Technical Design Report

I. Abstract

This document outlines the steps taken by the Robocats at Montana State University to develop an existing Autonomous Underwater Vehicle (AUV), Typhoon 2, for the 2023 RoboSub Competition. This included changes to the electrical/mechanical systems, as well as software reworks and the development of a hydrophone system. Experimentation and testing procedures for these changes/developments were also recorded.

II. Competition Goals

Over the course of the year, the focus has been on the restructuring of the internal systems within the AUV. This included the physical restructuring of the electrical system, the passthroughs used to prevent leaking, and a complete software rework. Along with these improvements, a new hydrophone system was implemented into the AUV. With these systems, our competition goal was surmised into 4 tasks - the coin flip, gate, buoys, and the octagon.

2.1. Task 1 (Coin Flip)

The first task to be undertaken is the coin flip. The AUV will need to be able to rotate from varied starting positions while searching for the gate, then proceed to approach it after locating it. The capability to turn and move were implemented into previous iterations of the AUV, meaning that the main developmental focus for this task was for vision processing to identify the gate.

2.2. Task 2 (Gate)

Task 2 is to pass through the gate. This is a vital task, as it is required for qualification. Further investment into vision recognition is required, as to identify which side the AUV will pass through. The “Earth” side will be attempted, as the shapes associated with that destination might be easier for the vision system to identify. Style points will be attempted, as 2 full rotations (720$_{\circ}$) of yaw will be attempted within the gate. These subtasks require similar capabilities to Task 1.

2.3. Task 3 (Buoys)

The third task to be undertaken by the AUV is contacting the buoys. In order to complete this task, vision recognition will be required to identify the correct buoy location based on the side of the gate passed through in the previous task - previously, this was decided to be the “Earth” destination. When the selected buoy has been found, the AUV will approach and displace the buoy.

2.4. Task 4 (Octagon)

Following the buoy, the hydrophone system will be utilized to pick up the sound from the pingers at the center of the octagon. Using this signal, the AUV will then approach the octagon and surface within it, ending the run.

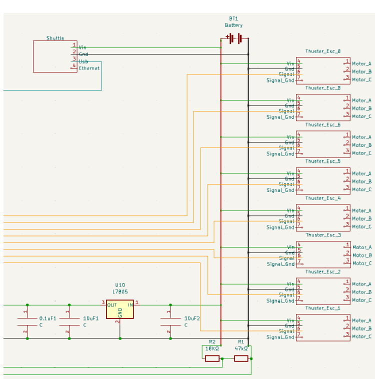
III. Design Strategy

For this season, the main focus for design was to develop a more complete and professional version of the previous design. For most cases, the improvement of existing systems was the main focus. Other systems, however, were developed within the season, requiring an ideate-prototype-test design process to develop them.

3.1. Electrical Rack

In previous seasons, numerous issues occurred with the unorganized electrical system. A portion of this year was therefore dedicated to developing a more compacted, integrated design to take up less space, leaving more for other subsystems.

The new system consisted of a custom Printed Circuit Board (PCB), with integration of power and signal distribution. On the system, board-mounted ESCs were included using 3D-printed parts. Also, a Teensy 4.1 was used in place of the previous Arduino Mega to control the thrusters. The electrical schematics were developed in KiCAD, and a part of the schematic was recorded in Figure 3.1.1.



3.1.1 Electrical schematic of the ESCs for the Electrical PCB.

This redesign reduced space used by the electrical system, freeing more up for other subsystems within the waterproof compartment. An image of the new integrated system was displayed in Figure 3.1.2.

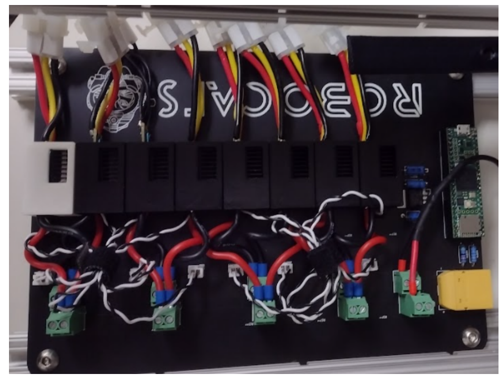


Figure 3.1.2. Electrical board mounted on the AUV.

Lastly, a rewiring of the internal part of the AUV allowed for easier repairs and further development.

3.2. Passthrough Integration

At RoboSub 2022, the competition for the RoboCats ended when the AUV began to leak. Multiple attempts were made to save the AUV, but nothing tried was able to stop the leak. After the competition, the leak was attributed to a wire passthrough that had not been properly waterproofed. Due to this, another portion of the year was dedicated to replacing all of the wire passthroughs to ensure that they were easily replaceable and sufficiently watertight for the entire competition in 2023.

The passthroughs were replaced with Blue Robotics 6.5mm Low Compression WetLink Penetrators. The final result of this replacement was recorded in Figure 3.2.1.

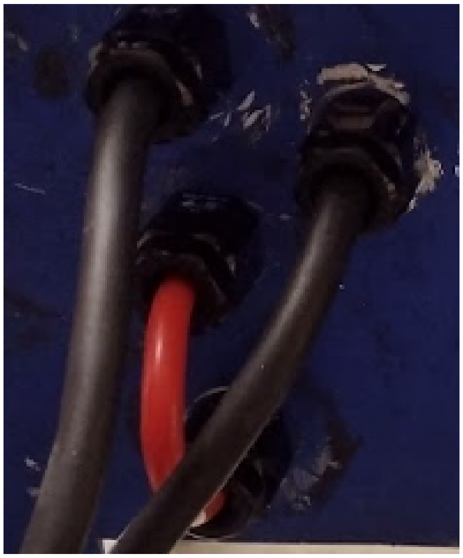


Figure 3.2.1. Some replaced WetLink Penetrators on the AUV.

3.3. Vision

For computer vision, YOLOv4 was utilized for object detection and the models were trained based on last year's trained weights. It was also refined with data gathered by videoing the course during RoboSub 2022. By building on the foundation created last year, the object detection model was able to more accurately target buoys, gates, and other course obstacles.

3.4. Hydrophones

A hydrophone system was developed by a capstone team for integration into the RoboCats AUV. Development began at the start of the Fall 2022 semester, and continued until the end of Spring 2023. The system uses a multilateration algorithm to pick up on the pinger signals in the water and determine the coordinates of the pinger relative to the AUV. The block diagram of the system was recorded in Figure 3.4.1.

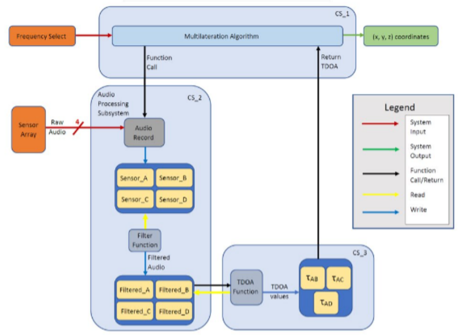


Figure 3.4.1. Block diagram of the hydrophone system.

The final hardware setup for the hydrophone system consisted of 4 Aquarian Audio Hydrophones and a Behringer U-PHORIA UMC404HD USB audio interface. The system diagram was displayed in Figure 3.4.2.

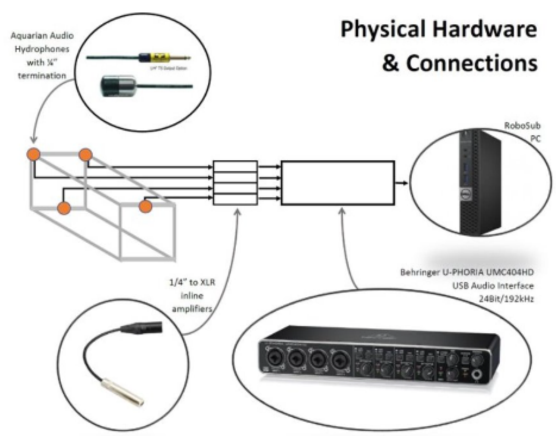


Figure 3.4.2. Hydrophone system hardware diagram.

IV. Testing/Experimentation

4.1. Electrical Testing

In order to test the functionality of the electrical system, a test program was created to send power to the thrusters. This was to ensure that the new board was capable of delivering maximum current required.

4.2. Waterproof Testing

The testing plan to test the water resistance of the AUV was 2 steps - the first step was to utilize a pump to pressurize the AUV and maintain pressure, while the second step was to test the AUV in water. In both of these cases, the AUV did not show any signs of severe leakage - a slight leak was identified in step 1, though that was attributed to pressure loss within the pump itself.

4.3. Vision

Vision testing was completed in a similar manner to training, where images of last year's targets were used to identify the success rate of the system.

4.1.4. Hydrophones

The hydrophone system went through numerous iterations of development, including testing. Each test was completed and the results were recorded and analyzed. An overview of the different testing plans and methods were recorded in Tables 4.4.1 and 4.4.2.

Table 4.4.1. Testing methods and results for the hydrophone system.

Num	Name	Test description	Results
1.1.1	Frequency Range	Set pinger for variety of frequencies from 25 KHz to 40 KHz to ensure hydrophone works in required bounds	Passed
1.1.2	Differentiation of 1 kHz gaps	Creating Matlab waveform at different frequencies between 25 to 40KHz and verifying filter can differentiate 1 KHz gaps	Passed
1.1.3	Work in course dimensions	Place pinger an increasing distance from hydrophone in the pool and verify that waveform can be detected in audio file	Passed
1.1	System must be able to detect sounds of specific frequencies	A random pinger frequency that is within competition ranges will be set and the system will attempt to detect and record it	Passed
1.2.1	Filter Selection	Set waveform in Matlab at different frequencies from 25 to 40 KHz and verifying that waveform only shows when correct frequency is filtered for	Passed
1.2.2	Frequency Setup Time	RoboSub team members will be given an overview of our solution, then will be timed when setting the desired frequency of the system	Passed
1.2	System must be able to detect specified pinger from multiple in pool	Multiple pingers will be set at different arbitrary frequencies and the system will attempt to filter and record just one of them	Passed
2.1.1	Under 2 Meter Accuracy	Artificial TDOA's mimicking perfect TDOA's for the situation will be fed into the multilateration algorithim	Passed
2.1.2	Over 2 Meter Accuracy	Artificial TDOA's mimicking perfect TDOA's for the situation will be fed into the multilateration algorithim	Passed
2.1	Pinger location must be determined within a specified radius	Array will be placed various locations in the pool both over and under 2 meters from the pinger at a specific frequency, location will be computed	Failed
2.2.1	Return Type	The multilateration algorithim will be ran with arbitrary numbers and the output will be moitored	Passed
2.2.2	Algorithm Speed	The system will be tested as a whole and the speed it completes and reports the location calculations starting from when the signal is first received by the hydrophones will be recorded	Passed
2.2	Location	The software of the system will be tested as a	Passed

Table 4.4.2. Testing methods and results for the hydrophone system, cont.

	Communication	whole and the output from the system will be monitored	
3.1.1	Array Height	When inspecting build plans for hydrophone array, calculate the height of the array	Passed
3.1.2	Array Width	When inspecting build plans for hydrophone array, calculate the width of the array	Passed
3.1.3	Array Length	When inspecting build plans for hydrophone array, calculate the height of the array	Passed
3.1.4	Array Weight	When inspecting build plans for hydrophone array, calculate the weight of the array without aluminum	Failed
3.1	Array geometry	Once hydrophone array has been constructed, verify that array fits size and weight specs.	Passed
3.2.1	Solution Adpatation	The RoboSub team will be tasked with altering the hydrophone locations and changing the code to reflect the new locations	Passed
3.2	Solution Must Function with various conforming array geometries	The hydrophones of the system must be able to be in different various placements without destroying the functionality of the system	Passed
Obj 1	System must be able to detect a pinger	Pinger of arbitrary frequency will be placed and the system will detect it	Passed
Obj 2	System must be able to determine the location of a pinger	Pinger of arbitrary frequency will be placed at an arbitrary distance from the system and the system will detect it and calculate its location in relation to the system, submarine will be moved relative to calulcted location	Failed
Obj 3	System must integrate with existing RoboSub	Entire system will be placed in the pool on frame replicating RoboSub chassis connected to computer via one usb port. Pinger location will be computed	Passed

As described in the results tables, most tests returned positive results, meaning that most test subjects behaved as expected. Specific subjects that had issues failed, including consistent accuracy as described in Figure 2.1. This meant that the hydrophones were not able to identify the location of the pingers within 2 meters in all cases, with max error being 6.1 meters.

Other errors included less integral factors to the system's functionality, but the testing that was done helped to refine the hydrophone integration to the existing AUV.

V. Acknowledgements

RoboCats at Montana State University would like to thank all of the people involved in the continued development of the project, including the capstone team involved in developing the hydrophone subsystem. Special thanks to the team's sponsors, NAVSEA and BlueRobotics, for providing necessary resources to allow these developments to continue. The contribution from these sponsors cannot be overstated. Additional thanks to Montana State University, the Norm Asbjornson College of Engineering, and the RoboCats club advisor, Dr. Bradley Whitaker, for all of the continued support.

VI. Resources

[1](2020). Retrieved 12 June 2022, from https://github.com/theAIGuysCode/tensorflow-yolov4-tflite

[2] K. Rust et al., "Robotic Autonomous Vehicle Navigation (RAVN)", MSU EELE, Bozeman, MT., United States, April 2021

[3] X. Xu et al., "RoboSub: Object Recognition and Localization", MSU EELE, Bozeman, MT., United States, April 2021

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost (If New)	Year of Purchase
Buoyancy Control						
Frame	McMasterCarr (Student Designed)	Extruded T-slot	6061 Aluminum 1"x1"	Custom		2018
Waterproof Housing	Student Designed			Custom		2018
Waterproof Connectors	Seacon	All-Wet Underwater Electrical Wet-Made Connectors	8-pin, water tight	Purchased		2018
Waterproof Connectors	Blue Robotics	WetLink Penetrators, 6.5mm	6.5mm, LC	Purchased	$100.00	2023
Thrusters	Blue Robotics	T200	390W, waterproof	Purchased		2020
Motor Control	Blue Robotics	Basic 30A ESC	30A	Purchased	$275.00	2022
High Level Control	PJRC	Teensy 4.1		Purchased	$30.00	2022
Actuators						
Propellers	Blue Robotics	Included with Thrusters		Purchased		
Battery	Blue Robotics	Lithium-Ion Battery	14.8V, 18Ah	Purchased		2018
Converter						
Regulator	DigiKey	7805 Voltage Regulator	5V Regulator	Purchased	$1.50	2022
CPU	Amazon	Intel NUC7i7BNHX1	i7 7th Gen, 16GB RAM	Purchased		2018
Internal Comm Network			12C, Serial			
External Comm Network			Ethernet (SSH)			
Compass	Included in AHRS					
Inertial Measurement Unit (IMU)	Sparton	AHRS-8	9 axis	Purchased		2020
Doppler Velocity Log (DVL)						
Vision	Microsoft	Lifecam Cinema: H5D-00013	720p, 30 fps, 5 MP	Purchased		2020
Acoustics	Sweetwater	U-PHORIA UMC404HD	24Bit, 192 kHz	Purchased	$180.00	2023
Manipulator						
Algorithms: Vision	Student Designed					
Algorithms: acoustics	Student Designed					
Algorithms: autonomy	Student Designed					
Open source software	Arduino	Arduino				
Programming Language(s)		C++, Python 3				