Desert WAVE: Phoenix AUV Rising

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***Abstract*— Desert WAVE (Women in Autonomous Vehicle Engineering) is a rookie team from Arizona set to compete in the 2019 RoboSub Competition. The team's autonomous underwater vehicle, named Phoenix, includes 10 thrusters as well as a passive sonar, doppler velocity log, fiber optic gyroscope, and two cameras. The main purpose of this team is to provide students with opportunities to apply the knowledge and skills learned in the classroom to a real world setting. Phoenix is capable of precise autonomous navigation, manipulating objects, locating the position of an acoustic signal, and classification via vision processing. This paper reviews the team's strategy for the competition, hardware and software design, and results from several tests that were conducted.**

***Keywords*— AUV, Women in Engineering, RoboSub Competition**

I. Introduction

Desert WAVE (Women in Autonomous Vehicle Engineering) includes 14 members. The team was formed through a partnership between the Si Se Puede Foundation (SSPF) and Arizona State University (ASU). The team is primarily comprised of women studying engineering at ASU. While a few of the team's students come from a background in robotics, mainly FIRST Robotics, the majority of the team is new to the field.

The team was formed partially as a response to a lack of women in the engineering field. According to the Joint Economic Committee of the U.S. Congress, the engineering field is comprised of only 14% women [1]. Team-based modes of learning in undergraduate education are a way to encourage collaboration and prepare students for the workforce. However, one study suggests that "informal and indirect contexts" in project teams can "relegate women to traditional gender specific roles and performances" when their male counterparts, who often form a majority, assume that women will take on organizational, managerial, or menial tasks as opposed to more technical work [2]. With this in mind, the RoboSub Competition provides experience with both robotics and team-based learning while an all-woman team provides an environment unencumbered by many traditional gendered pressures. However, the team does face the pressure to be competitive in order to not perpetuate the negative stereotype that women cannot be successful engineers. As such, the team aspires to transcend this part of its identity so that others recognize Desert WAVE as a great team, and not simply as a novelty. Similarly, the students on the team aspire to be recognized for the merits of their achievements as engineers and not for their gender.

Arguably the most important member of Desert WAVE is the autonomous underwater vehicle (AUV), Phoenix, shown in Fig. 1. Just as the mythological Phoenix rises to new life from its ashes, Desert WAVE's Phoenix was born again from the donated parts of Carl Hayden High School's autonomous submarine.

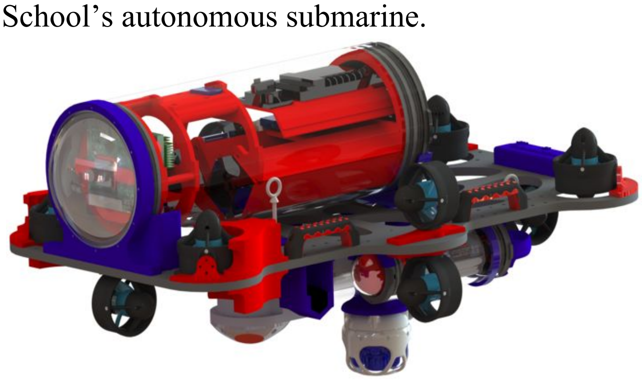

Fig. 1 CAD render of Desert WAVE's AUV, Phoenix

II. Competition Strategy

Desert WAVE's team primarily consists of freshman engineering students. As such, the 2019 RoboSub Competition will be many members' first robotics competition. Walking into this season, Desert WAVE's strategy was to minimize manufacturing time to maximize time for testing and developing the skills necessary to form the foundation of a competitive team for years to come. Tasks deemed essential for this year were:

- Getting in the water as fast as possible
- Integrating the fiber optic gyroscope (FOG), doppler velocity log (DVL), and passive sonar
- Collecting data (videos, logs, images) in preparation for next year's competition

Desert WAVE chose to design the AUV as a minimum viable product. Therefore, non-critical elements were added post-initial construction for integration into the main system. The majority of Phoenix was constructed using commercial-off-the-shelf (COTS) components. Parts that needed to be custom-made were designed using SolidWorks and 3D printed. This method of fabrication simplified the AUV construction since no members held manufacturing experience prior to joining the team.

Early on in the design process, the team realized it would not be possible for the AUV to function at a high level for all tasks. Therefore, the team analyzed the mission rules to determine how to obtain the maximum number of points given the team's limited experience and resources. Consequently, the team focused on developing systems for navigation, vision, and mobility. With these systems alone, Phoenix can earn points for passing through the gate, following the path markers, hitting a buoy, navigating to the pinger, surfacing in the octagon, and completing the run before the allotted time. The AUV was designed to be upgradeable which allows for the implementation of add-on components such as a marker dropper and torpedo launcher.

III. Design Creativity

A. Mechanical

Phoenix is designed to grow with the experience of the team. The frame, designed in SolidWorks, was manufactured using a computer numerical control (CNC) router. Key elements accounted for in the design were the placement of a wide angle downward facing camera, incorporating rounded features into the frame design to prevent the robot from unintentionally catching on external objects in the water, and the integration of four independent pressure vessels. The pressure vessels include two battery pods, housing for the DVL, and the main hull. All pods are made of clear acrylic tubes to allow for visual feedback from the electronics. Additional holes were placed on the frame in preparation for upgrades.

Phoenix was designed with fault tolerance in mind. The AUV is outfitted with ten thrusters for six degrees of freedom control. This level of redundancy means that if one thruster fails, Phoenix can still potentially complete the current mission and navigate safely to the surface. Not only do the additional thrusters add to the redundancy of the controls, but they also allow the AUV to move forward at a top speed of 1.2***m/s***. In addition to the four thrusters in the surge direction, thrust in the heave direction is also controlled by four thrusters. The final two thrusters allow for fine alignment control in the sway direction.

One of the upgrades not considered in the original design was the marker dropper mechanism. In order for the team to qualify for the time bonus, either marker droppers (garlic) or torpedoes (stakes) would need to be successfully deployed during the mission. From both hardware and software perspectives, adding a device to drop markers was seen as a lower technical risk than a torpedo launcher. Pinballs were selected as markers and were painted green to make them easier to recover and less likely to corrode. The markers are housed in a 3D printed chamber and a water sprinkler solenoid holds and releases the balls.

The most ambitious mechanical component designed by the team is the internal lattice of the main hull, shown in Fig. 2. The lattice is used to mount all of the major electronic components of the AUV. Similar to the frame, the lattice was intended to be upgradeable. However, the design did not account for the sheer size of the wiring. Although functional, the internal lattice will be the focus of future improvement.

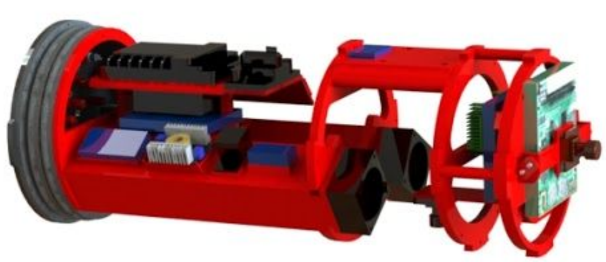

Fig. 2 CAD render of the main hull's internal lattice

B. Electrical

Nearly all of the AUV's electronics are housed in a single main hull. These electrical systems are powered by a single LiPo battery located in a separate battery enclosure. A second battery enclosure is the home of an identical battery that powers the thrusters. Having two independent power supplies ensures that the large currents drawn by the thrusters never impact the performance of the rest of the electronics.

While many of the AUV's electronics are COTS, Desert WAVE designed a number of original printed circuit boards (PCB). The AUV's PID controller is enabled by an Arduino Teensy 3.5 microcontroller. It runs embedded C++ code that handles hardware interfaces, sensor fusion, as well as attitude and depth control. The AUV mainboard is a PCB that was designed and built by the team as a carrier board for this Teensy. It uses streaming packet based communication to control the AUV. Packets are sent containing the current AUV settings, debug info, and/or telemetry data. The AUV mainboard processes and distributes these packets to/from the main mission computer, an NVIDIA's Jetson TX2, which handles the higher-level tasks such as mission management, outer control loops, network communications, vision processing, and data logging.

The FOG assists in navigation, positioning, and maintaining heading of the AUV. This model requires three separate DC power supplies to operate safely: +5 VDC, +15 VDC, and -15 VDC. Additionally, each power supply necessitates a specific powering off and on sequence**.** As no ready-made power supply exists to perform this operation, the team designed and built a custom PCB, seen in Fig. 3, to handle this sequence. It utilizes an Arduino Pro Mini microcontroller and MOSFET switches to control the outputs to the FOG.

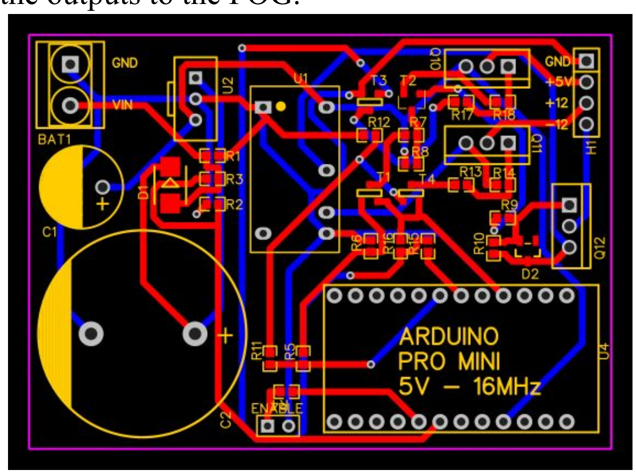

Fig. 3 Team designed PCB for the FOG power supply

C. Software

The software system of the AUV uses a combination of algorithms to integrate inputs from the DVL, Subsonus, cameras, and FOG to generate behaviors which are implemented by the thrusters and actuators. In particular, this section highlights two important algorithms: the Mission Planner and vision processing systems.

The Mission Planner allows the AUV to receive a set of commands entered by a user, written in Java. Multiple interfaces allow the Mission Planner to communicate with the Teensy board while transmitting/receiving data packets, such as communication provider, telemetry destination, packet sender, packet destination, and command interfaces. When the Mission Planner is executed, it establishes the AUV settings, reads and displays telemetry data, and allows a user to determine the mission order as well as set each mission configuration. Once the order of missions is determined, a user can turn on the mission enable switch which transmits a set of packet data to the Teensy board embedded in the AUV.

Vision processing allows the AUV to see and classify objects while underwater. Vision processing begins with a stream of video from a MIPI camera which feeds into Darknet's Demo algorithm. Darknet YOLO, hereafter referred to as Darknet, is an algorithm designed to detect and classify a set of objects, as trained by the team prior to processing. Darknet creates a set of coordinates which create a box around the object of detection as shown in Fig. 4. The object's coordinates are then fed into the AUV Command Reader, allowing the AUV to make decisions based on the distance, type of object, and accuracy of object detection.

III. Experimental Results

In addition to individually testing each component out-of-water, experimental testing centered around three focal points: simulation, acoustics, and buoyancy.

A. Simulation

Simulation testing was performed before the initial construction of the physical robot over a course of 20 hours. In parallel, a CAD model was developed in SolidWorks to help predict the center of gravity, buoyancy, thrust, and drag of the AUV. Both linear and quadratic coefficients of drag were considered, yielding a system of differential equations. The simulator, powered by Unity, is a real-time development platform primarily used to test the pre-qualify code while the AUV was still under construction. The simulator mimicked the AUV's thrusters and sensors while simulating autonomous and teleoperated modes.

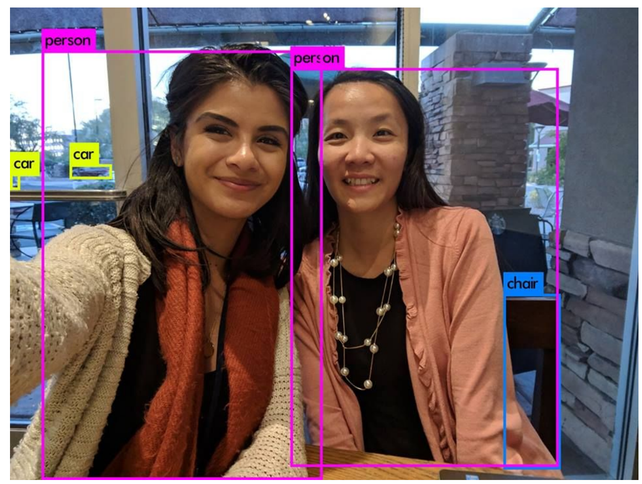

Fig. 4 Darknet object detection of two team members

B. Acoustics Testing

The AUV is able to position itself using acoustics by utilizing a Subsonus hydrophone array [3]. To test the functionality of the Subsonus and the software used to interpret the information it gathers, the team conducted a testing session for six hours. The Subsonus was placed in the center of a pool and an acoustic pinger was moved around to determine what location yielded the least interferences. The best reading came when the pinger was against a wall 0.8***m*** away, limiting the amount of reflections. An image of the test setup is shown in Fig. 5. The pinger parameters were 25***kHz***, 2***ms***, 0.5***W***; the Subsonus setting was 2***ms***. Additional testing is required to determine if the reversal of these components will yield different multipaths. Future tests will be conducted in a larger body of water to mitigate the echoing of the pinger against close walls.

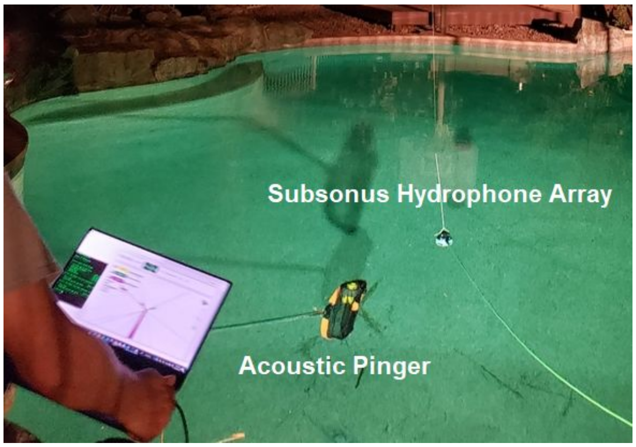

Fig. 5 Setup for acoustic experiments

C. Buoyancy Testing

Buoyancy testing began once the AUV was watertight and all of the main mechanical and electrical components were integrated into the AUV. This testing took approximately three hours over the course of multiple tests. Initial testing revealed that the front end of the AUV was positive. In addition to the large displacement of the 8***in*** hull, the choice to position the hull as far forward as possible, to avoid obstructing the front-facing camera, caused a noticeable amount of pitch upwards.

To combat this, multiple 3D-printed lead shot holders were designed to be attached to the front of the AUV, as shown in Fig. 6. While the magnitude of pitch was minimized, further testing revealed a small amount of pitching was still present. Steel weights were added incrementally to the front and foam sheets to the back to fine tune the final buoyancy and bring the AUV as close to neutral as possible.

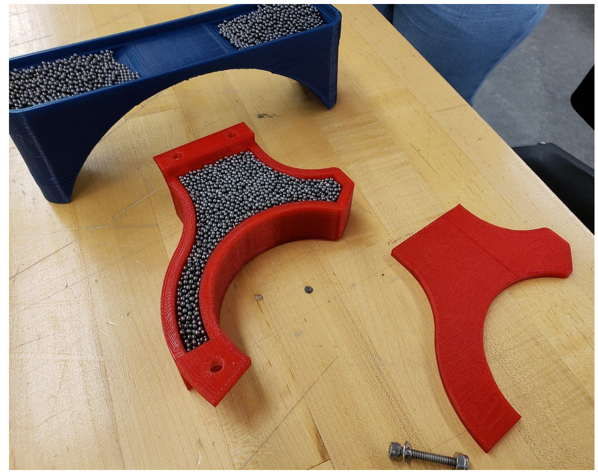

Fig. 6 Two of the 3D printed lead shot holders

ACKNOWLEDGMENT

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- Arizona State University
- Shebbie's Live Life Series
- Carl Hayden High School

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Appendix A: Expectations

Subjective Measures			
	Maximum Points	**Expected Points**	**Points Scored**
Utility of team website	50	42	
Technical Merit (from journal paper)	150	135	
Written Style (from journal paper)	50	45	
Capability for Autonomous Behavior (static judging)	100	90	
Creativity in System Design (static judging)	100	85	
Team Uniform (static judging)	10	10	
Team Video	50	45	
Pre-Qualifying Video	100	100	
Discretionary points (static judging)	40	20	
Total	650	572	
Performance Measures			
	Maximum Points		
Weight	See Table 1 / Vehicle	-125	
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate Maintain fixed heading	150	150	
Gate: Coin Flip	300	300	
Gate: Pass through 60% section	200	0	
Gate: Pass through 40% section	400	400	
Gate: Style	+100 (8x max)	200	
Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the “Path” (2 total)	100 / segment	200	
Slay Vampires: Any, Called	300, 600	300	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	1400	
Drop Garlic: Move Arm	400	0	
Stake through the Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	0	
Stake through Heart: Mover lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	1000	
Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	0	
Random Pinger second task	1500	0	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + fractional)	Tx100	500	

Appendix B: Component Specifications

Component	Vendor	Model/Type	Specs	Cost
Buoyancy control	Blue Robotics	• Stainless steel ballast x10 • Subsea Buoyancy Foam: R-3312	• .43 ***lbf*** • 8"x4"x.5"	• $9.00 x10 • $9.00 x5
Frame	Port Plastics	PVC sheet	.5" thick	Donated
Waterproof Housing	Blue Robotics	• 8" enclosure x1 • 3" enclosure x2	• 24" long • 11.75" long	• $253.00 x1 • $46.00 x2
Thrusters	Blue Robotics	• T100 Thruster x6 • T200 Thruster x4	• Max thrust: 5.2 ***lbf*** • Max thrust: 11.2 ***lbf***	• $119.00 x6 • $169.00 x4
Motor Control	Blue Robotics	Basic ESC x10	30***A*** brushless ESC	$25.00 x10
High Level Control	Mouser	Teensy 3.2 Dev board	ARM processor	$32.50
Actuators	Lowes	Sprinkler valve	24***V***	$12.00
Propellers	Blue Robotics	• T100 Propellers x6 • T200 Propellers x4	• 3" diameter • 3" diameter	Came with thrusters
Battery	Blue Robotics	LiPo batteries x2	4 cell, 18***Ah***, 16.8***V***	$289.00 x2
5***V*** Power Supply	Vicor	Development board	20***A***, 5***V***	Donated
CPU	NVIDIA	Jetson	256-Core NVIDIA Pascal GPU, Dual-Core NVIDIA Denver 64-Bit CPU	$598.00
Internal Comm Network	Simrex Corporation	WiFi Radio	5***GHz***	$200.00
External Comm Interface	MCI Networks	Fiber Optic Transceiver	5V ST / Ethernet set	$250.00
Programming Language 1	C++			
Programming Language 2	Java			
Compass	Scuba Professionals of Arizona	Dive Console	Magnetic	$50.00
Internal Measurement Unit (IMU)	Sparkfun	Razor IMU	3-axis	$30.00
Doppler Velocity Log	Teledyne	Explorer 600	4-Head	Donated
Camera(s)	Leopard Imaging	LI-IMX274-MIPI-M12 x2	1/2.5" 8.51M CMOS HD digital imager	$249.00 x2
Hydrophones	Advanced Navigation	Subsonus	Range of 1000***m***	Donated
Algorithms: vision	Darknet and YOLO			
Algorithms: acoustics	Proprietary			
Open source software	OpenCV			
Team size (number of people)	14			
HW/SW expertise ratio	9/5			
Testing time: simulation	20 ***hours***			
Testing Time: in-water	25+ ***hours***			