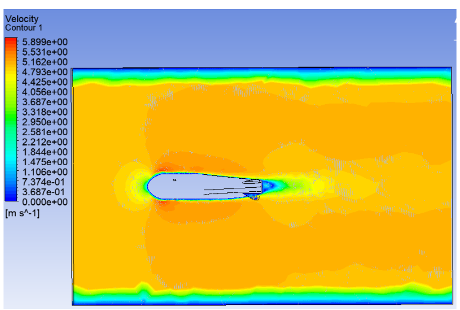

Fig. 14: Velocity profile of fluid around the torpedo.

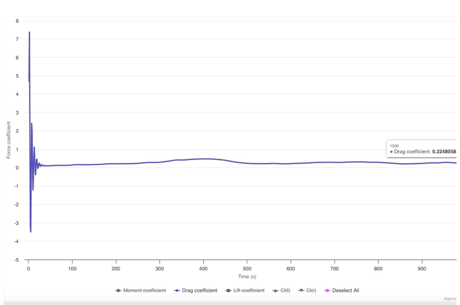

Fig. 15: Drag coefficient of torpedo over time.

Additionally, the first iteration of the torpedo mount broke during testing due to the reaction pressure force from the actuator. For the next iteration of design, FEA was used to analyze the stresses within the mount to ensure the material doesn't reach its yield strength and break as it previously did.

5) Arm: Two varying arm designs were made and both tested to see which one would be most effective. To test the arm, 3D printed props such as the spoon and cup were printed. The arm was then used to pick up these items numerous times to both verify reliability of the system, and strength of the grasp itself. The testing was conducted using the pneumatics testing procedures described above. In the end a flat claw with large surface area and strong linkages was chosen as it more reliably and consistently held and maintained the objects in the control of the AUV.

B. Hardware

1) Battery Board: The battery board underwent extensive testing to ensure it could meet safety and reliability requirements for the bot. Before any subsystem tests were performed, we inspected each soldered component and performed continuity checks to ensure the electrical connection aligned with the schematics. Then, we proceeded to perform subsystem tests. The voltage monitoring system was tested by comparing cell voltage values printed over serial by the board's MCU to direct voltage values measured by Digital Multimeter. Then, low voltages were intentionally introduced to the measurement pins (using a variable DC power supply) to verify that the MCU registered the error and shut off system power. To test the temperature monitoring subsystem, a heat gun was set to 80°C and used to heat the thermocouple, while the output of the MCU was monitored to ensure it registered the correct temperature and shut off system power. We tested the final subsystem, leak detection, by dropping water water introduced onto any of the leak sensors, and shut off power. Finally, all the subsystems were verified to work together by testing each subsystem sequentially on a combined physical and software stack.

Our initial design used an LDO to provide 10V to the microcontroller, which – while within the MCU board's tolerable voltage range – resulted in high current draw from the 14.8V batteries and generated excess waste heat. By researching the board, we determined this was because the board further dropped this 10V to 3.3V using an LDO, which is highly inefficient for this purpose. To resolve the issue, we replaced both LDOs with a buck converter which outputs 3.3V, reducing the current draw from 150mA to 35 mA. Current draw was measured using a clamp multimeter.

IV. Acknowledgments

The work achieved by Bruin Underwater Robotics was only possible due the support of a number of individuals and organizations. We would like to first give special thanks to Professor Veronica Santos for her unwavering support and drive for our team to succeed, as well as to ASME at UCLA for their allocation of resources and space for our project. Furthermore, we would like to acknowledge UCLA Recreation for providing a location for water tests.

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