Technical Design Report

I. Abstract

This document details the processes undertaken by the Robocats at Montana State University to prepare for the 2022 RoboSub Competition. This vehicle was designed in prior years, meaning this year was dedicated to upgrading the existing Autonomous Underwater Vehicle (AUV) and experimenting with possibilities for future systems.

II. Competition Strategy

Within the past year, we have developed our AUV and increased the range of capabilities through the improvement of internal systems. The electrical system, specifically, was replaced to increase spatial efficiency. This allowed for more complicated systems to be included on the AUV. With these newfound capabilities, we split our goals for the competition into three main tasks - the coin flip, gate, and buoys.

2.1 Task 1 (Coin Toss)

The first task we decided to undertake is the coin toss. This requires rotational capability and vision to identify the relative position of the gate in comparison to our AUV. Also, our AUV must be able to move to approach the gate. Previous iterations of the AUV had these capabilities, and the current one is no different. All of the necessary systems are implemented on the current version of the AUV.

2.2 Task 2 (Gate)

The second task to complete is the gate. This is the most important task, as it is required for qualification. This task requires further vision recognition to identify the gate and the side that we pass through. We plan to obtain a multiplier through style points, completing a 360∘ spin about our vertical axis. This requires rotational capabilities as well, and should earn us a 4x multiplier. Lastly, we decided to pass through the bootlegger side, as the contrast of the bootlegger's gun is greater than the G-man's badge. This will help with vision recognition, and will help with Task 3.

2.3 Task 3 (Buoys)

The last task we will complete before surfacing is contacting the buoys. To complete this task, the AUV will first identify the location of the correct buoy through vision recognition. It will then proceed towards it and place the image of the Bootlegger's Gun in the lower section of its vision in order to avoid the cables below the buoy. When the location of the gun is correct, the AUV will then proceed into the buoy, displacing it visibly before rising to the surface and ending our run.

2.4 Overview

Our run will begin with the coin toss, where our AUV will then locate the gate, proceed through it. While moving through the gate on the Bootlegger's side, the AUV will complete a 360° spin about its vertical axis, earning a 4x multiplier. It will then proceed to the buoys and slightly displace the Bootlegger's buoy, before rising to the surface and completing the run. This process requires 4 dimensions of motion - three translational dimensions and one rotational dimension. Also, each task we have to complete requires vision processing and analysis in order to identify the path our AUV must take. Logically, pathing and vision were the main focuses of our team throughout the past year. Other experimentation with new concepts and further capabilities of the AUV were explored alongside its current developments.

III. Design Creativity

As has been done in previous seasons, special attention was given to the design process. Implementing an ideate-prototype-test design process allowed for extensive creativity while still upholding rigorous design standards set forth by the team. The prototype-test iteration allowed for this flexibility in design, encouraging a more complete development of ideas as well as analysis of their performance, satisfaction of requirements, and design complexity. The results of applying this process were novel and creative solutions for our many components and subsystems.

3.1 Electrical Rack

Towards the end of the 2020-2021 season, we realized that our AUV's ever-evolving electronics system warranted a redesign of the electrical rack. The existing solution consisted of a triangular frame with solid faces which offered mounting points for electrical components. Though this served the early needs of the AUV's more primitive electrical systems, the addition of new electrical systems highlighted the shortcomings of this design; poor expandability and inefficient use of space. To address both of these issues, we moved from a close-faced triangular truss to an open rectangular prism which better utilized the space offered in our watertight electronics chamber. Constructed from 1” x 1” 80/20 aluminum extrusion, this new frame is both lighter and more expansive. Additionally, machined channels along the four length-wise extrusions allow for non-conductive plexiglass plates to easily be slotted into the frame, as pictured in figure 3.1.1 below.

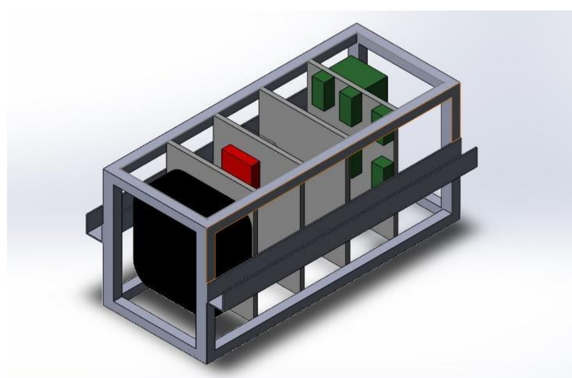

Figure 3.1.1: New electrical rack design

These plates can be tailored to fit the mounting needs of specific electronics, while still ensuring effortless attachment to the AUV.

3.1.2 IMU

An imperative part of the Typhoon 2 is its Inertial Measurement Unit or IMU. The IMU chosen was the Sparton AHRS-8. The AHRS-8 was chosen for its wide range of uses such as its highly accurate gyroscope, accelerometer, magnetometer and thermometer. All this in a small module with low power consumption. These allow the robot to be able to be certain of its position and allow better flexibility in maneuverability.

3.2 Computer Vision

In order to properly navigate the competition environment and accomplish tasks, the AUV needed computer vision subsystems for object recognition and localization.

3.2.1 Object Recognition (OILT)

Our team often includes specific project sub-teams, such as for senior design projects. In the design of our vision system, we had two of these. The object recognition and classification system was designed by team OILT, while the implementation system was designed by team RAVN. This need to accommodate independent contributing parties helped lead to our decision to utilize a modular design. The agreed upon intersection of these subsystems is a shared CSV formatted file. In order to establish our object recognition system, we expanded upon a pre-trained YOLO (You Only Look Once) neural network [1]. From there, we labeled competition specific datasets to enable training the neural network for tasks the sub is expected to undertake. During runtime, we chose to have our algorithm output centroids, bounding boxes, and object types into the shared CSV file.

3.2.2 Vision Implementation (RAVN)

On the implementation side of the computer vision, RAVN's algorithm takes these details as input and generates an approach response from the motor controllers. For example, if an object is identified as a buoy with a Tommy Gun image, we will want to adjust the sub's position such that the object is centered on the bottom half of our view.

3.3 Torpedo System

The design of a torpedo system was implemented to expand the capabilities of the RoboCats team and future AUVs. For this group, this was new territory that we wanted to understand, so we developed multiple possible designs for the system.

3.3.1 Spring-Based Torpedo System

The first possible design identified was the spring-based system. This idea utilizes a spring to launch the torpedo. The spring is an active system, meaning that we would need to utilize an activation system to prevent premature discharge of the torpedo. This was seen as a somewhat negative aspect of the design, as the actuator would need to be placed in an area currently submerged. This could be avoided, however, through the use of resettable mechanical systems to launch torpedoes. Due to limited manpower, a prototype for the spring-based torpedo system has not been developed, though we plan to create one within the next year.

3.3.2 Pneumatic-Based Torpedo System

The next design proposed for the torpedo system was a pneumatic system. This design would utilize pneumatic solenoids to fire, and use compressed air to discharge torpedoes. This system is the opposite of the spring system, as the launcher is now the activation system while the restraints are the active system. We developed a proof of concept for the pneumatic launcher over the year, and will develop it further to hopefully implement it next year.

IV. Experimental Results

4.1 Torpedo System Experimental Results

Through testing, we were able to find that about 100 psi should be able to launch the torpedoes while using 1/4 inch tubing. Using this information, we developed a proof of concept using 1/4 inch tubing and pneumatic solenoids. This proof of concept was found to not work to launch torpedoes. This was due to flow restrictions within the solenoid, which prevented the full pressure from the pressurized canister from being transferred to the torpedo. Further research and experimentation are being done to reevaluate the size of solenoids needed to complete the task.

4.2 Vision System Experimental Results

Given the critical importance of the computer vision sub-system to our AUV’s autonomy, a great deal of time and effort was devoted to adequately testing this component. These tests targeted both the recognition and classification system (OILT) as well as the corresponding implementation system (RAVN).

4.2.1 Object Recognition (OILT) [2]

To assess the performance of our recognition and classification system, we allocated 20% of our classification dataset for training purposes. Due to difficulty with in-water testing as a result of COVID restrictions, a portion of this data was sourced from other RoboSub teams through the RobotNation data sharing program. That being said, these data were collected in a manner such that they closely replicate the expected operating conditions during the competition. After collecting and wrangling our testing dataset, we established a set of parameters to guide the testing process—-that is, we established quantitative constraints which would define our success/failure thresholds. To test the accuracy of the classification system, computer predictions were compared with a corresponding frame which was manually labeled by a human agent. The difference between the predicted and actual location of the object was used to determine the recognition system's % error in accuracy. During final tests, it was determined that approximately 95.63% of predictions made by the system fall within a 10% margin of error, well within the requirements set forth by our testing specifications.

4.2.2 Vision Implementation (RAVN) [3]

Similarly to previous tests, a set of specifications were established to guide the testing process and define the success/failure conditions. These specifications focused on multi-object processing, informed position vectoring translation, and computation performance. To assess multi-object processing, a series of tests were developed which each used 100 frames containing four to six objects of interest. Metrics were collected on object identification success rate as well as prioritization success rates. Additionally, tests were performed to validate the implementation interface's ability to report accurate movement vectors. These tests involved providing the system with consecutive frames that simulate the AUV's vision when following the predicted path. During the last frame, a check was performed to verify that the object's centroid was within the middle 10% of pixels along the X and Y axis of the frame. Lastly, the performance of the software interface was assessed by performing a test with 1000 input files containing data for randomly placed objects of varying sizes and classifications. For each file, the time to prioritize object navigation and generate movement vectors were recorded. The mean of these times was calculated to be 0.451μs which satisfied the corresponding test specification.

4.3 Maneuver Testing

With limited pool testing availability, we have successfully identified and replaced all malfunctioning thrusters, thus ensuring that the current state of the AUV will be capable of multidirectional maneuverability with our 8 thrusters. The next step will be to properly calibrate all of our planned motion patterns upon arrival at the competition site. To do so will involve a repetitive testing cycle where we run our scripts for neutral, forward, reverse, dive, elevate, spin left, and spin right. Motor controller values will be adjusted after each iteration until we are satisfied that the AUV behaves in the anticipated manner.

4.4 IMU Testing

Testing of the Sparton AHRS-8 was done in multiple stages. After establishing a communication script to ping the tool for data, we then started testing the capabilities of the module. This was done by maneuvering the IMU outside of the robot and exporting the data in the form of CSV files. This would allow us to see what the robot would see and look for issues. We also developed a noise suppression filter to remove data anomalies and convert data to more familiar forms like Fahrenheit and degrees heading.

V. Acknowledgements

RoboCats at Montana State University would like to thank all the people and organizations who were involved in the continued development of this project. The critical role of our sponsors, NAVSEA and BlueRobotics, for providing the necessary resources to make this experience possible, cannot be overstated. An additional thank you to Montana State University, the Norm Asbjornson College of Engineering, and especially our club advisor Dr. Bradley Whitaker, for all the continued support.

VI. References

[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	Cost (If New)	Status
Buoyancy Control					
Frame	McMasterCarr (Student Designed)	extruded T-slot	6061 Aluminum, 1"x1"		
Waterproof Housing	Student Designed				
Waterproof Connectors	Seacon	All-Wet Underwater Electrical Wet-Mate Connectors	8pin or 10pin, water tight		
Thrusters	Blue Robotics	T200	390 watts, waterproof,		
Motor Control	Blue Robotics	Basic 30A ESC	30A,		
High Level Control	Arduino Mega				
Actuators					
Propellers	Blue Robotics	Included with Thrusters			
Battery	Blue Robotics	Lithium-ion Battery	14.8V, 18Ah		
Converter	Amazon	Yeeco DC DC Buck Voltage Regulator	Input voltage:DC7-36V; Output voltage: DC1.25-32V		
Regulator					
CPU	Amazon	Intel NUC7i7BNHX1	i7 7th Gen, 16GB RAM		
Internal Comm Network			I2C, Serial		
External Comm Network			Ethernet (SSH)		
Compass	Included in AHRS				
Inertial Measurement Unit (IMU)	Sparton	AHRS-8	9 axis		
Doppler Velocity Log (DVL)					
Vision	Microsoft	Lifecam Cinema: H5D-00013	720p, 30 fps, 5 MP		
Acoustics					
Manipulator					
Algorithms: vision	Student Designed				
Algorithms: acoustics					
Algorithms: localization and mapping					
Algorithms: autonomy	Student Designed				
Open source software	Arduino	Arduino			
Team Size (number of people)	15				
Expertise ratio (harware vs. software)	1				
Testing time: simulation	0				In Development
Testing time: in-water	1 hr				
Inter-vehical communication					
Programming Language(s)		C++, Python 3			