Technical Design Report (TDR)

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I. ABSTRACT

This document encapsulates the design strategy and engineering decisions underpinning the development of McGill Robotics' autonomous underwater vehicle (AUV) for the RoboSub competition. Leveraging our novice status, we strategically focused on mastering fundamental, movement-based tasks before transitioning to more complex challenges. Our competition strategy dictated an innovative system architecture, fostering the development of versatile mechanical, electrical, and software subsystems. Trade-off studies informed our design decisions, resulting in an optimized AUV chassis and streamlined electrical system. This approach translated to a modular and efficient AUV that is primed for navigating through the competition tasks. Our testing regimen ensures the reliability and robustness of the system, paving the way for competitive performance in underwater robotics.

II. ACKNOWLEDGEMENTS

We would like to take this opportunity to express our sincere gratitude and appreciation to all the project team members, sponsors, and partners who have contributed their time, expertise, and support throughout the duration of this project. Their unwavering commitment and dedication have been instrumental in our success as a team, and we are truly grateful for the collective effort that has gone into making this project a reality.

To our project team members, your hard work, collaboration, and relentless pursuit of excellence has been key in this process. Each of you has brought unique skills and perspectives to the table, and your collective efforts have ensured the smooth execution of every task and milestone. Your tireless efforts, enthusiasm, and professionalism have been the driving force behind our accomplishments.

To our sponsors and partners, we want to express our deep appreciation for your belief in our project and your generous support. Your financial contributions, in-part contributions, guidance, and mentorship have not only provided the resources necessary to bring this project to fruition but have also served as a source of motivation and encouragement for our team. Your unwavering faith in our vision has been invaluable, and we are truly grateful for your partnership.

It is truly an honor to have had the privilege of working alongside such a talented and dedicated group of individuals. This project would not have been possible without such collective contributions.

III. REFERENCES

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IV. TECHNICAL CONTENT

Our competition goals drive our system design and testing approach. We optimized the AUV's underwater movement with a symmetrical frame and ballasting. The software design features an adaptable planner package, efficient vision processing, and precision-oriented propulsion for accurate recognition, navigation, and interaction. Trade-off studies led to a modular chassis design, simplified electrical system, and component/unit testing to examine specific changes. Integration testing connects mechanical and electrical components to the AUV, while software components undergo ”gazebo” simulation testing. Simulation testing with realistic behavior is used for debugging. In-water testing in the McGill pool allows for real-world evaluation and refinement. Our strategic thinking, design choices, and engineering decisions aim for an efficient, adaptable AUV that meets competition goals.

V. COMPETITION GOALS

Before this year, not a single member of our team had developed an autonomous robot, let alone an underwater one. Instead of seeing this as a major roadblock to achieving success at this year's RoboSub and beyond, we embraced our youthfulness and lack of experience as an asset.

To use a nautical analogy, we were akin to novice sailors handed the helm of a vessel destined for unfamiliar waters. A veteran sailor may navigate the sea using well-known routes, locked into time-honored practices, comfortable in the predictable rhythm of familiar tides. But as newcomers to the field, we had no such navigational bias.

Our journey was not dictated by the courses of past voyages. We had the freedom to craft our own maps, to trace new routes shaped by the winds of innovation and curiosity. This daring approach, while initially daunting, allowed us to make bold decisions, to fearlessly pursue unproven paths.

By channeling our inexperience into a compass for exploration, we charted a course towards fresh solutions and designs. This fresh perspective allowed us to approach our journey strategically. Instead of attempting to conquer every possible challenge, we decided to start small. We resolved to focus on tasks that were purely movement-based, such as the ”Destinaton” (Gate) Task, the ”Start Dialing” (Buoy) Task, and the ”Path”. These tasks were akin to our navigational stars, guiding us through the vastness of our endeavor.

With this strategy in place, we transitioned away from the unknown waters and into the depths of our project. We saw the value in developing sub-systems that were not only manageable but also foundational to all autonomous capabilities of our AUV. The technologies required for these tasks would not only allow us to meet our current objectives but also serve as building blocks for more complex challenges such as the ”Goa'uld Attack” and ”DHD” Tasks.

Our reason for this approach was twofold. First, we recognized the importance of not overloading our team with the creation of numerous complex subsystems at once. And second, we understood that mastery over these foundational, movement-based tasks would lay the groundwork for our future success in the competition and beyond.

The design choices, both mechanical and software, were honed precisely for these tasks. The symmetrical frame and optimized ballasting of our AUV streamline its underwater movement, a critical aspect for all these tasks. With its adaptable planner package, efficient vision processing, and precision-oriented propulsion system, the software design equips our AUV to accurately recognize, navigate, and interact with competition elements. With the goal of minimizing complexity and maximizing utility in mind, we conducted trade-off studies similar to those conducted in the aviation industry [2] on our AUV's chassis design. When comparing the previous single-form chassis design to our modular design we found a 45% decrease in components and more surface area for mounting additional features such as buoyancy blocks, weights, sensors, etc. The striking results of this analysis gave us confidence in our decision to pivot to a brand-new chassis.

Our electrical system's efficiency and adaptability are pivotal in achieving our objectives. The remodeled power board deftly governs power distribution, boasting an advanced kill-switch mechanism and low battery detection, while concurrently simplifying internal wiring to enhance safety and functionality. Again, in addition to the robustness and safety improvements of the power board, the selection for a singular board design was backed by a trade-off study between the complexity of the electrical system, using a nonentropic graph-based system analysis [3]. Compared to Clark's previous multi-board design, we reduced the overall complexity of the system. The sensor board is in perfect harmony with various sensors and the control system, guaranteeing rapid data collection and transmission essential for tasks like symbol identification in the Gate or Buoy Task. This seamless integration fosters real-time monitoring and decisive action.

VI. DESIGN STRATEGY

A. *Mechanical Design*

This year, we have modified our robot's chassis for better functionality and accessibility. With the new chassis, we have a more symmetrical and easy-to-ballast frame. We use blocks of 1 cubic inch stainless steel cubes with T-slotted framing structure to improve balance and the center of gravity. This allows great flexibility in our design, giving us the ability to easily mount elements such as our vision system and DVL. The propellers have been strategically positioned to simplify the matrix calculations and optimize controlled movement. The main hull is made of acrylic tubing and is sealed with latches. We also completely reworked the interior organization of the hull with a new sled mechanism for attaching our PCBs and electronics. The result was a more egonomic layout that allowed us easier access to the devices housed within the hull.

The killswitch was designed with a friction mechanism for easy insertion and removal. Its operation relies on the friction between the pulling component and the encapsulation component. We have explored several modifications, including mechanical and magnetic mechanisms. However, the initial mechanical approach proved overly complex given our current manufacturing capabilities, and the magnetic option interfered with the killswitch's read switch, an electrical component activated by magnets. To address these challenges, we sought a clean and efficient solution. We devised a method where friction is utilized to secure the killswitch. If the killswitch is no longer needed, it can be simply pulled out, as the friction is light enough for easy removal yet strong enough to hold it in place.

B. *Software Design*

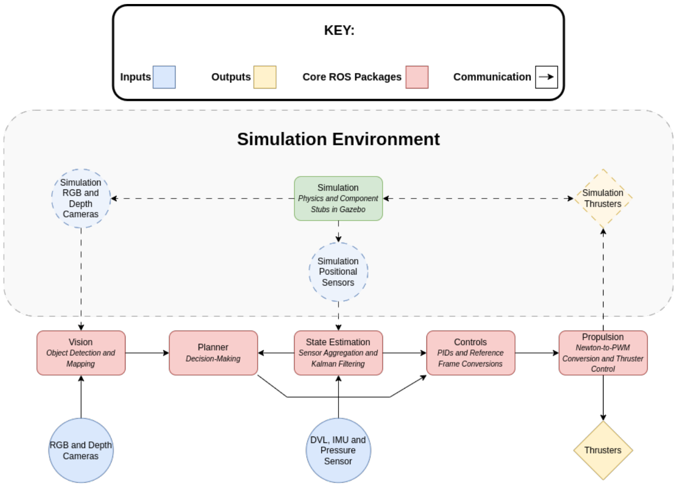

Fig. 1.

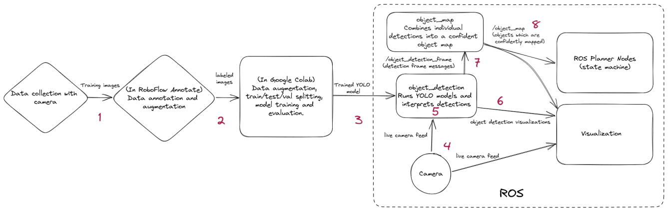

Fig. 2.

1) Planner: The planner package is responsible for making high-level decisions that the AUV executes depending on its current 'operational state'. It is structured as a state machine, which transitions between different behaviors (sub-states), depending on its current knowledge of the environment. These sub-states are also themselves state machines, which can be responsible for more complex tasks such as the gate, buoy, and octagon, or simpler behaviors like object search, lane marker navigation, etc. These missions interface with the controller through a simplified top-level interface that is then interpreted into PID setpoints and thruster efforts.

The vision package includes the machine learning training pipeline to augment image datasets, train YOLOv8 object detection models, and prevent overfitting. The vision package is also responsible for interfacing with our downwards and stereo camera setups into the appropriate ROS topics, as well as handling computer vision challenges specific to tasks in the RoboSub competition. These challenges include measuring the headings of lane markers, estimating the orientation and position of detected objects, and combining frame-by-frame detections into a best-guess map of all objects the AUV has encountered.

2) State Estimation: To understand the pose of the AUV at every point in time, the state estimation package interfaces with different sensors (DVL, IMU, and pressure sensor) to provide real-time information on position and orientation through ROS topics. We eliminate noise and potential drifting of the measurements using a Kalman filter and fuse redundant sensor readings together so as to provide the pose of the AUV with the highest possible accuracy.

3) Propulsion: The propulsion package is responsible for assigning the effort for each thruster resulting in the desired movement and converting the effort calculated to PWM (pulse width modulation). The assignment is calculated based on our thruster mapper matrix defined by the pose of our thrusters. The values for the conversion formula are specified by the provider of the thrusters as a curve. Thus, in order to convert the effort, we calculated a polynomial that fits the curve well.

4) Simulation: The simulation is based on Ignition Gazebo and uses SDF files to create objects and worlds. For the integration between ROS and Gazebo, we use the ROS package ”ros_ign_bridge.” Instead of having simple geometric shapes provided by SDF, we designed the simulation objects in Blender to better represent our real models.
As shown in Figure 1, the sim is connected to the other ROS packages through Vision, State Estimation, and Propulsion. The connection messages are sent by the sensors in the sim. Based on our robot, we added an IMU, front and down RGB cameras, a front depth camera, and a DVL.

C. Electrical Design

1) Electrical Architecture: With the implementation of the new power and sensor boards, the electrical architecture is clearer and streamlined. The power board provides battery and system protection while distributing power to the Jetson, sensor board, and thrusters. The power board MCU and Jetson communicate over a ROSserial bus. Sensors with integrated serial USB buses, such as the DVL or IMU, are connected directly to the Jetson. Other sensors interface with the sensor board, which communicates their data to the Jetson over a ROSserial bus.

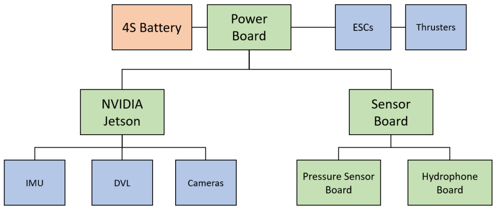

Fig. 3.

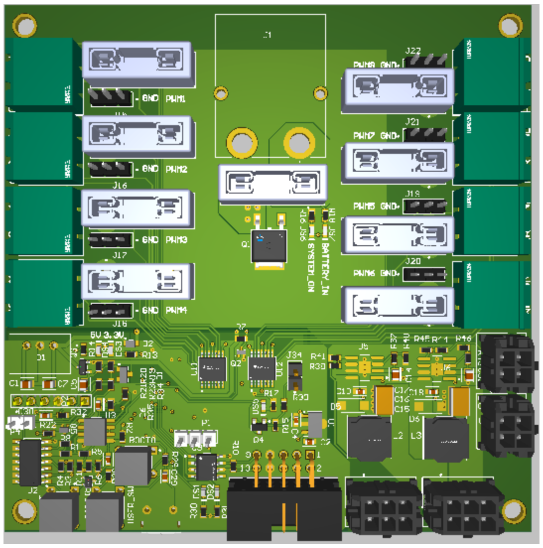

Fig. 4.

2) Power Board: The need for a new power board was apparent as our previous design was error-prone. The old kill-switch board uses a reed switch that allows power to flow when in contact with a magnet. This magnet is accessible outside the hull and stops power from flowing when it is moved away from the reed switch. The idea behind this design is that all thrusters can be shut down immediately in the water in case of emergency. This simple kill-switch mechanism needed redesigning to implement more safety features and centralize other functions. This year, a new power-board design has been designed. This board still implements the old kill-switch mechanism but also includes the ability to kill power from a Jetson signal, low battery voltage detection, fuses, thruster power distribution, and propulsion signal routing. The board also features voltage regulators that output 5V and 3.3V. The board includes connectors to supply our Jetson and other boards with power. This new design simplifies the wiring inside of the hull and also provides more protection than the previous implementation.

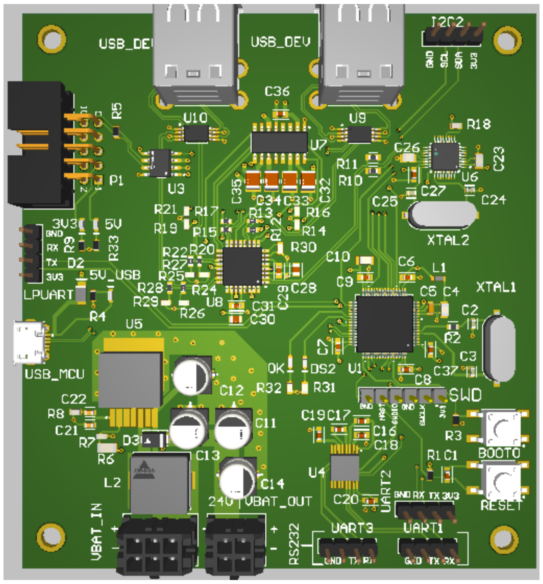

Fig. 5.

3) Sensor Board: The sensor board serves as a crucial interface between the robot's various sensors and the control system. With the capability to communicate using different communication protocols such as I2C and UART, this board seamlessly integrates with a diverse range of sensors, including the depth sensor. It ensures efficient data collection, processing, and delivery to the Jetson through a single ROSserial bus. It also includes the ability to implement a CAN bus. The sensor board excels in transmitting all the gathered sensor data to the control system, enabling real-time monitoring and decision-making. Its versatility makes it an essential component in enhancing the autonomy and performance of our AUV.

VII. TESTING STRATEGY

The testing strategy is tailored to suit the various sub-teams, as different tools prove more effective for specific components. However, the overall strategy can be divided into three main stages:

A. Component/Unit Testing

After implementing a new feature or addressing an existing bug, the initial testing phase involves a thorough examination of the specific change in isolation, without connecting it to the rest of the system. This testing process scrutinizes the change by applying a predefined set of inputs and meticulously observing the corresponding outputs.

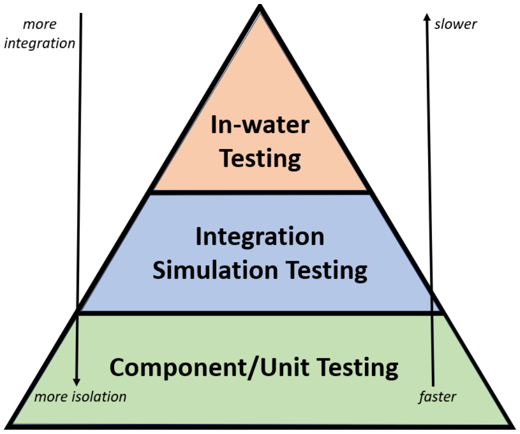

Fig. 6.

B. Integration Testing

The subsequent stage focuses on assessing the interaction between the component and the system as a whole. For mechanical and electrical components, this involves physically connecting them to the Autonomous Underwater Vehicle (AUV) and conducting dry-tests based on the AUV's specifications. Software components, on the other hand, undergo testing within the "gazebo" simulation environment before being dry-tested as well. The AUV dry-testing takes place with the AUV connected to an external power supply.

C. Simulation Testing

As a debugging tool, we test changes to the software on the simulation. Using the Ode physics engine and Hydrodynamics plugin, we are able to realistically simulate the robot's behaviour based on Fossen, 2011 [3]. For the Hydrodynamics plugin, we had to calculate the added mass and stability derivative parameters. Since our models have complex geometrical shapes, we used MeshLab to calculate those values. Then, we test our program until the robot's behaviour corresponds to our expectations and seems transferable to the pool.

D. *In-Water Testing*

Once the components under test are deemed ready for the final stage, they undergo in-water testing. The AUV is transported to the McGill pool, where the components are observed in action, and any necessary adjustments or modifications are made based on the observed performance. This testing phase allows for real-world evaluation and refinement of the components' functionality.

VIII. APPENDICES

A. *Appendix A: Component List*

Component	**Vendor**	**Mod**
ASV Hull Form/Platform	Blue Robotics	Wate
Waterproof Connectors	TE Connectivity	SEA
Propulsion	Blue Robotics	T20
Power System	Blue Robotics	Lith
Motor Controls	Blue Robotics	T20
CPU	NVIDIA	Jets
Teleoperation	PlayStation	PS2
Compass	N/A	N/A
Intertial Measurement Unit (IMU)	SBG Systems	Elip
Doppler Velocity Logger (DVL)	WaterLinked	A50
Camera(s)	Intel	Real
Hydrophones	N/A	N/A
Algorithms	N/A	N/A
Vision	Ultralytics	YOL
Localization and Mapping	Open Robotics	ROS
Autonomy	N/A	N/A
Open-Source Software	Open Robotics	Noe