Marine and Naval Technological Advancements for Robotic AutonomY (MANTA RAY)

KRILL

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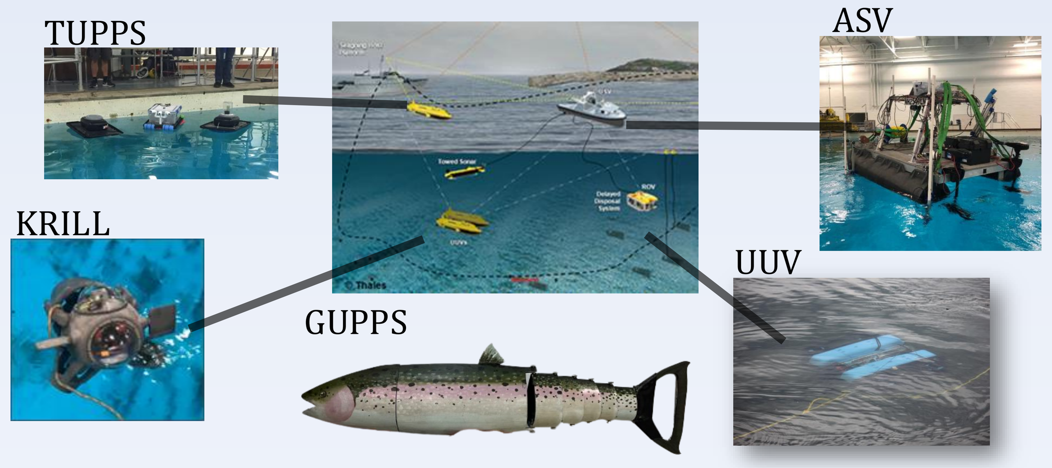
MANTA RAY Mission

Team MANTA RAY is an interdisciplinary project dedicated to creating, maintaining, and expanding a network of marine robots for seafloor mapping and underwater perception. The network began as just the Autonomous Surface Vehicle (ASV) and Uncrewed Underwater Vehicle (UUV) but has expanded to include a prototype of the ASV, named TUPPS (Test Uncrewed Performance Platform), and two kinds of remotely operated vehicles, the Ghost Unpiloted Performance Platform Submersible (GUPPS) and KRILL, in addition to the Safe Whale Tagging (SWaG) device designed for safe and non-invasive whale tracking/observation. With these systems, students work to develop improve communication between vehicles, develop autonomous behaviors and algorithms, and upgrade existing mechanical systems to improve precision and performance.



KRILL Mission and Goals

KRILL is an Uncrewed Underwater Vehicle (UUV) developed initially by the Naval Undersea Warfare Center (NUWC), Keyport WA. The purpose of KRILL is to be a modular observation class UUV which can be outfitted easily to new technologies. This UUV can be easily modified for a range of missions for the Navy from its design and magnetic connections. Our Goals for the KRILL team included three main objectives of creating a buoyancy control device, a thermal management system, and testing (for validation and organization).

Past Achievements

KRILL teams in the past have had the main goal of movement and achieving so with records of running at over one meter per second at a depth of 10 feet. Also, a Finite Element Analysis (FEA) on the hull to determine points of stress and the recommended maximum depth of the unit based off its material. Additionally, a new KRILL hull was designed for organization of the internals but due to its size it cannot be printed.

Software Implementation

KRILL uses a Raspberry PI 4 running Ubuntu 22.04 and uses ROS2 Humble for motor control.

There are two motor control schemes: direct & twist/dynamic (pick a direction, KRILL decides the motors).

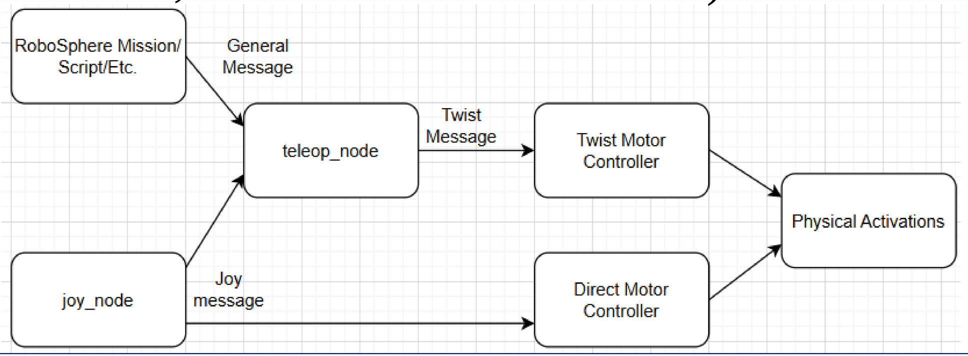


Fig 1: Krill software diagram

KRILL Internals

The internals of KRILL needed a rework due to limited space. The team spent time updating the internals with new Electronic Speed Controllers (ESC) along with fixing and rewiring all internal wires. A technical wiring diagram was also developed via KiCad to assist new and current users in setting up KRILL. The internal ballast was adjusted after buoyancy tests and sealed to prevent spillage. Replacement parts such as a rear motor bearing, side propeller housings and new propellers were also manufactured, replacing aging components. Overall, these tasks were designed to optimize the very little space inside of the KRILL hull for the best efficiency, performance and organization.

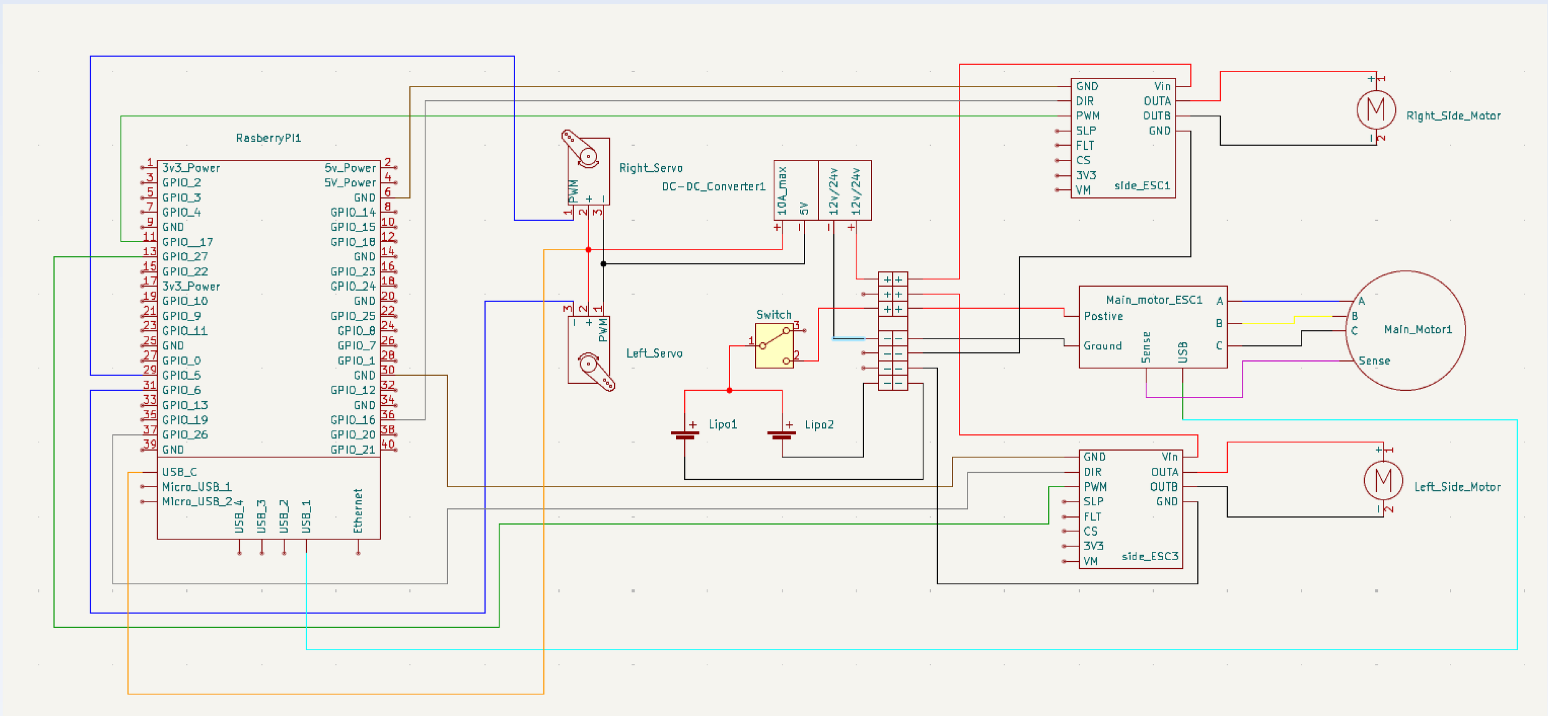


Fig 2:. KRILL Internal Wiring Diagram

Thermal Management

At the beginning of the academic year, KRILL had an issue with overheating of its internal components during normal usage and testing. After analyzing the unit, it was found that there was a high amount of friction between the bearings of the rear motor and the backside of the hull leading to some of the additional heat observed. KRILL's internal electronics were also outputting heat due to the lack of air movement within the hull. To remedy these two main issues, the team had devised a plan to construct a Printed Circuit Board (PCB) that is attached to two small fans and a thermistor, with the ability to read the temperature inside of KRILL. Once the air temperature exceeds 22°C the fans will turn on a push the air to the heat sink inside of KRILL, cooling the internals of the hull. Additionally, the team installed an upgraded Electronic Speed Controller (ESC) giving KRILL a thermal monitoring ability for the rear motor. To conclude the thermal analysis of KRILL, Infrared (IR) thermal images of KRILL were taken using a MLX90640 Camera driven by a Teensy 4.0 microcontroller. Images were taken before and after KRILL operations to depict observed temperature changes. These results can be seen in Figures 3-6.

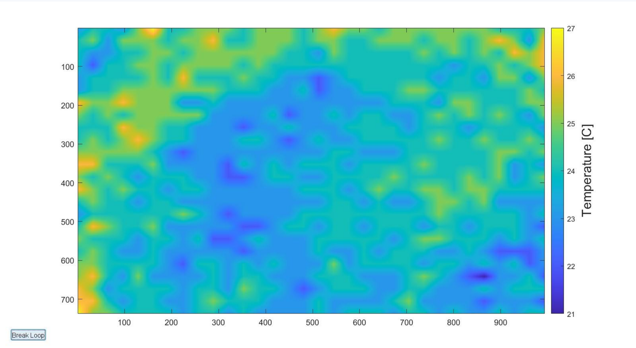


Fig 3. KRILL Without Top Plate Before Operation

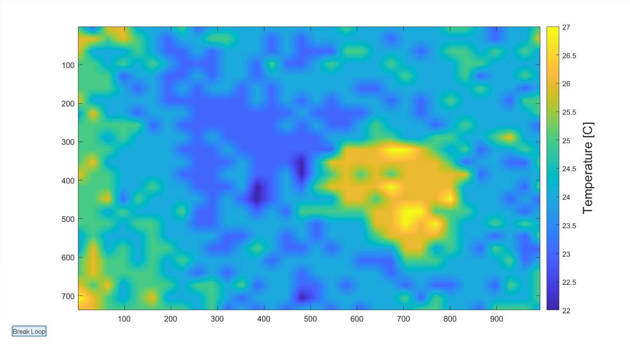


Fig 5. KRILL in Water During Operation

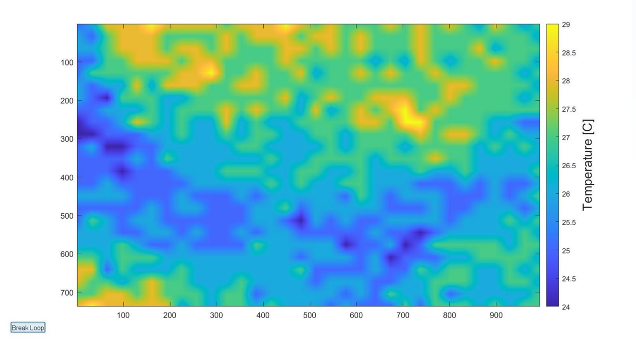


Fig 4. KRILL With Top Plate Before Operation

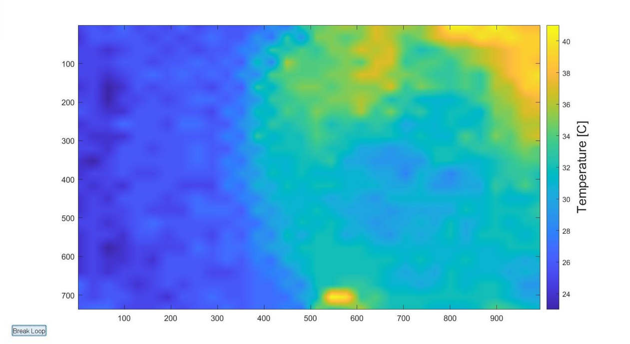


Fig 6. KRILL Without Top Plate After Operation

Fig 7. Forced Convection PCB design

Buoyancy Control Device

A Buoyancy Control Device (BCD) was developed to address KRILL's buoyancy and ballasting issues in the water column. Keeping with modular theme of KRILL, the BCD mounts onto of the top plate with a twist lock mechanism Figure 2. The BCD is a 3D rigid bladder that has valves to fill the tank with water, allowing KRILL to dive. For ascent, a compressed air valve is used to evacuate water from the BCD, filling the tank with air The BCD is controlled with 2 electronic solenoids; one controlling the compressed air input and the other being used to vent the tank.

Aside from hardware development, BCD performance was modeled using the MathWorks software Simscape. Using this model, pressure differences and mass flow readings were simulated for different points throughout the BCD. After initially creating a small-scale system with one valve and a step input, the system was remodeled to a two valve, then a three-valve step input system. After the step inputs were substituted for ramp inputs so the rate at which the valves opening could be dictated and measured throughout the system. By doing this, compliant pipe sizes can be determined along with the needed compressed air for the system, and the necessary rate at which air and water can flow in the system to achieve the desired buoyancy.

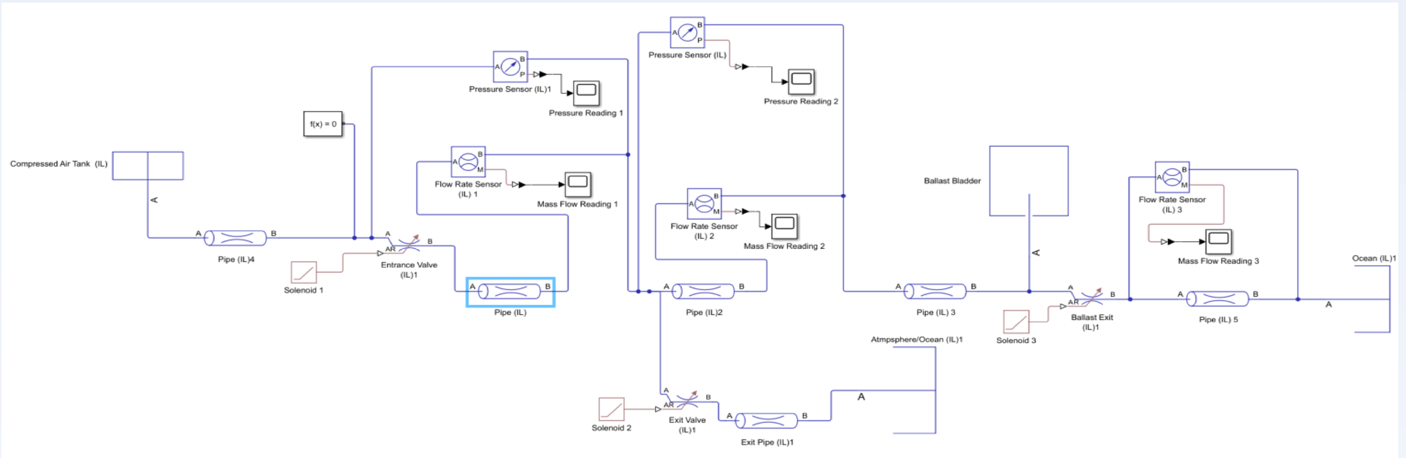


Fig 8: Simscape Model of the Buoyancy Control Device

Fig 9: Buoyancy Control Device Mounted on KRILL

Testing

This year has marked a major milestone with KRILL as it is the first year that the team has conducted open ocean testing as seen in Figure 8. The team was able to discover that KRILL is not as buoyant in seawater as initially thought. Testing in Chase faculties showed improvement with the new code, allowing real time adjustments to be made. Also, KRILL responded well with the incorporation of progressive motor control. KRILL's BCD also works as intended; recent tests show an increase in sink/surface time. Running simulations of the BCD in the Simscape program, the tests resulted in a mass flow rate of 0.11 kg/s of working fluid and a pressure difference of 12 psi. With all ramp rates being slightly different and starting at different times to clearly depict which stage of the process KRILL is under (submerging or surfacing).

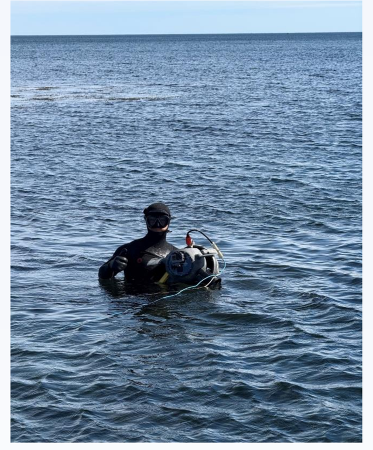


Fig 10. KRILL's First Ocean Water Test

Fig 11. KRILL in Chase Facilities

Fig 12. Point of View Image from KRILL Ocean Test

Future Work

- KRILL 2 & KRILL 3: The team will be acquiring two new KRILL hulls in the future, and with this years' team buying materials for a second operational KRILL, there can be objective built KRILLs for future years.
- Wireless Operation: KRILL can be 100% remotely operated and not connected to any external source to promote better autonomy for KRILL in the future.
- Better Heat Sink: By changing the material of the front plate in KRILL, it can promote better hear management and allow for a lower operating temperature inside of the hull of KRILL.

Acknowledgements

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