Robosub 2024 Technical Design Report

University of California, Los Angeles (Bruin Underwater Robotics)

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***Abstract*—The 2023-2024 season marks Bruin Underwater Robotic's (BUR) first endeavor into the Robosub competition and autonomous control as a whole. The design of Ambition is geared towards the completion of two simple tasks: gate and torpedoes. With accessibility and autonomy in mind, our engineers took great care in planning for assembly and reliable testing. Ambition represents BUR's most complex and abitious design, in hopes of paving the way forward for years to come.**

I. Competition Strategy

For this year's RoboSub 2024 competition, our team's first time competing in a RoboSub competition, we are debuting our robot, Ambition. Our design prioritizes the gate and torpedo tasks, with tasks that require a gripper set as reach goals. One of the main focuses of our robot was accessibility, giving us more time for testing and optimization than in previous years in preparation for the new challenge of a RoboSub competition.

A. Accessibility and Reliability

A driving goal for our team was the reliability and accessibility of our various systems. Our previous Remotely Operated Vehicle (ROV) required forty minutes of setup before entering the water. Moreover, certain systems and hardware designs ultimately lead to several power faults during operation. With these previous trials in mind, BUR was able to design a robust vehicle capable of completing tasks in the Robosub competition.

[1]Project lead

B. Course Strategy

As this is BUR's introductory season into autonomous systems, our AUV prioritizes the more simple tasks of the course: Enter the Pacific (Gate) and Mapping (Torpedoes).

The gate task is of the highest priority, as a similar task is used for pre-qualification. Using our onboard vision systems to identify the gate, Amibition will then approach the gate and pass under. Utilizing a PID controller, our AUV can lock its yaw position, guaranteeing that it passes through at the same heading.

The next task of priority is the torpedo task. Making use of our sensor systems, we will be able to navigate to the torpedo task with our downwards and front-facing cameras. Using our stereo camera, we will be able to perceive the depth of the target, allowing us to align our projectiles with the targets and fire at them using our onboard pneumatic systems.

II. Design Strategy

A. Mechanical Systems

The mechanical systems of the autonomous underwater vehicle (AUV) were first design to improve upon the failures of previous vehicles, and secondly to optimize performance for the selected goals.

1) Frame: A core focus during the design of the autonomous underwater vehicle (AUV) was accessibility and modularity. Previous years under the MATE ROV competition had made us aware of the dangers and frustration of poor assembly design. As such, this year's robot

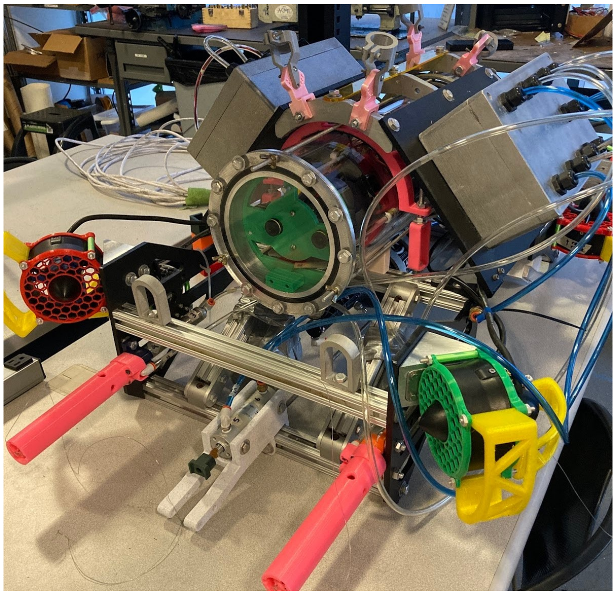

Fig. 1. Ambition, BUR's debut AUV.

was designed to prioritize easy access to the most utilized components. This was realized using a tented frame that allowed free access to the electronics bay. In doing so, alterations to the electronic hardware of the AUV could be easily accomplished. Moreover, the chassis of the AUV makes heavy use of an extruded aluminum profile, allowing for the addition of any unforeseen components. The original design was adjusted many different times, many of the iterations were made only possible due to the flexibility of our design. The brackets that connected and secured the "flaps" also served as the anchor to the hydrophone sensors, making it an integral part of our design.

2) Electronics Bay: The electronics bay (e-bay), is comprised of an acrylic tube that is positioned at the center of the robot and maintained in place by adjustable double clamp design. The e-bay was prevented from sliding by a polymer interface that was secured to the inner diameter of the clamp using epoxy. In addition, the clamps also served as guiding rails to the threaded rods that compressed the two end caps of the acrylic tube, keeping the internal electronics bay dry.

The e-bay also incorporates other parts into its overall design, like the aluminum flanges which provide a leak-resistant barrier and easier installation/removal for more convenient maintenance. Two types of O-rings are incorporated into the e-bay: piston and face seals. The piston seal is meant for hydraulic sealing and is installed around the interior of the flange. The smaller face seals are placed at the external side of the flange to mitigate leakage. The final major component of the e-bay is the end cap, which was laser cut to fit the acrylic tube and attached with cord grips. These are similarly placed at each end of the tube to prevent water from flowing in, although one is clear to allow the camera to record its surroundings.

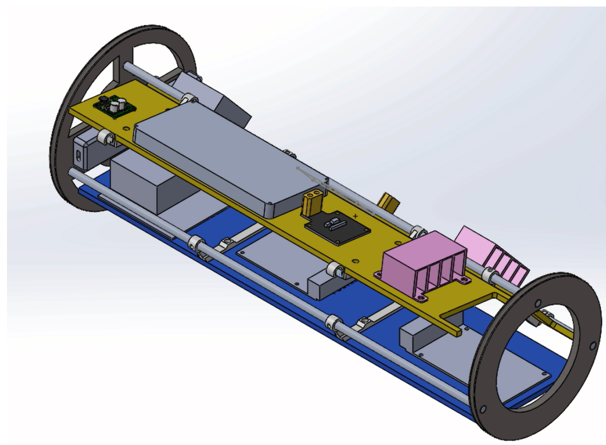

Fig. 2. SolidWorks assembly of internal mounting structure.

The internal mounting was designed to support the various electronic components such as: microcontrollers, power distribution boards, cameras, and printed circuit boards. In order to do so, we designed a support base with two disks connected by three aluminum rods. Three removable laser cut panels are attached and supported by rib supports that can snap onto the support aluminum rods. These removable panels were used to attach the various electronic componenetscseparatedly from the compact design that was meant to fit inside our 5.75 in. diameter tube. As a result, we avoided much of the cable connection problems that arise from cramped spaces.

3) Arm: The arm was designed based on previous years' tasks and constraints due to the frame of our robot. It is made of 3D-printed PLA, which allows for iterative design changes and is clamped via a pneumatic actuator connected to a paintball tank. The actuator drives the top arm downward onto the other arm, allowing it to scoop up objects below.

4) Torpedo: The torpedo was designed with the mechanics of an underwater projectile in mind. It is made of 3D-printed PLA to allow for iterative changes, with an infill of 80% for neutral buoyancy to increase accuracy. Postprocessing was used to reduce drag on its surface. It is held in place by friction, with little bulbs on its sides to guide it along the rails as it is actuated out.

5) Actuators: With our two torpedoes and arm relying on pneumatics, our actuation system involves a paintball tank connected to solenoid valves, which control the flow of compressed air to the actuators. Proper safety precautions, including a vented ball valve, two relief valves, and a pressure regulating keeping the operating pressure below the maximum pressure rating of the individual components were used.

B. Hardware Systems

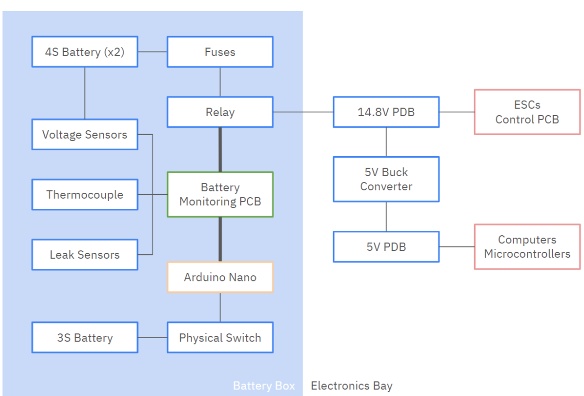

Fig. 3. Integration of battery monitoring board.

1) Power: Electronics are powered by two 14.8V 7.2Ah LiPo batteries and a separate 11.1V LiPo battery for the battery monitoring board and relay coils. The 14.8V line includes a 5V buck converter to power the computers and microcontrollers, a relay to act as a switch togglable by the battery monitoring system, and two 50A fuses on each individual battery.

Fig. 4. Batteries and battery monitoring board.

A custom battery monitoring board detects leaks and monitors battery voltages and temperature. In case of critical conditions (such as a leak detected), the battery monitoring board shuts off the power to the system by disconnecting the relay.

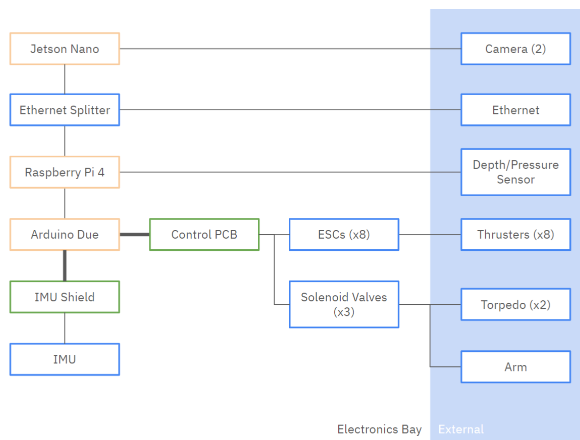

Fig. 5. Component level control integration diagram.

2) Control Board: The control PCB is mounted on an Arduino Due to send signals to the thrusters and ESCs. The board uses a similar circuit structure to our design from last year, scaled up to 8 thrusters and 3 solenoids to fit the competition rules. The bot's IMU is mounted on a separate Arduino Due to provide the robot with angular positioning data.

3) Hydrophone Board: This year, we began the development of a hydrophone data processing board for the ultrasonic pinger task. The hydrophone PCB collects data from four hy-

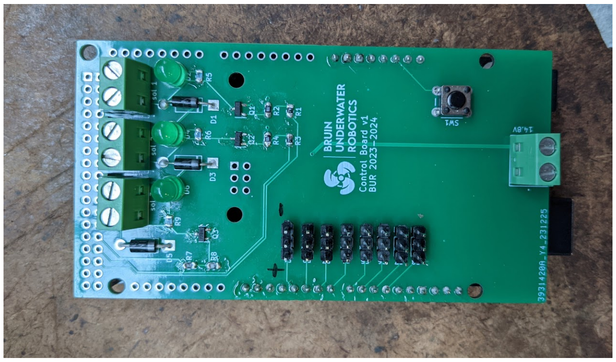

Fig. 6. Control board.

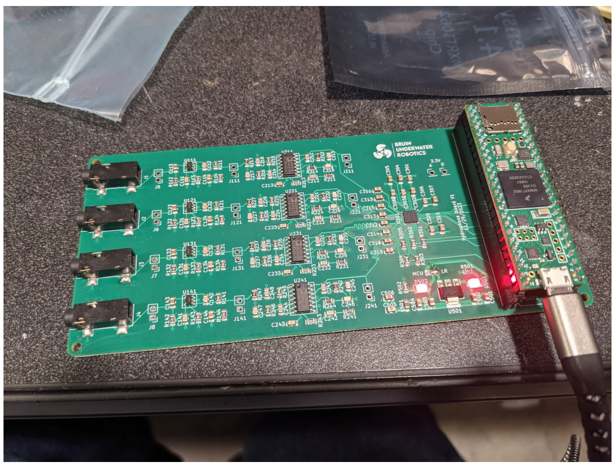

Fig. 7. Prototype hydrophone board.

drophones and consists of multiple stages. The audio signals are first amplified and filtered (7th order Butterworth low-pass filter) to remove interference and noise. A quad-channel audio ADC simultaneously samples the hydrophone signals at 192kHz and outputs a digital I2S signal, which is received by a Teensy 4.1 microcontroller for further processing.

C. Software Systems

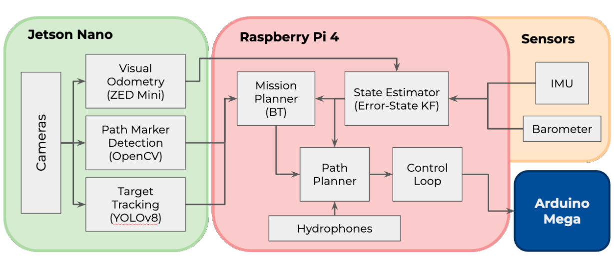

Fig. 8. AUV software diagram.

Although we had previous experience programming underwater robots for the Mate ROV competition, shifting to the autonomous format of the RoboSub competition was the largest challenge for us. Throughout this past year, we rebuilt our software stack from the ground-up in order to meet the requirements for autonomous operation.

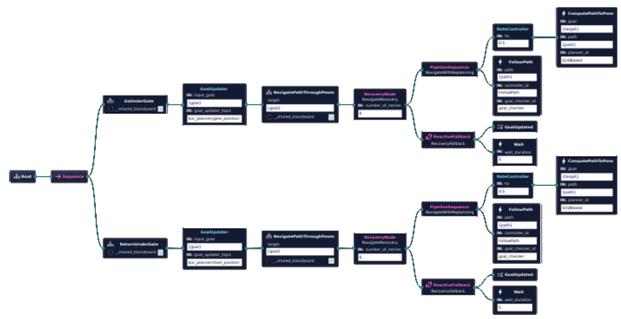

Fig. 9. Sample behavior tree.

We based our software stack on the ROS2 framework for handling inter-process communication. We chose ROS2 due to the modularity of its node structure - as additional capabilities came online over the course of the year, we could quickly integrate them into the system. For our mission planner, we used the BehaviorTree.CPP library in conjunction with the ROS Navigation2 package to direct the robot.

1) Guidance, Navigation, and Control: For state estimation, we used an error-state Kalman filter from the Robot Localization package to obtain position estimates via fusion of our three main sensors: IMU (acceleration & orientation), visual odometry from our ZED Mini (position & orientation), and bar sensor (depth). The prediction from the filter is used to update our behavior tree goal position.

For our control loops, we have separate PID controllers for each axis. The PID controllers take input from the state estimator and our IMU to do velocity and orientation control. The output goes into our custom thrust allocator [2][3] which translates the resulting control effort into motor outputs.

The motor outputs are sent via serial to an Arduino Due which has our MTi-3 IMU and handles the control of our motors and solenoids. We chose the Arduino Due because we had previous PCB designs of the Arduino Mega, and the Due is capable of running Micro-ROS. Using Micro-ROS allowed us to incorporate the Arduino into our existing ROS2 stack without having to write our serial communication library.

2) Vision: For localization, we utilize a ZED Mini Stereo Camera with the visual optometry library implemented via the ZED Software Development Kit to obtain position and orientation information for our Kalman filter. Furthermore, for recognition and tracking of competition tasks, we trained a YOLOv5 Model (CNN-based) on a dataset of game task images. This model was then optimized using Nvidia TensorRT for higher frame rates and faster inference on the Jetson Orin. We then utilized the stereo depth perception capabilities of the ZED Mini to obtain a depth map of the environment. Finally, using Nvidia's DeepStream SDKs and our object detection model, we segmented the game tasks by masking the 2D bounding boxes over the depth point cloud. These 3D bounding boxes of the game tasks were used for more precise tracking and movement to complement our path planner.

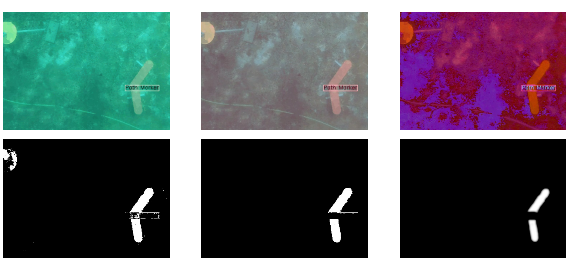

Fig. 10. Path marker filtering pipeline, from top left to bottom right: original image, color restored, HSV, thresholded, blob-removed, and blurred

In addition, we implemented a bounding box detector for the path markers, which is outlined in Figure 10. Since the path markers were a bright orange color that striking contrast with the surrounding water, we utilized various classification computer vision filters to isolate the path marker. First, we applied a color cast removal to remove the blue and green

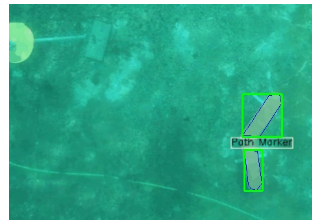

Fig. 11. Final bounded boxes overlayed on original image

hues in the image caused by the surrounding water. This increases contrast and causes the orange to stand out and be easier to isolate. The image was then transformed to the HSV color space and thresholded for the warm color values. Then, we applied a blob filter to remove small noisy detections and a Gaussian blur to further remove noise. The final thresholded white pixels were detected with a bounding box as seen in Figure 11.

III. Testing Strategy

A. Mechanical

As with all underwater vehicles, reliable and waterproof seals were our first mechanical priority. SolidWorks pressure simulations were performed on the endcaps of the electronics bay. Moreover, practical depth tests were performed in our campus pools, providing successful results in up to 15 feet of water. Other simulations were performed to verify the strength of our HDPE components to ensure no failures were to occur due to the forces applied by the thrusters.

Solidworks CFD was used to test the drag coefficient of different torpedo shapes for optimization purposes. Straight, curved, and no fin designs were printed, while guide rails that were straight and spun the torpedo were also made. Infill was varied and then all the designs were tested after CFD by launching each of them in person, measuring distance traveled, and accuracy.

IV. Acknowledgment

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.

Bruin Underwater Robotics would also give thanks to our generous sponsors, whose support provided the opportunity for our team to work on this incredible project. We would like to provide special thanks to SMC Pneumatics, Industrial Plastics Supply, and Protolabs for their generous donations to our team.

References

[1] L. Paull, S. Saeedi, M. Seto and H. Li, "AUV Navigation and Localization: A Review," in IEEE Journal of Oceanic Engineering, vol. 39, no. 1, pp. 131-149, Jan. 2014.

[2] T. I. Fossen, Handbook of Marine Craft Hydrodynamics and Motion Control. John Wiley & Sons, 2011.

[3] X. Wu, "Thesis," Flinders University, 2018.

V. Appendix A: Component List

Component	Vendor	Model/Type	Source	Cost	Year of Purchase
ASV Hull Form/Platform		Ambition	Custom	$1,700.00	2023
Waterproof Connectors	McMaster-Carr	Plastic Submersible Cord Grip	Purchased	$101.25	2023
Propulsion	Blue Robotics	T200	Purchased	$1,600.00	2021, 2023
Power System	Amazon	HOOVO 4S LiPo Battery	Purchased	$399.98	2023
	JLCPCB	Custom	Purchased	$400.00	2023
Motor Controls	Blue Robotics	Basic ESC	Purchased	$304.00	2021, 2023
CPU	Digikey	Raspberry Pi 4	Purchased	$75.00	2023
	Nvidia	Jetson Orin Nano 4GB	Purchased	$499.00	2023
Teleoperation	—	—	—	—	—
Compass	—	—	—	—	—
Intertial Measurement Unit (IMU)	Digikey	MTi-3 MTi 1 Accelerometer	Purchased	$449.00	2023
Doppler Velocity Logger (DVL)	—	—	—	—	—
Camera(s)	Stereolabs	ZED Mini Stereo Camera	Purchased	$399.00	2023
	Walmart	Camera Endoscope	Purchased	$26.89	2023
Hydrophones	Aquarian	H2D Hydrophone	Purchased	$796.00	2023
Algorithms					
Vision	OpenCV	OpenCV	Software Package	—	2023
	ultralytics	YOLOv8	Software Package	—	2023
Localization and Mapping	Charles River Analytics	Robot Localization	Software Package	—	2023
Autonomy	BehaviorTree.CPP	BehaviorTree.CPP	Software Package	—	2023
	ros-planning	Navigation2	Software Package	—	2023
	Clyde McQueen	Orca4	Software Package	—	2023
	ros-controls	Control Toolbox	Software Package	—	2023
Open-Source Software	OpenRobotics	ROS2 Humble	Software Package	—	2023