Design and Implementation of PoGenII

USU RoboSub Team

Written by Nathan Copier, Jacie Grow, Reed Thurber, Rachel Wall

Abstract - The USU RoboSub Team's autonomous underwater vehicle (AUV), PoGenII is designed to be capable of underwater navigation as well as completing various mechanical tasks. PoGenII is the second generation of the Poseidon model used in previous years. Improvements include refined vision recognition, electrical performance, and the addition of a mechanical dropper and torpedo launchers. PoGenII is designed to be completely modular to allow for a more adaptive and efficient underwater vehicle.

I. Introduction

The USU RoboSub Team (USURT) is a student engineering group located at Utah State University comprised of various engineering majors at every level, from freshmen to seniors. As of 2018, USURT has competed in the Association for Unmanned Vehicle Systems International (AUVSI) RoboSub Competition for three years in a row. For the past two years they have used their first generation autonomous underwater vehicle (AUV) Poseidon, which was limited by basic acoustic sensor capabilities and non-existent vision. For the 2018 competition, the same general design was rebuilt and adapted for better acoustic sensing, visual capabilities, and equipped with a new torpedo system. This design has been titled Poseidon Generation II (PoGenII).

II. Competition Strategy

This year the electrical and software teams have focused on improving the vision and power systems used on the first generation of Poseidon to ensure the team's capability of performing vision-dependent tasks. The mechanical team devoted the majority of research and development to the addition of a dropper and a torpedo launching system in order to accomplish the 2018 competition tasks.

Priorities were determined based on the relative difficulty of each task and the assigned point values with the rankings being first, the qualifying movement, then all movement and vision dependent tasks (Enter the Casino, Shoot Craps, Find the Casino), followed by the tasks dependent on the new dropper and torpedo system (Roulette, Hit the Jackpot) and finally tasks that required a mechanical arm (Buy a Gold Chip, Cash In).

PoGenII is designed to complete all of the qualifying maneuvers before gaining as many additional points as possible from the vision, dropper, and torpedo dependent tasks. We determined to not include a mechanical arm in this year's design, which allowed us to dedicate more time to refining our software and electrical systems in an effort to create a more reliable AUV.

III. Design Creativity

The 2017-2018 school year brought multiple opportunities to refine the previous version of the AUV and to also develop designs for new systems. Retaining the focus of multi-functional and simple designs drove USURT to be more creative in their approaches to electrical, mechanical, and software developments.

Figure 1 CAD model of PogenII

A. Electrical - The 2017-2018 USURT's electrical team introduced new organization and flexibility for PoGenII's electronics systems. These two characteristics were chosen as the focus due to recurring problems experienced during previous competitions, which included damages sustained from repeatedly removing boards from the array for repairs and processing power.

Electronics Modules

During the 2017 Competition USURT had difficulty diagnosing and replacing a faulty Arduino UNO and power distribution board. This was a problem that occurred due to the complexity of the wiring and mounting systems inside the dome of the AUV. To prepare for the 2018 competition, USURT decided to implement a modular electronics mounting system to help reduce the time and complexity of dealing with electronics on the submarine as well as reduce the damages sustained by individual boards when they are exposed in an open-air environment. Each electronic board or component is encased in removable acrylic modules to allow the electronics team to quickly test, modify, or replace a specific board or component without moving any of the other components. All modules are on a rack that can be placed on its side both for quick access to component wiring and to be removed from AUV entirely for testing or repairs (see figure 2).

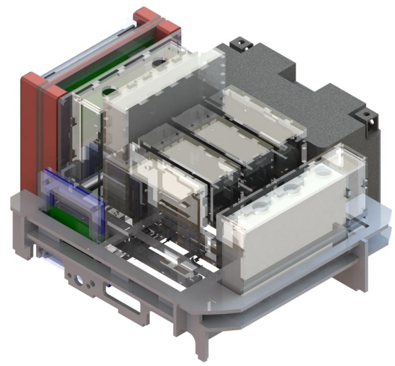

Figure 2 Electronic modules

Stackable Processing Power

During the design process, there was ambiguity about how much processing power PoGenII required to run the new vision software system USURT had started to research. USURT did not want to add too much processing power and shorten running time of the AUV, but needed a system that would be able to handle the undetermined load of the new system. In order to balance these two concerns the software splits the load between two and six Raspberry Pis. If all six Raspberry Pi's were used, there would be enough charge to run the entire 10 minute competition course length with acceptable maneuverability to complete the tasks selected. The current iteration of the AUV uses four Raspberry Pi's.

B. Mechanical - This year the USURT mechanical team focused their efforts on adapting the design of the first generation of Poseidon as well as developing new systems. The two main mechanical design challenges: retaining a modular design and developing a torpedo launching system.

Modularity
A majority of design and development for USURT occurs before the official AUVSI Robosub competition rules are posted for the year. This necessitates an adaptive design for the body of the AUV, allowing systems to be added or removed after the challenges are released, without compromising the overall functionality of the AUV.
To achieve this adaptable design we created a series of uniform struts in the shape of the chassis. This geometry enabled us to create a standardized design for 3D printed brackets that can easily snap onto the aluminum chassis. This modular design easily accommodates growth by allowing us to mount new systems as they are developed enabling the team to quickly adapt to new or changing tasks. In addition the modular brackets simplify the repair process enabling us to remove individual components as they require testing and work, without affecting the rest of the systems mounted to the chassis.

Torpedos
This is the first year that USURT has attempted to build a torpedo launching system for the AUVSI Robosub Competition. USURT wanted a torpedo launching system that was within allowable accuracy, easily launched, and reusable all while retaining minimal system complexity. The goal was to accurately target an opening two inches wide from a distance of four feet. Minimal interference from the launching system was important to minimize signal shadows on hydrophones, and minimize effect on the thrusters. A design using small refillable CO_2 cartridges imbedded in the torpedoes was chosen to allow for a longer continuous thrust impulse than possible with the shorter impulse created with an air burst behind the torpedo (see figure 3). This allows for sufficient velocity for an accurate shot, positive acceleration during the duration of the shot, reusability, control of launch pressure, and more efficient use of energy stored in pressure chambers.

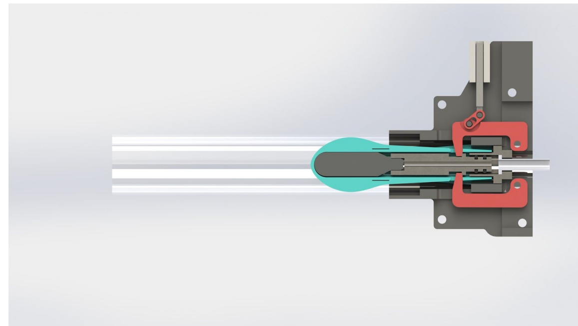

Figure 3 Torpedo launching mechanism

C. Software - Poseidon's coding and processing design was highly creative this year.

Communications
The previous system for Poseidon was simplistic and required significant effort to maintain. For 2018, PoGenII uses a cluster of computers to accomplish tasks. Each subsystem (Arduino, Raspberry Pi Hub, Raspberry Pi Agent, Raspberry Pi Vision, Raspberry Pi, IMU) uses different underlying systems to communicate. The agent and hub run on the same board and use Linux pipes. Arduino uses a serial connection with the hub. Vision uses TCP with the hub. An abstraction was implemented on top of these systems to provide a uniform interface. The interface is event-driven and allows components to react on data received. Each implementation serializes/deserializes the data and manages the connection internally. The new system provides more robust data transfer and allows the business logic to be functional and reactive.

Vision Recognition
Poseidon previously used a procedural system, based on OpenCV's template matching, to detect objects. Under testing conditions (clear, well-lit water, artificial

light), template matching worked well. Under competition conditions (murky water, natural light), template matching was fragile. To overcome this, the software team has been experimenting with a neural network based on Google's TensorFlow library (see figure 4). This poses additional difficulties, however. PoGenII lacks the space and power for a full-size GPU. The neural network must become much smaller and more efficient so as to run on a Raspberry Pi in real time. Training will still need to completed on a standard GPU, and the network will run on a Pi. The task seems plausible, given the nature of RoboSub's tasks, but more experimentation needs to be done.

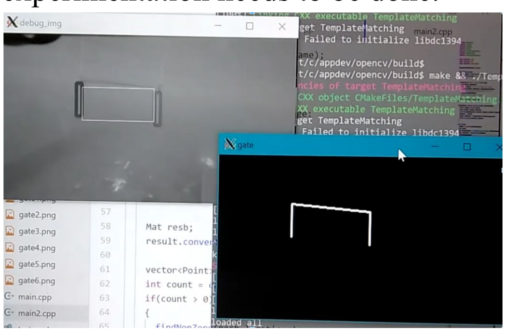

Figure 4 Visual recognition software

IV. Experimental Results

The USURT performs in-water testing for 90 minutes once a week. A total of eight testing sessions this year have been allocated to testing PoGenII against a series of qualifications. USURT's priority was to first ensure each seal on the AUV was waterproof. The next priority USURT focused on was weight and buoyancy calculations, followed by mechanical functionality as well as electrical efficiency. By verifying PoGenII's ability to meet each of these qualifications, the remaining time leading up to competition can now be dedicated to refining software capabilities.

A. Waterproofing

The first priority for in-water testing was to waterproof the dome that houses all electrical components. USURT initially experienced leakage at the seal between the electronics dome and the aluminum chassis. USURT decided to test different layouts and combinations of the o-rings that were used for the seal. Last year's design incorporated a single o-ring compressed between two flat surfaces. This year the chassis included two grooves to prevent the o-rings from sliding out of place. However, this change in design introduced a new issue: the grooves were too deep and didn't allow for a proper seal. After testing various combinations of o-rings and varying the depth of the grooves, USURT determined that the optimal layout was to use two o-rings in the existing grooves and adding a third ring between them. The two o-rings are used to align the third, which is responsible for the actual seal.

Further testing for a waterproof seal was required for the two main camera pods as well as each electrical component that would be mounted outside of the central dome. The majority of these tests were conducted in the lab using a small, clear tank. USURT tested the o-ring seals utilized at both ends of the camera pods, the epoxy seal for the external electrical connector, and the epoxy coating on each electronic component. This was simply done by suspending each component in the tank and checking for visible signs of leakage.

B. Buoyancy

Testing for weight and buoyancy was done concurrently with the design of the weight system. Utilizing an adaptive weight system composed of printed brackets and stackable washers, USURT was able to calculate the weight necessary to achieve neutral buoyancy. This same system allowed us to simulate the final weight of the AUV without risking damage to electronics systems while testing waterproofing during wet testing.

C. Torpedos

The majority of mechanical tests were focused on the new torpedo system. The torpedo body was tested for an airtight seal using the aforementioned clear tank. The same adaptive-weight technique for testing the AUV was utilized on a smaller scale to test buoyancy of the body of the torpedos (see figure 5). In-pool testing was reserved for the functionality of the torpedo release mechanism, testing for optimal fin design to ensure a straight path, and to determine the amount of pressure necessary to achieve a sufficient velocity.

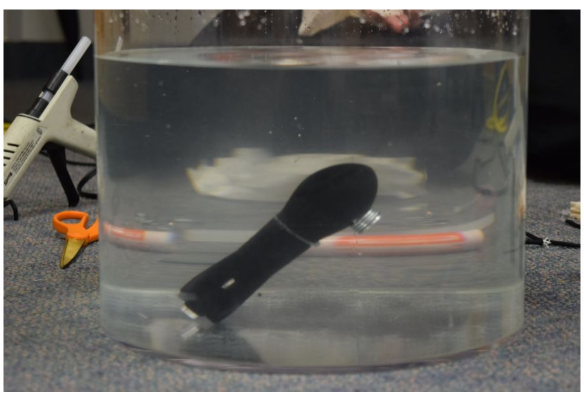

Figure 5 Torpedo buoyancy tests

D. Electronics

Before PoGenII was sufficiently waterproof, the electronic modules were assembled outside of PoGenII to simulate their respective positions beneath the central dome. Running the electronics in a controlled environment allowed USURT to determine what components were giving off heat. This enabled USURT to determine the positioning of each component, as well as identify which areas would need to be grounded to the aluminum chassis in order to disperse heat.

V. Acknowledgements

USURT would like to thank the Space Dynamic Lab and USU's CS, MAE, and ECE departments for helping us with essential funding. USURT would also like to thank USU's IDEA Lab and the Student Prototype Lab for allowing the team to use their space and tools in order to build PoGenII. USURT is also grateful to their adviser, Dr. Jonathan Phillips, for his support, advice, and encouragement. Finally, USURT acknowledges USU's Dean of Engineering, Dean Jagath Kaluarachchi, for his support of USURT.

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost (if new)
Frame	Central Valley Machine	Custom	Aluminum	$1,335.00
Thrusters	BlueRobitics	T200 Thruster x5	Forward @12V 7.8 lbf Reverse @12V 6.6lbf	$169.00 each
Battery	Gens ACE	LiPo Batteries x2	14.8V 45C 6750mAh	$106.99 each
CPU	Raspberry Pi	3 Model B x3	1.2 GHz Quad-Core 1 GB RAM	$35.20 each
Programming Language 1	JavaScript			
Programming Language 2	C++			
Compass	See below			
Intertial Measurement Unit (IMU)		GY-88	11-Axis	
Doppler Velocity Log (DVL)	n/a			
Camera(s)	Cimkiz	A860 Webcam	USB 2.0	$33.95
Algorithms: vision	TensorFlow object detection (experimental)			
Algorithms: acoustics	FFT			
Algorithms: localization and mapping	SLAM (experimental)			
Algorithms: autonomy	Procedural algorithm			
Open source software	OpenCV, TensorFlow			
Team size (number of people)	20			
HW/SW expertise ratios	4:4			
Testing time: simulation	20 hours			
Testing time: in-water	25 hours			

Appendix B: Outreach Activities

College of Engineering's E-State and Community Day

USURT had the opportunity to present at both E-State and Community Day. E-State is a week-long camp for high school students to encourage them to do engineering. Community Day is an opportunity for families local to Utah State University to come see projects the College of Engineering is working on. USURT allowed children to test-drive the rover (used to test PoGenII software when not in the water) to allow children a hands-on experience with what engineering can allow them to do.