MuddSub: Advancing Vehicular Autonomy

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Abstract—**This report discusses ongoing interdisciplinary research and development by MuddSub, a student-led, student-run underwater robotics team at Harvey Mudd College. MuddSub seeks to enrich student opportunities in robotics and autonomy, from mechanical and electrical design to software development and modeling, rooted in the College's robust systems engineering and computer science curriculum. This report first describes the autonomous underwater vehicles (AUVs), Alfie and Crush, and overarching project management and design process, through which MuddSub pursues short-term real world development, long-term technical development, novel research, and continued passionate student innovation. It then recounts design decisions for both AUVs and the subsystems by which they will meet competition objectives, and ends with commentary on the procedures used to verify and refine these designs.**

I. Introduction

Underwater robotics and the development of AUVs highlight the unique challenges of navigation and operation in turbulent, noisy environments: preventing flooding and failure under high water pressure, successfully distinguishing objects in low-visibility conditions, accurate localization and mapping in the absence of reliable external references, and compensating for otherwise undetectable drift due to ocean currents and turbidity. To surmount these demanding obstacles, students and researchers must incorporate cutting-edge methodologies, harnessing core principles of autonomy and contributing to future breakthroughs in this evolving field.

II. Competition Strategy

MuddSub relies on efficient resource and project management as it pursues these engineering challenges, especially given its small team size and limited funding. Preparing for the competition necessitates compromises, from down-selecting among which objectives to pursue in a given year, to designing mechanical subsystems for 3D printability at the cost of robustness. Such a compromise is discussed in Section III-E; MuddSub's actuator subsystems: a marker dropper and torpedo launcher created to tackle RoboSub 2025 Tasks 3 and 4 [1], respectively, were both designed such that a single servo actuates two mirrored mechanisms. This common working principle establishes both devices upon the same servo and similar code, but currently poses a design flaw in the torpedo launcher.

These actuators will be compatible across both MuddSub's tried-and-tested original robot, Alfie, and its work-in-progress experimental platform, Crush (Fig. 1). Alfie has been used since its inception in 2018 to onboard new MuddSub members and advance the team's goal of fostering student robotics experiences. With its straightforward software framework, modular chassis assembled entirely from flat, in-house-machined parts, and efficient off-the-shelf electronics, Alfie embodies simplicity, reliability, and ease of use. Meanwhile, Crush is an innovative, sleeker AUV, which when fabricated and assembled next year will enable MuddSub to explore new research and design directions. Crush will incorporate composite parts on a more compact frame, custom printed circuit boards (PCBs), advanced sensors like a doppler velocity log (DVL) and hydrophones, stereo cameras for enhanced depth perception, and an improved software framework.

Fig. 1: Renders of Crush (left) and Alfie (right).

III. Design Strategy

A. Alfie's Electrical System

Alfie's electrical system is powered by two 14.8V LiPo batteries. One battery powers the thrusters while the other powers the control electronics. This allows for the thruster battery to be completely disconnected (either manually or electrically with the kill switch) without impacting any of the other systems. This is particularly useful for debugging, as a majority of software work can be done without physical thruster feedback. High-level control of Alfie is performed on a NVIDIA Jetson AGX Xavier running Ubuntu and ROS. The Jetson communicates with the majority of the robot's sensors over USB serial and hands-off processing of low-level IO (thruster/servo PWM, I2C, physical switches) to a Teensy 4.1. This setup allows the Jetson to remain focused on issuing high-level control commands, while the implementation of those functions can be handled by dedicated hardware.

B. Alfie Software Modifications

This year, Alfie's software system was updated for testing and image detection. We worked to update the SLAM software and made basic changes to the navigation system. Within SLAM, we implemented closed-loop systems to ensure accurate position control, and investigated graph optimization techniques. We also worked to add computer vision software to Alfie, primarily with image detection and machine learning. We took multiple images of the objects in various locations (including underwater) and compiled them into a database, then fed this data into the YOLOv10 software to create a machine learning model that can recognize the marker as well as other underwater objects. We also added additional safety features to our teleop control mode, such as controller disconnection detection, and in upcoming years, we plan to expand our navigation software implementation with the addition of a Kalman filter to fuse our various sensor readings.

C. Crush Mechanical Design Updates

Crush improves upon Alfie's maneuverability and versatility by carefully balancing parameters like cost and mass. For example, utilizing existing club inventory has become a crucial consideration, while a design priority is minimizing mass given the smaller water displacement and buoyancy force that Crush will experience. Taken together, these factors required verification that reducing the wall thickness of Crush's electronics enclosure, to match existing Al-6061 stock, would not compromise its O-ring seal as the walls deflect under high pressure. Hand calculations revealed this as the greatest vulnerability dependent on wall thickness. Finite element analysis (FEA) using manually-coded materials in SolidWorks corroborated our calculations that the deflection at a 10-meter depth would indeed maintain the seal (by not exceeding 1 mm, 25% of the O-ring width). In fact, when considering the entire electronics enclosure, net deflection of the walls around the O-ring is massively reduced as the water isotropically compresses the enclosure (Fig. 2). These findings allow us to lower Crush's mass, avoid purchasing new stock, and discern next steps for fabrication and O-ring selection.

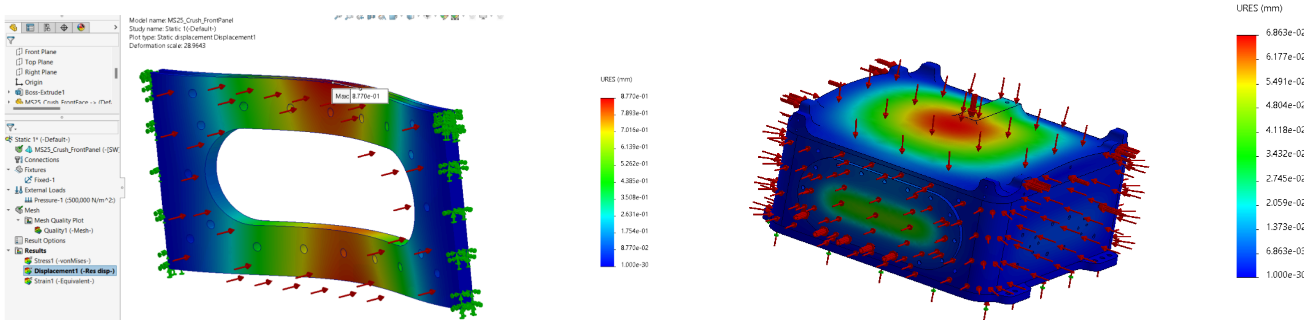

Fig. 2: Deflection of Crush's electronics enclosure at a 10-meter depth in SolidWorks FEA.

Additionally, we have further modified Crush's frame design and CAD infrastructure, from resolving previously unseen geometric oversights to dramatically redesigning its bellypan (the flat frame on which its many hardware components are mounted). Notably, the bellypan will now have the same mounting hardpoint dimensions as Alfie, and in a much greater variety of orientations (Fig. 3), facilitating the use of identical actuator designs across both AUVs and granting Crush more flexibility to serve as a prototyping platform.

Fig. 3: Crush's underside, displaying only several of many subsystem mounting orientations.

D. Crush Electrical Design Progress

This year, the electrical subteam investigated the use of hydrophones for listening to the pingers placed throughout the course. This will improve our robot's localization capabilities, allowing us to better find the locations of each challenge. Additionally, we completed first draft revisions of the PCBs for Crush. These included one board to handle regulating our 14-15V battery voltage down to the 12V, 5V, and 3.3V needed for our thrusters and control electronics (Fig. 4). We then designated a second board to manage the signalling logic and pinouts for our Teensy microcontroller (Fig 4). The boards are designed to be mounted on top of each other in the final robot, saving space and allowing for other systems to be included in the smaller body of Crush. These will also improve upon our current electrical setup by providing more stable connection points for the robot's electrical components, preventing problems caused by faulty connections.

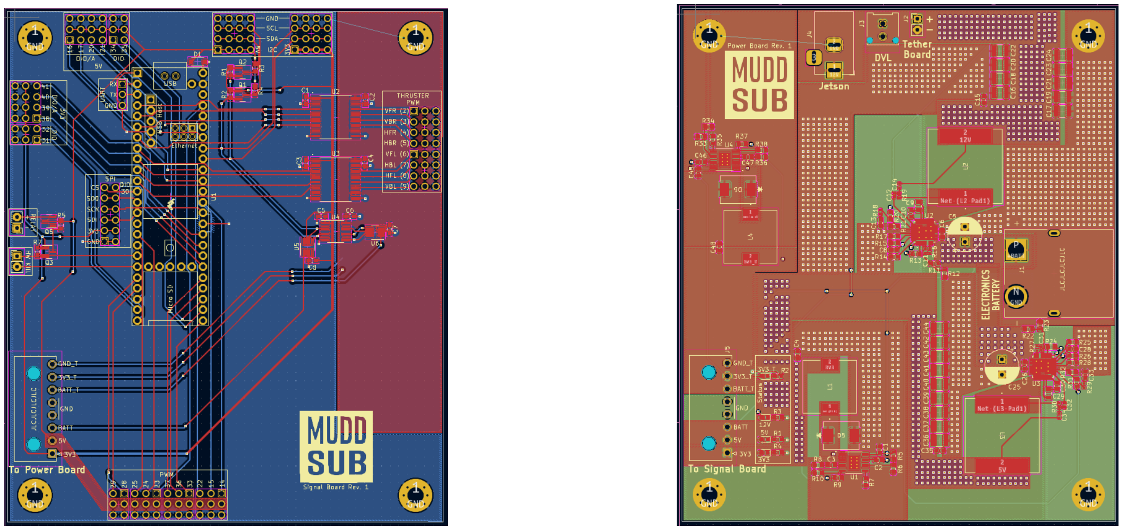

Figure 4: Revision 1 Designs for Crush's Signal Board (left) and Power Board (right)

After reviewing these designs with Professor Matther Spencer, we determined that we could remove the linkage between the boards by reorganizing the PCBs to be governed by a separation of voltage domains rather than a separation of functionalities. This would allow us to simplify the overall designs by removing many of the traces which are only necessary for cross-board IO. Future boards will iterate on the designs we finalized this year by relocating the various components to locations where they can be more easily interconnected.

E. Actuator Subsystem Iterative Process

This year saw the downsizing and refinement of the marker dropper (Fig. 5), as well as the exploration and iteration of a new design alternative for the torpedo launcher (Fig. 6). In both actuator subsystems, a single D646WP servo [2] mounted below the AUV is used to deploy two objects, mirrored across either side of the servo, by twisting at the desired time in one direction to deploy one object while constraining the other. As such, the devices share similar code, with the only differences being the catalyst, timing, and range of the servo's rotation, simplifying software design and testing.

In the case of the marker dropper, two weighted, dodecahedron-shaped markers are held up against gravity by an attachment mounted on the servo horn. As we successfully tested last year, this shape balances approximately spherical symmetry with an absence of rolling so that the markers land solidly on one face, while their high density drives rapid descent. Consequently, they attain an accurate dropoff trajectory, letting them settle in the correct half of the collection bin at the competition.

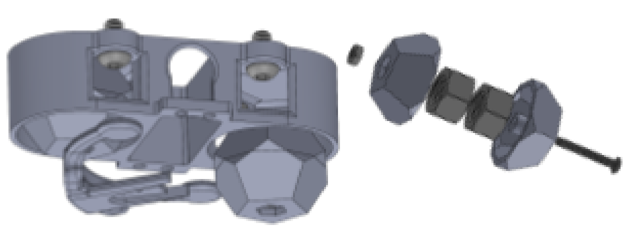

Fig. 5: Marker dropper releasing one of its weighted markers, which comprise two half-shells.

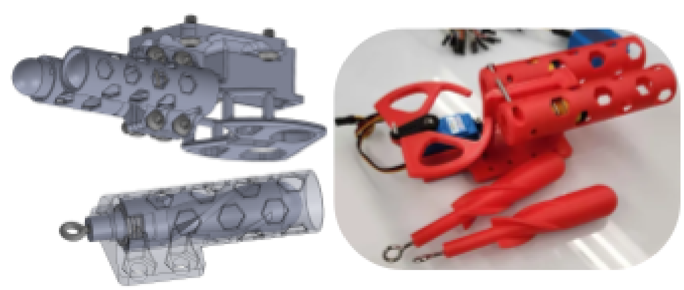

Fig 6: Work-in-progress dual torpedo launcher design and initial prototype.

Meanwhile, the torpedo launcher uses its own servo horn attachment to hook into eye-bolts that are screwed into spring-loaded torpedoes. As the servo rotates, one torpedo or the other is unhooked, decompressing its spring and rapidly accelerating its launchpad. We decided against further development for this year's competition, as we lacked time to work around this design's dependence on force transfer between strong springs and brittle PLA filament, but next year we will continue exploring this and other design alternatives.

IV. Testing Strategy

A. SLAM & Computer Vision

One of the primary goals of the SLAM and computer vision systems is testing the software effectively. For this, we simulate DVL data on the robot so we can test the SLAM software on land. This allows us to make easier modifications and work more closely with the robot. Using a competition object database that we compiled, we were able to make and train a model that was shown to recognize objects both on land and underwater. While we are still in the refining phase, we have been able to get basic computer vision available on the robot and for use in competition.

B. Controls & Thrusters

The majority of our control testing involved verifying that our thrusters correctly respond to teleoperated inputs. In order to facilitate this, we upgraded our control system to produce unified readouts of our thruster inputs, enabling us to directly perform integration tests of our control system entirely in software. This allowed for us to isolate software problems separately from problems in our electrical and mechanical subsystems. We were also able to unit-test our thruster-control pipeline in order to isolate low-level control problems from bugs in our navigation and state-machine systems. By conducting these tests entirely in software, we were also able to perform more dry-tests of the system, reducing setup and cleanup time, and allowing for more rapid iteration.

C. Electrical

The electrical team's efforts have been primarily focused on the new Crush subsystems. In order to ensure that the new PCBs are reliable, we've tested several of the proposed subcircuits by setting up circuit simulations in software such as SPICE and, in some cases, by building design prototypes and testing them with electrical monitoring tools. These include the designs for our software-controlled kill switch and I2C level-shifter, which were both verified to produce the correct digital outputs in response to our provided inputs. Additionally, we tested a number of proposed signal amplification/processing circuits for our hydrophone control board by using one of our hydrophones as a signal source and viewing the output on an oscilloscope.

We also conducted testing in conjunction with the hardware team in order to produce a proof-of-concept control setup for the new torpedo subsystem. This involved creating a basic manual-servo-control setup which allowed us to manually perform servo adjustments using push-button inputs. This allowed us to verify that the electrical subsystem could provide adequate control of the hardware prototype and gave us the opportunity to perform dry-tests of the prototype and configure system setpoints.

D. Hardware

We've begun testing the marker dropper in air, actuating the servo via microcontroller while unloaded and then with the markers loaded, narrowing down its optimal range of rotation and identifying and implementing fundamental design changes. In the future, we will repeat this testing underwater in Harvey Mudd College's tank room, until obtaining repeatability between trials, such that every time the markers are dropped from 3 ft above, they land within a 8"x8" square when dropped at zero velocity, or a 12"x12" square when Alfie is at full forward thrust. Additionally, we will address any potential hull compromises in Alfie's electronics enclosure by removing its electrical components and submerging it for 24 hours to detect and seal (via marine epoxy layups on either side of) any leaks.

E. Overall System

Finally, after full assembly and integration, we will ensure that all hardware functions underwater while the code runs directly from a fully waterproof Alfie, in response to manual inputs at first, and then autonomously in response to environmental stimuli. Afterwards, control testing will be done by having the robot track a predefined trajectory. Finally, we will test the state machine, as it relies on all other subsystems to varying degrees. However, it is possible to forego some of the more complex algorithms for the purposes of testing this overhead system. For example, the robot could just be commanded to follow a straight line until it reaches the destination for the next task rather than relying on sensor measurements. To test the state machine, the team will have the robot follow through the whole state machine and record data on the robot about sensor and state information to compare with the anticipated progression.

Acknowledgements

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