The Design and Implementation of the Syracuse University Orange Robotics' Competing Vehicle for the 2022 RoboSub

Zhuowei Zhang, Bei Luo, Kaifeng Chen, Luis Santin, Amia Diakite,
Alexander Callo, Arnaud Buard, Natalia Amado

Abstract

Amphitrite is the first underwater autonomous vehicle (UAV) designed and assembled by Syracuse University Orange Robotics (SUOR). This robot is made for the 2022 RoboNation's RoboSub competition. Since this is the first attempt to build our UAV, the goal is mainly to make the robot easy to build, modify and control, while covering as many tasks as possible without designing complicated subsystems. As the first attempt on a UAV for the competition, SUOR prioritizes goal-tracking and path-finding tasks and builds the mechanical, electrical, and software systems around this plan.

Competition Strategy

Because of the lack of experience in building underwater vehicles and autonomous systems, the team planned to approach the competition by focusing on the tasks that only require the correct maneuvering of the submarine's main body: going through the gate, following the path, potentially touching the correct buoy and surfacing inside the octagon zone.

The reason behind this strategy is that the ability to autonomously drive underwater in a correct path and direction is one of the biggest challenges for the newly established SUOR. And with the addition of cameras and a couple of basic sensors such as gyroscope and linear sonar, we will be able to achieve some of the simple tasks. This achievement will set the foundation for the team to take on further challenges in future competitions.

Design Creativity

The team is also suffering from a lack of resources in both skillset and funding. Therefore, to successfully tackle the tasks, each sub-team must design solutions that can be built with materials that are low cost and easily accessible, have a relatively smooth curve of learning, and achieve the goals set for the strategies. These are the principles when SUOR designed the mechanical, electrical, and software systems.

Mechanical Design

Frame structure

Amphitrite's frame is designed around stability, flexibility, durability, and versatility. Acrylic was used because of its lightweight, compact, and inexpensive material which allows for mass production. A 4-inch diameter PVC pipe was used as the main body to contain all the electrical components with 2 plates on both ends and 8 thread sticks to hold the submarine in position. The design creates greater stability and ability for the frame to absorb the shock in case of impact. Additionally, the design allows the team to easily place and rearrange sensors, cameras, thrusters, and other attachments if necessary.

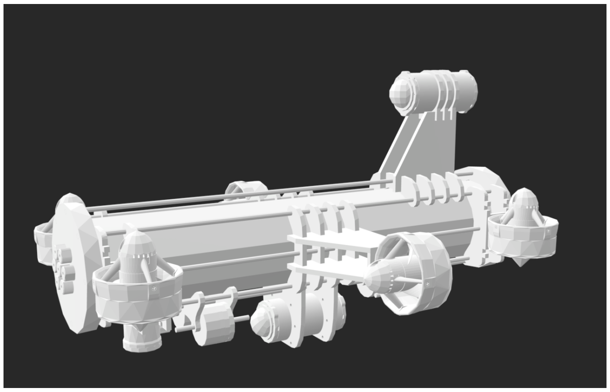

Fig. 1: CAD of Amphitrite

Interior structure

The interior structure of the Amphitrite is designed to allow the team to access electrical components easily, maximizing efficiency when testing the submarine. H shape structure was finalized due to the capability of absorbing shock and vibration and space capacity.

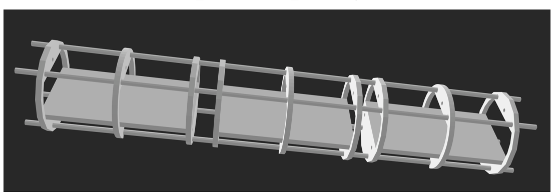

Fig. 2: internal assembly of Amphitrite

Buoyancy

The team designed AUV to be slightly positively buoyant, so in the case that there is a major system failure. Buoyancy is managed with lengths of brightly colored cylindrical polyethylene foam secured to the frame with zap straps on the top and Aluminum bars covered in plastic bags at the bottom, it avoids the AUV to flip over when in the water. The color of the foam helps to make the AUV more visible in the water, as well as easy to replace and adjust. It gives the AUV faster movement and acts as a failsafe when the AUV shuts down and needs to be retrieved.

Lighting System

Amphitrite contains two sources of light, one from the top and one from the bottom. The team chose to use a flashlight as the lighting source. To avoid flash light waterproof issue or purchasing an waterproofed light, the team instead placed the flashlight inside a cylinder and waterproofed the cylinder instead.

Electrical Design

The electrical team worked on integrating the multiple sensors, motors, and wires and coming up with the best way to connect all of these appliances together. The plan was to have the system of our mechanical and electrical design work in conjunction with each other. This was done by having designs of the framework of the Amphitrite. This allowed the team to come up with a plan on our designs and figure where there would be flaws or potential chances of improving the design.

Thruster

The team believes that faster submarine results in better performance. Wich brushless motors would accommodate this need due to their speed capabilities. After some research, the team decided to purchase six T-200 thrusters with ESC from Blue Robotic. Although one T-200 costs rightly around $200, the team believes that purchasing a mature thruster is more beneficial.

Software Design

From the start of the season, the software team has decided to follow a relatively established and stable technology stack to start the project due to limited experience. Amphitrite software system was implemented mainly through the Robotics Operating System (ROS) that will run inside a Ubuntu environment installed on the main computer. Sensors including the IMU and the sonar will be communicating through I2C with an Arduino Uno board. The Arduino board will use the Rosserial library to set up topic publishers and subscribers and communicate with the main ROS program on Raspberry Pi through the serial connection.

Amphitrite mainly leverages computer vision techniques to understand surroundings and make decisions on maneuvering. The three cameras are interfaced with the main computer through USB connections. Amphitrite has image recognition programs running as a node of the ROS program and publishes data on estimated object location and direction to other decision-making nodes.

Amphitrite will also use other sensor data to assist in decision-making. Amphitrite will gather depth information from the sonar to avoid collision with the bottom of the pool. Amphitrite also has leak detection through two leak sensors mounted near the end caps of the main body. Last but not the least, Amphitrite will use IMU to help maneuver smoothly and also adjust posture underwater in case of flipping or moving in unexpected directions.

Computer Vision

Amphitrite uses the OpenCV library for live detection of objects and labels. The software team also employs PyTorch and Convoluted Neural Network algorithms for training a few models on label classification, detecting gates and the buoys. Underwater images would be gathered during water testings to help with the training.

Amphitrite uses dual front-facing cameras to set up a custom stereo vision module for detecting labels and buoys in front of the vehicle while estimating the distance and depth of those objects. Another camera mounted at the bottom of the robot will be dedicated to detecting the path underneath the vehicle.

Sensor Interface

With the help of the ROSserial packages supported for the economic Arduino UNO, we can publish real-time data retrieved from the gyroscope and accelerometer to a custom ROS topic. One node running on the main computer will subscribe to that topic and make decisions on the speed signal sent to each thruster on the next spin. We use this technique to transmit data while easily interfacing with sensors.

Simulation

The team plans to implement simulation using Gazebo to test computer vision and control programs ahead of the competition. Gazebo is natively supported by ROS and is easier to kick start as the first simulation project for the team. The simulation programs will be implemented for further study and testing of PID control and computer vision programs ahead of the competition.

Experimental Results

Mechanical

Amphitrite's engineering process began by dividing the submarine system as a whole into components, such as the structure, material, and waterproof. For each component, the team brainstormed ideas individually listed the advantages and disadvantages of each idea, and narrowed down the list to two to three “best” choices. After further discussion, the optimal idea was chosen for experimenting.

Frame

Once the optimal design was chosen, the team build the prototype at a 2:1 scale by using ABS material with the 3D-printing machine and four thrusters facing up for vertical movement, following our club's low-budget philosophy. The prototype was discussed with the general engineering department to comparatively analyze the pros and cons. With further analysis, the team finally selected the official Amphitrite model.

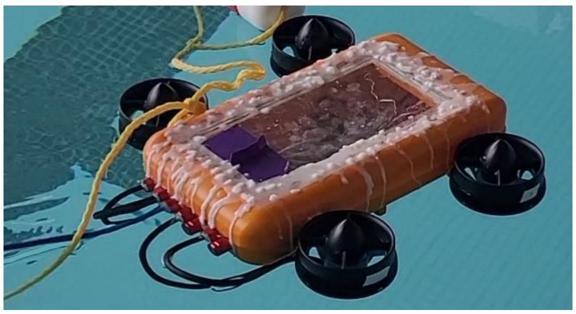

Fig. 3: Prototype

Material

Although the team used ABS material to build the prototype, the team decided to use acrylic for the official model. The reason is that Acrylic is relatively more durable and has a high melting temperature of 320 F, capable of external impact, violent vibration, and heat from the electrical components. Not only this, ABS material would need a longer time to build the submarine compared to acrylic.

The team purchased acrylic plates instead of cubes and used a laser cutting machine to cut acrylic into parts. To operate the laser cutting machine, the mechanical engineer self-taught Adobe Illustrator and Autodesk Inventor. By adjusting the frequency, speed, and number of cutting times in the laser cutter, perfect cuts of acrylic were made.

Waterproof solution

Waterproofing was one of the most significant aspects of the project. The team designed several solutions to make sure no liquid leaks. The team tested different materials that could be used for sealing such as wax, liquid flex seal, and waterproof tapes. After several experiments, the engineers concluded that different situations should use different waterproof solutions.

For the screws and nuts, the engineer filled the space between the cables and the whole liquid flex seal, a liquid rubber that will dry after contact with the air. For the main body structure, a nonpermanent and reusable material is required since the team needs to reach the critic board frequently. The Team decided to use liquid silicone to make a sealing ring by filling it into a mold that engineers created with a 3D printer. Placed the rings on the edges of the tube and use pressure to forbid the entry of the liquid.

Fig. 4: molds (pink) and silicon ring (blue) for waterproof

Electrical

The electrical team was in charge of overcoming problems of managing power distribution while also keeping the integrity of the design. Another problem that was encountered involved coming up with the safety switch for the competition. The responsibility for the electrical team was to integrate the safety switch in a way where it was easily accessible and connected to the battery of the Amphitrite.

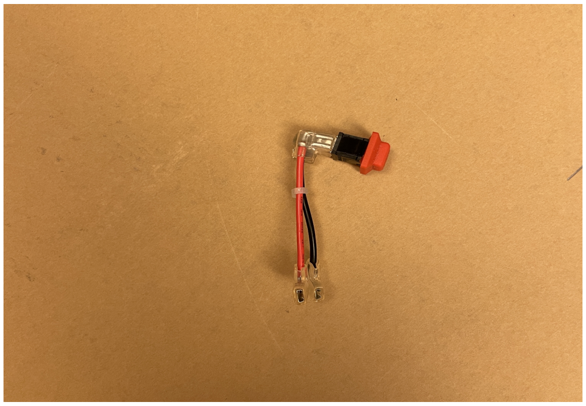

Fig. 5: Safety Switch

Software

The software subteam has implemented the Raspberry Pi to Arduino communication with full installation or required environments and packages in the prototype vehicle. The tests show promising results of using ROS and the ROSserial library to pass sensors and control data around the vehicle.

The use of the current choice of IMU has also been tested on a separate self-balancing car robot as a testbed for learning PID controls.

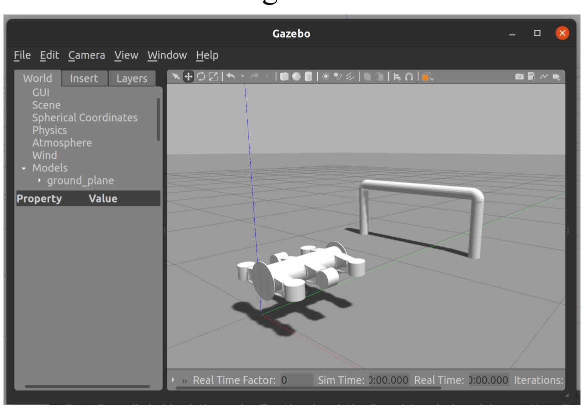

Fig. 6: A basic simulation attempted to approach the gate task

From the early stage of building the simulation environment, it has come to our attention that it is time consuming and unrealistic for the current software team to build a realistic simulation of the vehicle in an underwater world. Therefore, in the next steps the software subteam will use abstraction to simplify some factors such as vehicle model details and fluid dynamics. The team will also use an open-source library Project Dave, which is also based on Gazebo, for an easier approach of simulating the underwater environment. This could save time and leave room for the team to focus on testing the code for computer vision and the robot's closed loop control system.

Acknowledgments

SUOR would like to thank all active members who contributed to the design and assembly of the prototypes, the competition robot, and graduates who contributed to the resources and management of this organization. We also greatly appreciate the support from Syracuse University Student Activities which provides semester funding for our regular activities. Special thanks to our faculty advisor Dr. Victor Duenus for the support, Syracuse University College of Engineering and Computer Science(ECS) for funding our registration and providing machine shop resources, Mechanical and Aerospace Engineering department chair Dr. Young Bai Moon, and Electrical Engineering and Computer Science department chair Dr. Jae C Oh for providing funding in support of SUOR's attendance in the in-person competition.

References

Arvind Sanjeev. (2018). How to Interface Arduino and the MPU 6050 Sensor | Arduino. *Maker Pro*. https://maker.pro/arduino/tutorial/how-to-interface-arduino-and-the-mpu-6050-sensor

Home. (2022). *Project DAVE*. https://field-robotics-lab.github.io/dave.doc/

Rabinowitz et al. - CTHULHU The Design and Implementation of the Duke.pdf. (n.d.). Retrieved June 12, 2022, from https://robonation.org/app/uploads/sites/4/2020/08/RS20_TDR_Duke.pdf

Rabinowitz, S., Jiang, E., Chakraborty, N., Fowler, T., Arivoli, M., Gondalia, S., Jun, H., Chang, E., Miron, D., He, E., Chung, M., Bi, A., Yang, K., Wang, V., Chen, R., Lindstrom, K., Heller, J., & Cameron, C. (n.d.). *CTHULHU: The Design and Implementation of the Duke Robotics Club's 2020 RoboSub Competition Entry*. 8.

Redmon, J., Divvala, S., Girshick, R., & Farhadi, A. (2016). *You Only Look Once: Unified, Real-Time Object Detection* (arXiv:1506.02640). arXiv. https://doi.org/10.48550/arXiv.1506.02640