Progress Report #1

AUV Project

Phase I

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ME 4913

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This independent study for phase 1 constitutes the design and development of a proof-of-concept autonomous underwater vehicle (AUV) capable of meeting all technical requirements to participate in the International Robosub Competition. Progress report #1 and #2 document the technical development of the project.

Executive Summary

Progress report #1 of the AUV project describes completed tasks after the project's start date of February 3, current tasks underway, and next month's tasks. Progress report #1 is part of milestone # 1 out of the four milestones that constitute the project. Completed tasks since February 3rd include the creation of the project's Gantt chart and presentation of project presentation #1 detailing the AUV's technical requirements. Current tasks are geared towards completing milestone #2 through conducting AUV research on technical designs, researching the equipment parts list, learning CFD simulation software, developing the project's CAD model and in performing CAD simulations. Next month's tasks also constitute the completion of milestone #2 in purchasing the equipment parts list and in the actual proof-of-model build.

Completed Tasks

Completed tasks for phase I of this AUV independent study project for the month of February consist of completing a project Gantt Chart for the length of the academic spring semester and a power point project presentation describing the technical requirements and advanced desired capabilities of the AUV for phase II. The Gantt Chart is shown in *Figure 1*.

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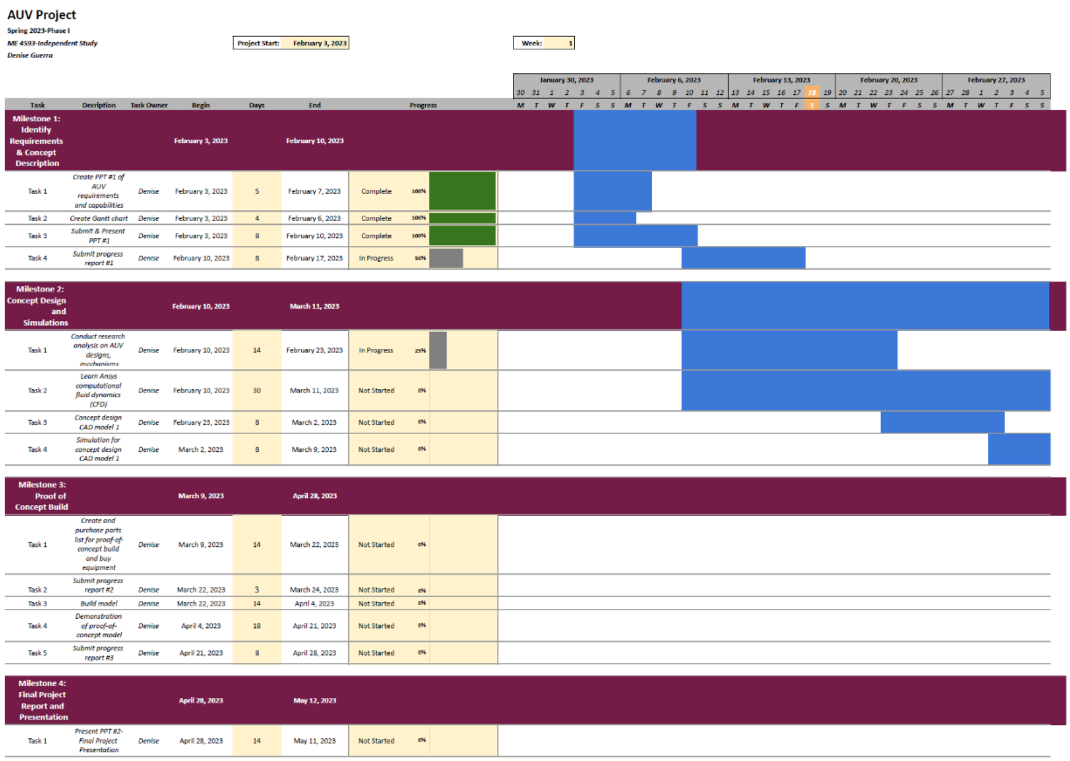

Figure 1 Gantt Chart for AUV project

There are four project milestones in the Gantt chart each with associated tasks needed to complete each project milestone. Milestone #1 is *Identifying Requirements & Concept Description*, Milestone #2 is *Concept Design & Simulations*, Milestone #3 is the *AUV Proof-of-Concept Build*, and Milestone #4 is the *Final Project Report and Presentation*. The project start date is February 3, 2023 and the project end date is May 12, 2023. Milestone #1 required completion of the project presentation outlining the AUV's technical requirements and creation of a Gantt Chart for the project. Milestone #1 has been completed and Milestone #2 is currently underway. Milestone #2 includes conducting research on AUV designs and basic functionality. Also included is the beginning of learning Computational Fluid Dynamics (CFD) using Ansys software, starting the SolidWorks Computer Aided Design (CAD) of the AUV model and running simulations in SolidWorks for examining different shapes, sizes, and materials being considered for the AUV. Milestone #3 includes creating an equipment parts list for the AUV and purchasing the items on the parts list for the construction and demonstration of the proof-of-concept AUV. Milestone #4 consists of submitting a final project report and power point presentation of the final project.

The AUV project presentation created during milestone #1 delineates the technical requirements for the AUV's design. The AUV's technical requirements consists of including an emergency kill switch into the design, have an attached tethered harness, have guarded propellers or thrusters, and the AUV must have no part that extends outside the surface of the water. The maximum dimensions for the AUV are 6ft x 3ft x 3ft, and its weight must fall into a range of 49-84lb. The AUV must have full autonomous capability and communication is not allowed between the AUV and an off-board computer or user. The AUV must also be battery powered with battery power not exceeding 60 V DC and the batteries are not allowed to be charged at any time within the sealed vessel. The AUV must demonstrate the ability to maintain a constant heading and depth while fully submerged and in transit. The AUV must also demonstrate the ability to move forward, backward, left, right, downward, and upward at a depth of between 5ft-9ft.

Current Tasks Underway

I am currently researching the basic mechanical and electrical components to build an underwater vehicle to prepare for the creation of a parts list to purchase for next month's task.

Additionally, I am looking into the AUV designs of winning teams who competed in the 2022 International Robosub Competition as reference material to learn how to design a superior submarine. I am also currently considering various materials, sizes, and shapes for the AUV SolidWorks CAD model and how they will affect the AUV's weight through running simulations in SolidWorks. I am also examining different techniques to make the underwater vehicle waterproof. I am considering a minimum weight of 49 lb and an a weight of 66 lb for the design of the submarine. The material, shape, size, as well as the AUV's electronics and propellers/thrusters effect the submarine's overall weight. The material chosen for the shell of the submarine must be able to withstand water pressure ranging from a depth of 5ft-8ft. Additional criteria to consider in material selection consists of its density, malleability, corrosion resistance, thermal resistance, toughness, and strength.

Materials being considered for this project include aluminum, steel, fiberglass, carbon fiber, syntactic foam, Polyisocyanurate foams, polyurethane, and polyvinyl (PVC). Cylindrical, rectangular, spherical, and tear-dropped shapes being considered for the shape of the submarine including hollowed or non-hollowed designs. The size of the submarine will affect its maneuverability, mobility, and space needed for all necessary electronics and propulsion system. I am for a middle size of 3ft x 1.5ft x 1.5ft, a maximum size of 4ft x 2ft x 2ft, and a minimum size of 2ft x 1ft x 1ft. Waterproofing methods to be considered include using water resistant coatings, gaskets, O-rings, waterproof servos, and using wetlink penetrators. Regarding battery power, there are different options to consider such as alkaline, Ni-Cad, Ni-MH, Li-ion batteries. Battery properties such as the power capacity (C-rate), nominal voltage, power density, recharging method, shape, and pack size all should be considered on a pro/con basis.

Considerations for the on-board AUV computer include using a Raspberry Pi or NVIDIA Jetson for powering the camera and sensors and using an Arduino and electronic speed controllers for motor control. Criteria to consider when selecting the on-board computer for the AUV depends on the computer's capability for the required functions necessary for the submarine to perform, power output, resource availability for debugging, compatibility with sensors, and if it is user friendly. The AUV will also require an emergency stop system that will utilize a dedicated relay kill switch. The AUV will need to be equipped with several essential sensors to provide the submarine with the ability to be remote controlled, orient itself, and sense its surroundings.

The required sensors consist of a sonar sensor for motion detection, camera to relay images to the user, a transmitter and receiver for communicating to the submarine's remote control, an inertial measurement unit for its orientation underwater, and a sensor for leak detection. It's important for the underwater vehicle to also be remotely operated in addition to being fully autonomous. This is important in case the AUV's autonomous program runs into any errors and can't perform its necessary functions. It's remote-controlled operating capability allows for overriding autonomous commands, can be useful for testing purposes, video display, and can serve as an additional kill switch. This allows the submarine to have two modes available, autonomous, and remote controlled.

The submarine's propulsion system should include thrusters to provide the AUV with several degrees of freedoms and vectored thrust. The AUV should maintain a neutral buoyancy and activation of the kill switch should make it positively buoyant. Compressed air, buoyancy foam, and using syringes as ballast tanks are several methods to consider for buoyancy control. The top three winning teams in the 2022 International Robosub Competition constituted the

National University of Singapore, Carnegie Mellon University, and Amador Valley High School Robotics. The National University of Singapore won 1st place in the International Robosub Competition. Their AUV weighed 52 lb and was 2 ft x 1.15ft x1.67 ft (*l x w x h*). Their AUV's mechanical design consisted of a rectangular frame CNC manufactured out of aluminum, equipped with fiberglass floats, a 3D-printed nylon shell, and a 3D metal printed battery enclosure. Their propulsion system utilized seven thrusters giving the AUV six degrees of freedom. Main electrical system components consisted of a custom designed power monitoring board, a backplane system, a Raspberry Pi 3, an Intel Core i7-7600 CPU, a Nvidia Jetson module, a custom designed data acquisition system, machine vision cameras, custom designed linear actuators and LiPo batteries. The team's AUV had an IMU, pressure, fiber optic gyroscope, and doppler velocity log sensors. Software languages used consisted of ROS, Python 3, TensorRT, and an Ubuntu software operating system. The team used Gazebo and MATLAB Simulink to run simulations for the AUV. Figure 1 displays the AUV CNC frame design without the surface floats and Figure 2 displays the AUV design with the surface floats.

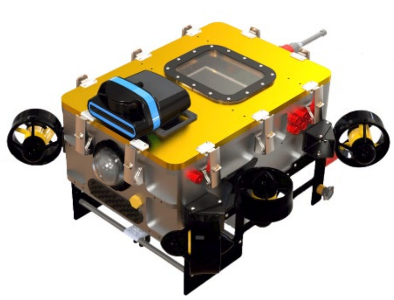

Figure 1- CNC AUV Frame

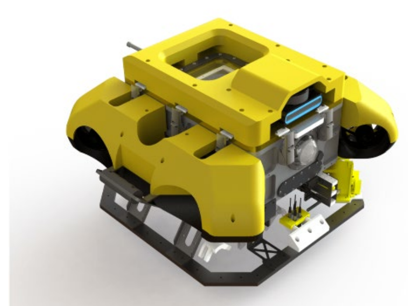

Figure 2- AUV with surface floats

Amador Valley High School Robotics won 2nd place in the International Robosub Competition. The team's AUV weighed 61 lb and was 2 ft x 2.8 ft x 1.33 ft (*l x w x h*). The team's AUV mechanical design consisted of an aluminum frame, a main compartment carbon fiber enclosure, carbon fiber battery and hydrophone enclosures with an electronics rack made of plywood. The AUV has 8 thrusters, is pressurized to match the depth of the water it is traversing, and waterproofing is done via O-rings epoxy adhesive, and waterproof connectors. The team's electrical system design consisted of a Intel i7-4790T on Jetway NG9J-Q87 Mini ITX motherboard as the main CPU, a NVIDIA GTX-1080ti GPU for machine learning, and an ATmega 2560 for mother control and interfacing with control sensor. The team's electrical system also contained machine vision cameras, and a custom designed FPGA module for data acquisition and signal processing. The team's AUV had an IMU, pressure, and doppler velocity log sensors. The team's AUV is powered using two Lithium Polymer batteries and their thermal management system consisted of a thermal wicking lid and a water-cooling system. Software languages used consisted of ROS, C, PyTorch, OpenCV, and an Ubuntu software operating system. The team used Gazebo to run simulations for the AUV. The Amador Valley High School Robotics AUV can be seen in Figure 3.

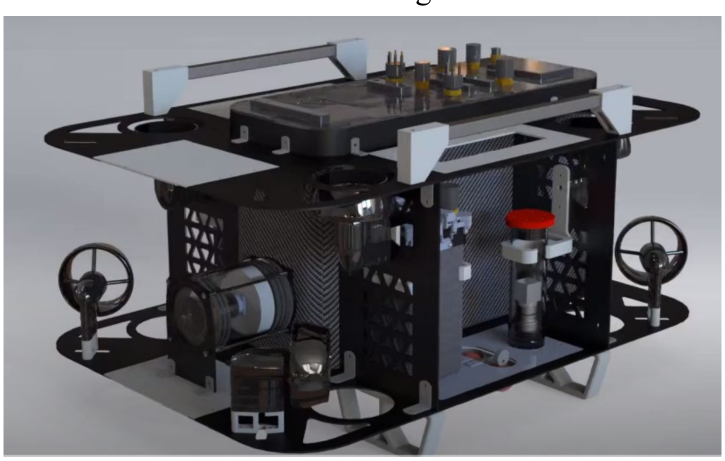

Figure 3- Amador Valley High School Robotics team AUV

Carnegie Mellon University won 3rd place in the International Robosub Competition. The team's AUV weighed 55 lb and was 3.25 ft x 1.75 ft x 1.16 ft (*l x w x h*). The mechanical design of the team's AUV consisted of an aluminum frame, acrylic tubes that hold the electronics and batteries and buoyancy foam. Waterproofing was done using O-rings as well as using waterproof connectors and waterproof actuators. The propulsion system was powered by 8 thrusters. The team's AUV used a NVIDIA Jetson AGX Orin as the main on-board computer. The team's AUV had an IMU, doppler velocity logger, hydrophones, depth, and ping sonar sensors. The AUV was also equipped with a custom power distribution board, stereo cameras, a LiPo battery, and electronic speed controllers. Software languages used consisted of ROS, C++, Python, OpenCV and MATLAB using the Ubuntu software operating system. The team used Gazebo to run simulations for the AUV. The AUV from Carnegie Mellon University can be seen in Figure 4.

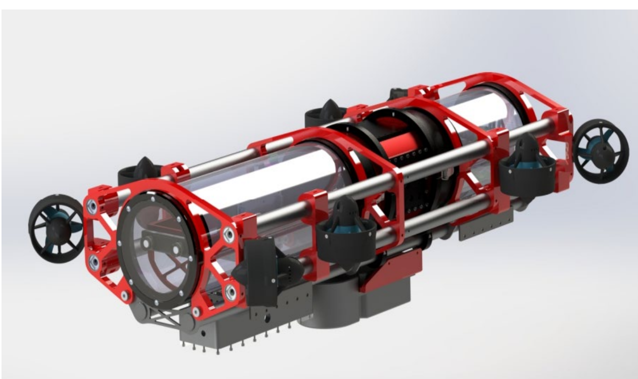

Figure 4- AUV from Carnegie Mellon University

Upcoming Tasks

Upcoming tasks for next month consist of several SolidWorks simulations, Ansys simulations, circuit design, creating and purchasing the equipment parts list, proof-of-concept build, and developing the necessary computer programming to make the submarine function properly with its on-board computer, remote controller, sensors, and ability to perform basic autonomous commands. SolidWorks simulations will simulate the weight of a variety of material candidates aforementioned that will constitute the shell and frame of the underwater vehicle to determine the best material that meets all necessary criteria. Ansys simulations for CFD will simulate drag studies, and buoyancy studies taking into consideration various candidate shapes, size, weight, propulsion system of the submarine. Circuit design for the AUV will consist of creating a circuit that connects the on-board computer with all sensors, power system, propulsion system, and the remote controller. The circuit design will also consider strategic locations where the AUV’s sensors will be placed.

References

1. https://bumblebee.sg/competitions/robosub/2022/

2. https://avbotz.com/vehicles/nemo#mechanical-team

3. https://tartanauv.com/kingfisher/