USU RoboSub Autonomous Underwater Vehicle Team: Design and Implementation of the Submarine Poseidon

***Abstract*—The submarine Poseidon is an autonomous underwater vehicle designed for the AUVSI RoboSub competition by the Utah State RoboSub Team. The design and build of Poseidon has been developed by 20 members over four years from 2013-2017, and brought to completion by a current team of 12. The primary objective of the team is to provide students with hands-on experience in engineering and computer science. The secondary objective is to build a fully functional and autonomous submarine. Over the course of the engineering process the vehicle has been fully modeled by SolidWorks CAD software. With four years of combined research and development, this year's vehicle is an improvement on all previous designs. Poseidon is lighter, more durable, and stronger than ever before.**

Particularly notable advancements include development of a functional electrical and software system using an Arduino Duo, Beaglebone Black, and Raspberry Pi that allows the vehicle to process information and make decisions similar to a human brain, and an upgraded vision system utilizing OpenCV library and Python programming. Additionally, Poseidon has undergone a mechanical overhaul in both a redesign of the frame and improvements in the electrical system organizers and hulls. Poseidon employs a litany of sensors in order to achieve the objectives of the USU RoboSub team for this year's competition such as identifying color, locating a pinger and surfacing at its location, and identifying and traveling through a gate. All competition objectives are autonomously achieved by the vehicle.

I. Introduction

The primary objective of the Utah State RoboSub team is to design and build an autonomous underwater vehicle (AUV). The concluding vehicle is a cumulative effort of three primary teams: Mechanical, Electrical, and Software. Additionally, the submarine is the product of the accumulation of multiple small projects requiring extensive hands-on learning, critical problem solving skills, and interdisciplinary communication among team members. Upon completion of the vehicle the USU RoboSub team will compete in the annual AUVSI Foundation International RoboSub competition. The competition is located at the TRANSDEC facility in San Diego, California, USA in late July.

The competition has been designed to challenge students to complete an obstacle course by an AUV built themselves. The obstacle course simulates real-world applications such as underwater mapping and search and rescue.

II. Design Strategy

Poseidon is the cumulative result of four years of progress and design. Year one brought the team together after almost all original team members graduated. Year two was devoted to exploring the creative process with features, controls, and submarine designs. Year three resulted in a better organization system and an overall product for the 2016 competition. Year four saw new induction of members, reorganization of leadership, and the creation of Poseidon Generation 2 (PoGen2) which incorporated major mechanical improvements that will allow more innovation for the 2017 competition and subsequent years.

Year four took place from spring 2016 to spring 2017, and is when the primary redesigning and completion of PoGen2 took place. The team focused on making the submarine lightweight, durable, and functional. As a byproduct of this, Poseidon now has a small and compact electrical footprint. The intention of making PoGen2 lightweight determines material choices for its chassis, and affects programming as programmers have to compensate for the buoyant nature of the craft.

Poseidon has to be durable in order to protect expensive hardware inside the brain components, as well as compensate for lack of experience from being a new team including crashing during testing. The team has been on a fast timetable due to working primarily during the fall 2016 to spring 2017 school semesters in addition to completing normal engineering workloads. Ordering new parts and fixing breakdowns has taken time away from actual testing, giving software team members less opportunity to finesse the submarine's brain and software capabilities.

The main focus for year four has been upgrading Poseidon into PoGen2, designing a better frame to suit hardware and sensor needs, while not decrementing the software team's process through too extreme an overhaul. Though complex, high-quality sensors such as a Doppler Velocity Log were available to the team, other sensors have been substituted to allow the software team easier programming and increase the efficiency of development. For instance, PoGen2 relies heavily on the compass sensor to self-correct and achieve the initial gate entry. Torpedoes and arms are currently being researched and developed, but were not ready in time for the 2017 competition. The USU RoboSub Team hopes to have these completely developed and tested in time for the 2018 competition.

Poseidon has received several upgrades during year four such as a modified chassis allowing for better sensor and pod placement, a better-sealed and shortened external enclosure for the brain to allow for better waterproofing and less buoyancy, and newer generations of various sensors. Each upgrade required additional time for manufacturing, mounting, and testing, but allowed for improved reliability and capability of the overall submarine. In addition, upgrades and the general light weight of the submarine have caused Poseidon to have a small and compact electrical footprint, allowing for longer testing runs without replacing and charging batteries.

III. MECHANICAL SYSTEMS

Poseidon's mechanical system consists of the chassis, lower and upper external enclosures and camera pods, thrusters, and sensor and thruster mounts. The lower and upper external enclosures protect the electrical components of the brain and non-water-resistant sensors from water damage. The chassis provides mounting points and protection for sensors, enclosures, and thrusters, as well as providing weight distribution for the vehicle. Manufactured parts and assemblies are designed in SolidWorks, then manufactured either manually, with CNC machinery, or FlashForge Dreamer 3D printer.

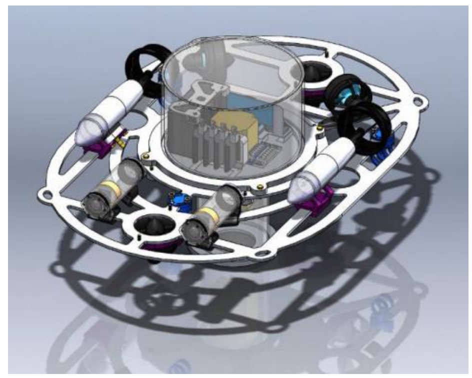

Figure 1: SolidWorks rendering of the AUV Poseidon

A. Chassis

The chassis' design determines the options for position and orientation of each mechanical component in the vehicle, in addition to maintaining structural integrity and rigidity of the vehicle. Poseidon's frame implements an ovular, flat design with bar supports to mount sensors. Waterjet CNC machining allow for rapid manufacture of the chassis when modifications are required. This increases speed of assembly and allows for more time to be delegated to testing.

Vehicle components are secured directly to the frame by screw, zip tie, or 3D-printed friction fit mounts. This reduces complexity and saves weight on the overall vehicle. All components are placed to minimize and equalize drag friction, as well as to adjust the center of mass as close as conveniently possible to the center of the AUV. The frame design is focused on overall integration and utilization of vehicle components, and ease of use and manufacturing.

B. External Enclosures

Poseidon's upper enclosure contains and protects the electrical brain system of the vehicle, including the Arduino Duo, Beaglebone Black, and Raspberry Pi 3. Made with 3/16 and 1/4-inch acrylic polymer, the enclosure is lightweight and allows for viewing of electrical systems in order to determine issues and connectivity status. Problems with leaking occurred with the first generation of Poseidon due to imperfections in cutting and fitting of sides and top of the enclosure. This was first resolved by using acrylic cement, creating a seamless seal from the top of the enclosure to the sides. Now this has been resolved by a newly manufactured bubble-type hull that does not need additional sealing measures.

The lower enclosure is sealed in the same way as the first generation of Poseidon, with acrylic cement. The lower hull is designed to house a Doppler Velocity Log (DVL), but due to time and knowledge constraints the lower hull currently serves as a counterweight to achieve near-neutral buoyancy.

The camera pods are produced using 2 inch BlueRobotics pod kits, providing protection for the Docooler webcam 12 MP, and allowing for clear visuals for the submarine. A goal after the time this paper is written is to have bottom-facing cameras --in addition to the counterweights-- housed in the bottom hull.

C. Thrusters

For Poseidon there are two different thrusters being used. The primary thrusters responsible for the longitudinal motion are VideoRay Brushless motor s (shown in the figure below).

Figure 2: VideoRay Thruster

Two VideoRay thrusters are aligned parallel to the submarine's centerline offset from the main capsule. These thrusters have been chosen for the amount of thrust available, about 20 lbs, and for the adaptability. As can be seen in Figure 2, the front end has a translucent capsule inside of which an LED light is placed. The LED light is at least 300 lumens bright and can get up to 1000 lumens bright in order to aid the computer vision software.

The second motor being used is the BlueRobotics T200 thruster. These thrusters were chosen when it was discovered that the original SeaBotix thrusters proved to have too little thrust at 4 pounds. The T200 thrusters each have a maximum thrust of roughly 10 lbs. Like the VideoRay thruster, the T200 thruster is also a brushless motor (shown in the figure below).

Figure 3: BlueRobotics T200 Thruster

For Poseidon there are a total of four of T200 motors. Two of them are used for longitudinal depth control while the other two are used for lateral side-to-side and yaw control.
All six thrusters are controlled by using pulse width modulation (PWM) along with an electronic speed controller (ESC).

D. Mounts

Sensor and thruster mounts are primarily 3D printed using a Flashforge Dreamer 3D printer. ABS plastic has been used despite difficulty in manufacturing complex prints due to its higher durability. Sensor mounts have been designed for attachment to the chassis using friction fit methods. Thruster mounts have been modeled to allow nuts and bolts.

IV. ELECTRICAL SYSTEMS

Poseidon's electrical systems are responsible for power, communication, and sensing capabilities. The electrical system is comprised of power systems, serial communication, thruster control, hydrophones, and other general sensors. The power system provides power for all peripherals, determining the amount of time the vehicle can swim. The serial communications system makes up the bulk of the brain capabilities of the vehicle, allowing for sensors to transmit data to the vehicle's main computer components such as the Arduino Duo. Thruster control systems determine the vehicle's movement and depth capabilities. Hydrophones work with a pinger to determine object distances. Other general sensors guide Poseidon in determining its heading, orientation, and acceleration. NanoProtech (an electronic protective coating) has been used on all water-sensitive electronics to prevent corrosion and potential short circuiting.

A. Power System

The power system consists of a handmade power distribution board and relay array mounted directly to the chassis. The power distribution board provides power for all required peripherals. Peripherals include the network switch, BeagleBone/USB power, thruster/ESC power, headlights, hydrophones, and external sensors. The relay arrays turn the motors' electronic speed controllers on and off based on a hardware interrupt event created by the kill switch. The power system's power is provided by one 12 volt 18Ah lithium-iron battery, which allows an average swim time of 4 to 6 hours.

For connection regularity, white is positive and blue is negative. The power distribution board has been built from a 3D printed design and hand-cut steel inlay.

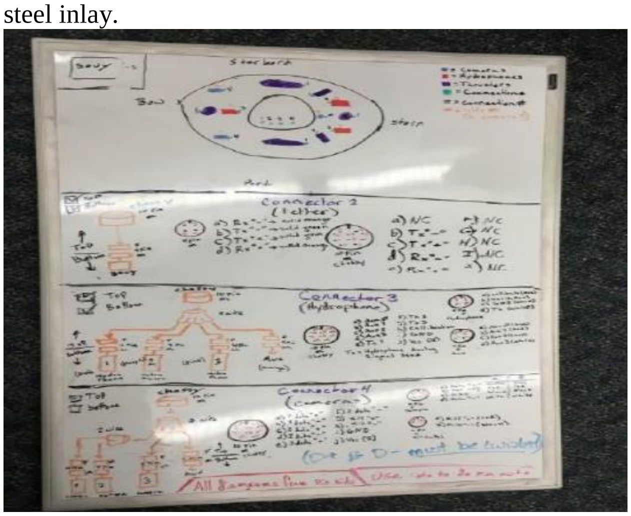

Figure 4: Early whiteboard pinout diagram for wiring consistencies. At the time of this paper being written electrical documentation was being updated and digitalized.

B. Serial Communication

Serial communications interface between the computer and various sensors and boards. The BoneCentral communicates with the Arduino Duo via standard USB. BoneCentral and PiVision each communicate with one another (and with external devices via tether) through a standard Network Interface Connection (ethernet, switch, and router).

C. Thruster Control

Thrusters are controlled by electronic speed controllers (ESCs). Each ESC can handle a current load up to 35A. Currently Poseidon utilizes HobbyWing ESCs that enable forward and reverse motion for brushless motors, but because they were designed for off road vehicles, a future development may be to implement a change to small open source and light weight ESCs produced by BlueRobotics. Poseidon's main forward thrusters are VideoRay thrusters. VideoRay thrusters are capable of putting out a maximum thrust of 10.5 pounds and consume a maximum voltage of 17 amps. The thrusters have been modified to allow the installation of lights on the forward part of them allowing better utilization of available chassis space.

Poseidon's dive and vectored-strafe thrusters all consist of BlueRobotics T200 thrusters. T200s are small, compact, powerful, and affordable, putting out a maximum thrust of 10.5 pounds. Compared to the forward VideoRay thrusters they require higher voltage for equivalent strengths, but overall are smaller in size and weight. The dive and vectored-strafe thrusters consume at most 25 amps of power.

D. Hydrophones

Poseidon uses three Spartan PHOD-1 hydrophones in order to use triangulation to determine object distance and direction. The triangulation algorithm used for Poseidon comes from the "Apollonius' Problem". Sparton sensors have been chosen due to available customer support, ease of use, availability, and list of features. Each hydrophone draws about 10mA of current and has an audible range from 10Hz to 50kHz.

The USU RoboSub team has used a Teledyne ALP-365 pinger identical to the one used in the AUVSI competition in order to accurately test and program the hydrophones. The competition only uses audible ranges between 25 kHz and 40 kHz.

E. General Sensors

In order to determine heading, orientation, and acceleration Poseidon possesses a generic 9-axis inertial measurement unit (IMU). The unit contains a MPU6050 accelerometer, gyroscope and temperature sensor, a HMC5883L compass, and a BMP085 pressure and temperature sensor.

A generic water pressure sensor is used to measure exact external water pressure to determine the vehicle's depth within the pool. Additionally, Poseidon uses a generic water temperature sensor in order to calibrate the hydrophone drivers to the approximate speed of sound underwater. Poseidon utilizes a DS18B20 water temperature sensor using the 1-Wire interface.

V. SOFTWARE

Poseidon's software is the driving force of its brain capabilities, allowing it to make decisions autonomously by interpreting data from external sensors and cameras. The software system utilizes four simple microcomputers along with a microcontroller in order to provide vision and is based primarily on a Linux operating system. All code is stored on GitHub and is open source for others to benefit from.

A. Computers

Poseidon has one Arduino Duo, a basic microcontroller. The vehicle also currently utilizes one Beaglebone Black: microcontrollers similar to Raspberry Pi but more suited for robotics. Poseidon was originally to use three of Beaglebones for vision processing. After discovering the Raspberry Pi's image data capturing abilities were more user friendly, the three Beaglesbones were replaced with one Raspberry Pi 3.

B. Vision

Poseidon's vision programming uses a library called OpenCV, an open-source software library with an abundance of useful computer vision tools enabling systems to virtually 'see'. Vision code is written in Python and connected via sockets in order to gain and interpret information.

C. Operating System

Linux Debian is the ideal choice for Beaglebone Blacks due to an abundance of community support and available software packages. Linux Debian is also straightforward in installation and simple to use.

V. Experimental Results

Poseidon is now in the software and pool testing phase. At the beginning of the fall 2016 a pressure tank was fabricated to test camera enclosures and other electrical components for potential leaking problems. Due to length of development, pool testing has occurred bi-weekly since September 2017. Pool testing stopped whenever there was potential for electrical damage due to water leaking or delays in code development. Testing is still underway to prepare Poseidon for the 2017 RoboSub competition.

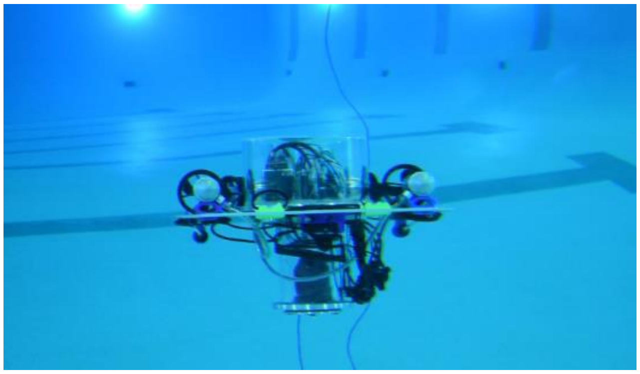

Figure 5: In-progress pool testing of Poseidon

VI. ACKNOWLEDGEMENTS

The USU RoboSub team would like to thank all the individuals who have supported us over the past year, including the Utah State University Computer Science Department, the Utah State University Engineering Department, and the Space Dynamics Lab.

The USU RoboSub team would also like to especially thank our adviser Dan Watson.

VIII. Appendix—Outreach Activities

The USU RoboSub team has provided outreach to the community by organizing a SeaPerch workshop to InTech High School (Logan, Utah). For the workshop and subsequent testing, team members supervised and taught students as they soldered, programmed, and assembled PVC submarine vehicles. This provided opportunities for local youth to gain experience and encouragement in technical and engineering skills.