Desert WAVE: *Return of the Dragon*

N. Esquival Vazquez, P. Garibay Jaquez, G. Hernandez, L. Matancillas, N. Rodriguez, K. Vasudev, J. Villanueva Castro

Mentors: B. Emami, D. Frank, B. Kahn, D. Kahn, F. Lajvardi, F. Nueperger, C Trevino

Abstract - Desert WAVE (Women in Autonomous Vehicle Engineering), based in Arizona, is aimed to compete in the 2024 RoboSub Competition with the return of their Autonomous Underwater Vehicle, Dragon. Desert WAVE is made up of 7 students from different backgrounds.

Their competition strategy is based on strengthening reliability and accuracy in task execution. This is to be accomplished by improving Dragon's pneumatic system and enhancing the data collection process for waypoint navigation. Doing so allows Dragon to increase accuracy with every task, and a higher chance of consistent success. Along with that giving Dragon vision to further improve accuracy. With these improvements Dragon will be able to accomplish additional tasks such as bins and possibly shooting torpedos.

Dragon has 10 thrusters, a passive sonar, doppler velocity log, fiber optic gyroscope, and two cameras. Dragon is designed for tasks such as precise navigation, object manipulation, acoustic signal detection, and vision-based classification. With these sensors the team was able to fix the pneumatics issue and successfully be able to use pneumatics to drop the markers into bin and shoot torpedoes after testing and final adjustments.

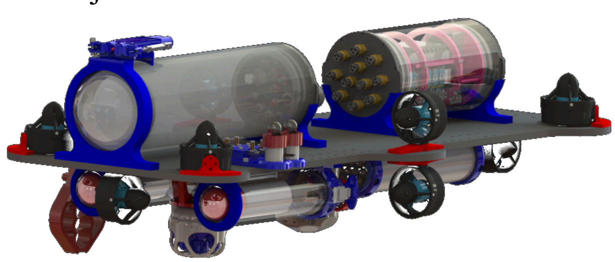

Fig. 1. CAD rendering of Dragon

Competition Strategy

Desert WAVE's competition strategy is based on strengthening reliability and accuracy in task execution. The goal is to accomplish this by improving Dragon's existing pneumatic system, incorporating vision correction, as well as making the data collection process for waypoint navigation more efficient.

I. General Strategy and Course Approach

For the 2024 RoboSub competition, Dragon will not be using machine learning for the task execution. Instead, Dragon uses a process called Dead Reckoning. Dead Reckoning calculates Dragon's position on the field using direction and distance traveled via landmarks. Desert WAVE can assign multiple waypoints for each task with longitude and latitude. Using Google Earth, we find visual markers near or around the course that are also present on the map, and draw a straight line. The intersection of these lines is the waypoint created for each task. Each intersection has to meet at a 90 degree angle to account for parallax, or the way light bends underwater. With this data collection process, Desert WAVE is able to create a map, similar to points on a grid, for Dragon to travel and execute tasks using HSV vision upon arriving at given waypoint.

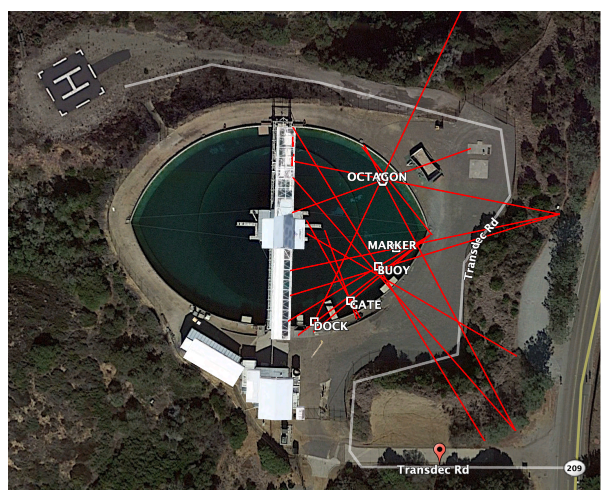

Fig. 2. Example of course survey used in previous years

The coordinates given to Dragon also decrease Dragon's course time, allowing Dragon to run the course 3 times in 20 minutes in last year's finals. Dragon also surfaced the Octagon three times in the final rounds, while other teams competing averaged one surface per match. The current method of waypoint collection gives Dragon an accuracy of one foot. Waypoint navigation is the general strategy for Dragon for a number of factors:

- Previous years competitions show consistent accuracy in task execution

- Reduces times per each course run, allowing Dragon to do multiple rounds of tasks per match
- Past experience in data collection and implementing navigation from team members

Factors such as limited time and water testing have made the complexity of machine learning not a priority for this year's competition. Instead, Desert WAVE has opted to improve its current navigation system. When creating waypoints, the team will be using a Leica GS18 GPS system. This tool brings our waypoint distance accuracy for each task from 1 foot to 1 inch. This will allow Dragon to be more precise in dropping markers in corresponding colored bins. Since Dragon is given coordinates with a smaller margin of error than before, it also allows Dragon to travel faster to each task.

Desert WAVE uses the DVL and FOG to calculate the distance traveled. Dragon knows its starting position, it can also determine our final position. Without good sensors, this is difficult to do reliably, since incorrect measurements will lead to complications; however, Dragon's sensors are highly accurate. Most teams use landmarks (see them with cameras or vision) to fix any errors they have. Dragon does not have much error to fix, allowing Desert WAVE to navigate without the use of vision or machine learning. Rather than using machine vision for navigation between tasks, we use computer vision to make minor adjustments in tasks such as the bins and torpedoes. This tool allows Dragon to get to the final stretch, inevitably increasing the number of points collected in each match.

A. Task Execution

1. Rough Seas

When starting the mission, prior to the coin flip, Dragon is aimed towards the Octagon; this is defined as 0 degrees. Using a prior coordinate from our course survey and Dragon being oriented towards the Octagon will allow Dragon to determine how to drive towards the gate. This allows Dragon to find the Octagon no matter how the AUV is oriented before using the mission switch. Once the coin toss determines Dragon's starting position (heads or tails), the mission switch is activated, initiating Dragon's movement.

2. Enter the Pacific

As Dragon progresses towards the first task, it will aim for Style Points by rotating to its maximum yaw orientation. This task marks the initial use of vision capabilities, activated once Dragon reaches the designated waypoint at each task. With our vision we will be choosing the red (CW) tasks since we have calibrated our HSV vision to recognize the red. The objective includes recognizing the clockwise (CW) flags positioned on either side of the gate and navigating through the red (CW) side for the rest of the mission. By sticking with our red (CW) challenges we are able to attain more points then following the color given.

3. Buoys

Upon reaching the task's designated waypoint, vision capabilities activate to identify the red buoy. Dragon executes a clockwise circle around the buoy, utilizing either a square path or ensuring the front-facing camera maintains focus on the buoy throughout its rotation. Once completed, Dragon proceeds to the next task.

4. Mapping

The software will detect and identify the largest red openings and align Dragon accordingly. This process will be sequential, focusing on one target at a time, as the system is designed to launch a maximum of two torpedoes per round. Upon target acquisition, the software will command the pneumatic system to activate the solenoid, which in turn will engage the piston to open the torpedo lid and launch the spring-powered torpedo.

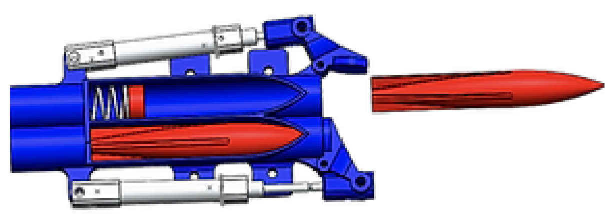

Fig. 3. CAD rendering of Dragons torpedo launcher

5. Bins

The waypoint navigation system guides Dragon to the designated task location. Upon arrival, the bottom-facing camera is activated and the vision system detects the red half of the bin. The software then instructs Dragon to align the marker dropper with the red side of the bin. Once aligned, the software commands the pneumatic system to activate the solenoid, which in turn engages the piston to release the pinball.

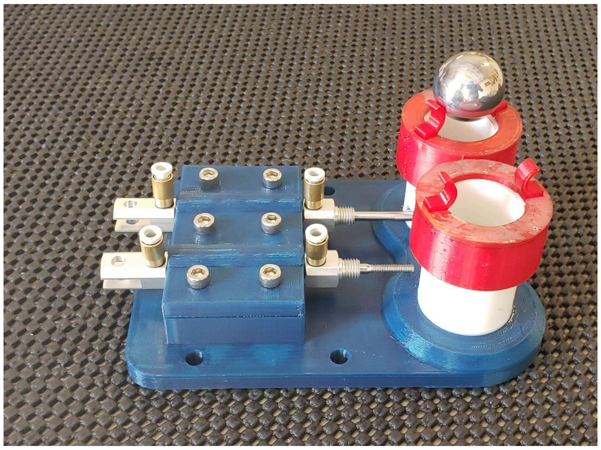

Fig. 4. Image of Dragon's Marker Droppers

6. Octagon

Upon reaching the proper waypoint, Dragon will surface within the octagon.

II. Design Strategy

Dragon's design was made with modularity in mind in order to reduce the amount of hassle when adding/modifying systems. All of which have been lessons learned from the team's first AUV, Phoenix.

A. Hardware

1. Chassis

The chassis of Dragon is designed with a modular approach. It features separate hulls for the computer, thruster speed controllers, two batteries, and pneumatics systems. This modular design facilitates damage control, especially in the event of a leak, it minimizes the impact of the failure. For example, having two distinct battery hulls ensures that if one hull experiences a leak, only the power supply to that specific hull is compromised.

To evaluate the buoyancy of the design, all hulls were initially mounted on a wooden chassis. This step was crucial before selecting the final material. In addition to enhancing damage control, the separation of systems also reduces the complexity of each module's design and allowed for multiple hulls to be designed and manufactured at the same time.

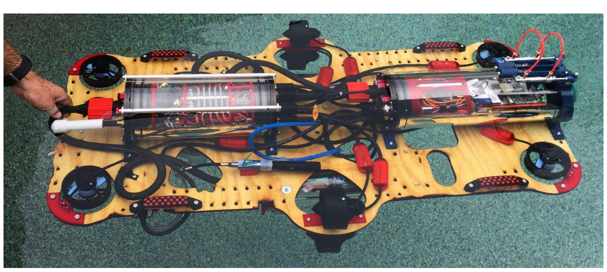

Fig. 5. Image of wooden practice frame of Dragon

The modular nature of the design necessitated the use of telemetry for communication between the electronic components. After thorough buoyancy testing, High-Density Polyethylene (HDPE) was selected as the material for the final frame due to its near-neutral buoyancy and machinability.

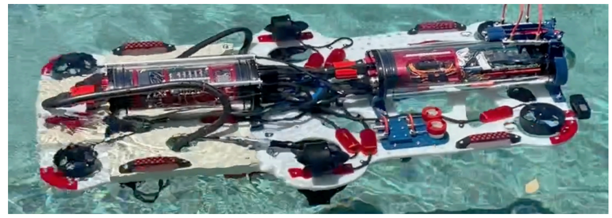

Fig. 6. Image of Dragons final frame made of HDPE

2. Thruster Hull

The thruster hull is designed to house all electronics associated with the thrusters. This includes components such as the fuse panel, speed controllers, LEDs, fans, and other necessary electronics. The thruster hull is powered by one of two 4-cell LiPo 16.8 V batteries.

For propulsion, Dragon utilizes 10 Blue Robotics T-200 thrusters. The configuration of Dragon's thrusters allows for both free rotation and translation with redundancy, ensuring robust and reliable maneuverability. This design aspect draws inspiration from the team's first AUV, Phoenix. The emphasis on speed in the surge direction in this configuration enables the team to perform more runs during the mission, thereby maximizing the time bonus.

3. Pneumatic Hull

The pneumatics hull is powered by the computer hull. The pneumatic system utilizes pressurized air canisters (CO_2 cartridges similar to those used in BB guns) and is controlled by solenoid valves. The system has the capability to operate up to eight solenoids, but only four are currently utilized for the torpedo and marker dropper manipulators. A student-designed pneumatics shield is responsible for activating these solenoids. This shield receives commands from the AUV main board located in the computer hull.

4. Computer Hull

The computer hull houses an Nvidia Xavier nx, two of the four student designed boards. All communication boards are in this hull, and is responsible for communications between subsystems. This is the AUV main and Sensor integration board. As well as the two cameras, one front facing and the other downward facing.

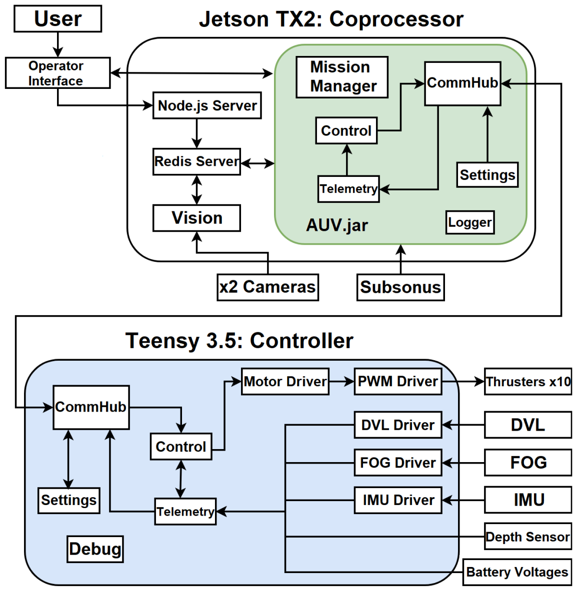

Fig. 7. Software Architecture of Dragon

An antenna/radio board is also located here which allows us to connect to Dragon when it is surfaced in the water. Fans are also located to circulate air while Dragon is on to avoid overheating of any components. These fans are controlled by a switch as placed in the hull. The hull can be removed to be worked on separately

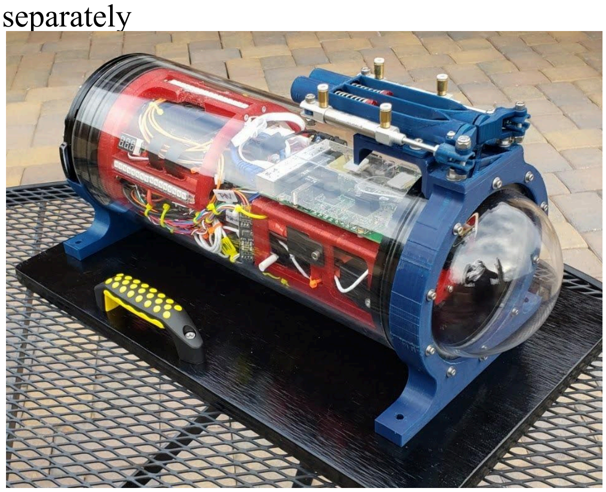

Fig. 8. Image of Dragon's Computer Hull (removed from main frame)

5. Battery Hull

The batteries are separated into different hulls to enable independent operation of the computer and thruster hulls. This design ensures that if one battery hull becomes flooded, the other hull remains undamaged, thus reducing potential damage. Additionally, this configuration allows for more efficient power distribution to both the computer and thruster hulls also reducing power fluctuation. If all our thrusters are being used at the same time it could cause the computer to brown out if both the thruster and computer are using one battery. Separating the two will stop this problem.

6. Electrical Boards

There are four custom boards designed by students. For example the AUV main board is responsible for sending and receiving commands across all boards. Detailed information about these boards can be found on our website and in the 2023 technical design report. The pneumatics board receives commands to activate solenoids and control manipulators, while the thruster board manages all ten thrusters. Additionally, the sensor integration board collects data from various sensors, including the FOG, DVL, depth sensor, and Subsonus.

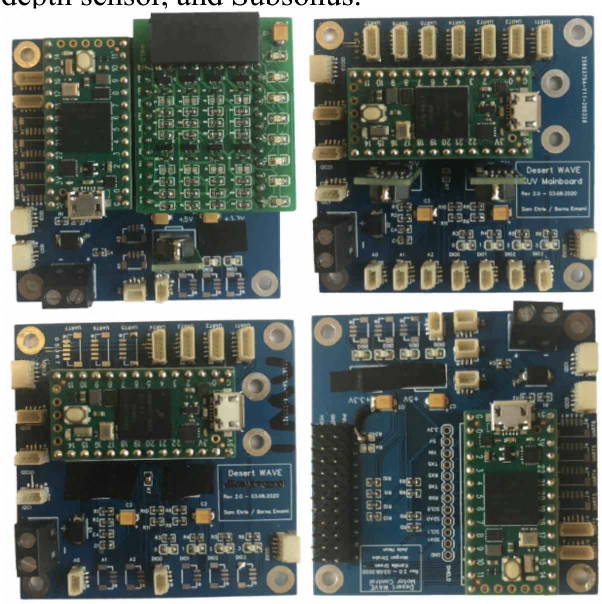

Fig. 9. Images of Dragons different electrical baords

B. Software

1. Vision

To significantly enhance the team's performance from the previous season, the team integrated computer vision into Dragon's system. By combining existing sensors, the team implemented an algorithm called waypoint navigation. This algorithm accurately pinpoints positions on the field and navigates to them with ease. However, for tasks such as navigating through gates, approaching buoys, launching torpedoes, and targeting bins, computer vision enables

precise position correction, aligning Dragon more accurately with the task at hand.
The vision processing system utilizes the HSV color space to detect the color red. The algorithm identifies the largest red region, encircles it, and places a dot at the center of the circle. These visual data points are then converted into coordinates that inform Dragon of the object's distance, allowing it to move 80% closer to the target without overshooting.
The system is equipped with two Leopard Imaging LI-IMX274-MIPI-M12 cameras: one front-facing and one bottom-facing, ensuring comprehensive visual coverage for navigation and task execution.

2. Fiber Optic Gyro (FOG)

A fiber optic gyroscope (FOG) operates by injecting two laser beams into a coiled fiber optic cable in opposite directions. It detects changes in orientation by measuring the difference in the arrival times of the two beams. A change in orientation results in one beam taking longer to reach the endpoint compared to the other.
Using this sensor over time has allowed the team to create even greater accuracy overtime. This fine-tuning process involves integrating the FOG with the doppler velocity log (DVL) and depth sensor to enhance overall navigational precision.

3. Subsonus

A hydrophone array is capable of detecting pings or sound waves emitted by a source and determining the direction of the incoming signals. When the transmitted signal is sent at a consistent frequency, the receiving hydrophone array calculates both the direction and distance to the source. This information is then used for precise navigation towards the transmitter.
Although previously not utilizing the Subsonus system in competition, the team has conducted acoustic testing with it on Dragon This season, the Subsonus system has been tested with that data from previous seasons, and with additional water testing, to determine the distance and direction from the ping transducer. Gifting the AUV with this capability for the random pinger selection task, and earning additional points by completing the task with the pingers in the correct order.

4. Doppler Velocity Logger (DVL)

The doppler velocity log (DVL) is an acoustic sensor that measures velocity relative to the seafloor. It operates by transmitting four acoustic beams (or "pings") towards the seafloor and calculating the velocity based on the return signal's response time. The displacement, which indicates the AUV's movement from its initial position, is determined by measuring the shift over a given period.
The team has consistently utilized this sensor over the years and has found it to be sufficiently accurate for competition. The DVL will be used this season to ensure reliable velocity and displacement measurements.

Positional Accuracy Testing with DVL

Distance (*m*) Measured by DVL	Test 1 Distance (*m*) Measured by Distance Meter	Test 2 Distance (*m*) Measured by Distance Meter
4.00	4.164	4.950
5.00	5.339	5.952
6.00	6.315	6.952
7.00	7.364	7.957

Fig. 10. 2023 Table showing DVL accuracy

III. TESTING STRATEGY

Desert WAVE is committed to consistent in water, out of water, and simulation based testing. Each main component of Dragon has its own testing process that are maintained by members of Desert WAVE to ensure maximum efficiency.

A. STRUCTURE

Solidworks, identify center of mass. Add weight to all the things on the dragon and test on CAD to see how to distribute weight.
Water testing: Listing (tilt left or right) attitude remains neutral (so it floats evenly) helps determine how we move weight, add weight or flotations.
HDPE started warping possibly because the material is thinner and may warp under Arizona heat. Added aluminum angle (L shape to give shape to HDPE and adds weight, so will need to retest weight distribution for buoyancy.

B. PNEUMATICS

In previous years Dragon's pneumatic system did not have the appropriate software to communicate properly. Desert WAVE tests pneumatics by connecting the computer directly to the pneumatics board, and ensures all solenoids can be fired. To ensure everything is electronically functional, communication is tested between the computer and the hull. Not only that the pneumatic system can fire a solenoid, but that the computer can also recognize that the same solenoid was fired.

C. THRUSTERS

Performing pre operational checks on all thrusters indicating specific directions of up, down, left, right, forward, back, and rotation. Once tested individually the team will test thrusters in tandem to ensure no overloads take place.

While updating the structure of AUV, the team added 4 aluminum angles along the body. While water testing, the angles obstructed the water flow causing the AUV not to properly yaw. In solution, cutouts on the aluminum angles were made where the thrusters are located to help water flow.(see fig.2.) Testing confirmed that after the cutouts were made the AUV was able to turn without issue

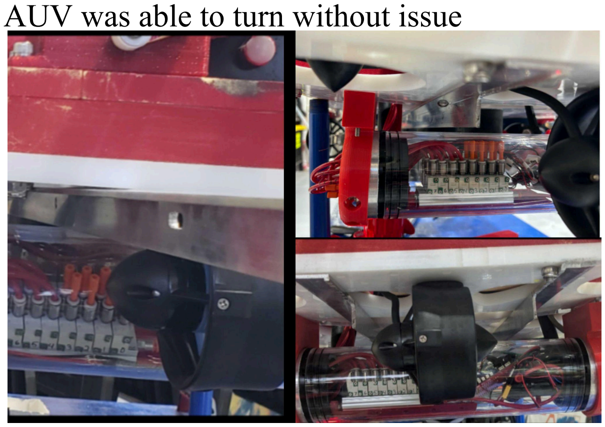

Fig. 11. Aluminum angle before cutouts (left) and Aluminum angle after cutouts (right)

D. COMPUTER VISION

Operator interface by seeing what Dragon can see and then we can use any algorithm or code we have to see if it can identify an image open CV (open library). Before testing the vision in the water the team checked the camera's view on Dragon and see if it is able to identify a red object out of the water. When testing that there was a weird filter on the camera that distorted the vision due to the red and blue on the camera's view. Later on that problem was resolved by editing the camera's view.

When finally being able to test the vision Dragon was placed into the pool with the red and blue bin about 8ft away. The team ran a five step process which involved taking a picture of where the bins are and then moving 80% of the way to get to the correct position and then take another picture and then move 80% of the remaining distance to center the AUV, and so on three more times. Dragon was sent off and the first time it saw the bin but couldn't align, so Dragon just ended the mission. The team fixed the code to make sure it would keep trying till it was lined up with the bins. That allowed Dragon to successfully identify the bin and drop the markers into the red side for the very first time.

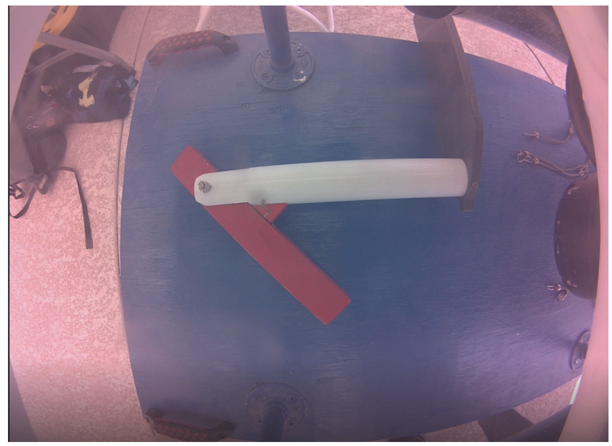

Fig. 12. Image captured with the red and blue hues

IV. CONCLUSION

The team's goal for this year was to give Dragon vision and be able to use pneumatics for the competition. To do this they were able to implement computer vision (CV) using HSV to see the red bin. With that software they were also able to implement the pneumatics software that made the hardware on Dragon from the previous year functional.

After recent tests they have been able to see that they have been able to do just that. With the time they have left they are able to test and fine-tune vision to ensure a smooth run at the competition.

V. ACKNOWLEDGEMENTS

Desert WAVE is immensely thankful for all the support from our parent sponsor, the Si Se Puede Foundation. The team would also like to thank the following: Falcon Robotics, Shebbies Life series, KVH, Intel, Advanced Navigation, Craigg and Barbara Barrett Foundation, Makerbot, Simrex, Princetel, SOAR, Connect Tech, Nvidia, IMC Networks, Port Plastics, Keen Engineering, State Farm, Pairmate, Hanney Reels, Solidworks, IBM, Western Alliance Bank Corporation, KST Digital Servo, and Blue Robotics.

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VII. APPENDIX A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom / Purchased	Cost	Year of Purchase
ASV Hull Form	• Port Plastics • Blue Robotics • Blue Robotics	• 6” enclosure • 6” enclosure • 3” enclosure x3	• 20” long • 11” long • 11.75” long	Purchased	• $125.00 x1 • $98.00 • $86.00 x3	2021
ASV Hull Platform	Port Plastics	HDPE sheet	.5” thick	Custom	$125.00	2021
Waterproof Connectors	MacArtney	• Optical Series • Circular Series	Industry standards	Purchased	• $5,000.00 • $3,000.00	2021
Propulsion	Blue Robotics	• T100 Thruster x10 • T200 Thruster x6	• Max thrust: 5.2 *lbf* • Max thrust: 11.2 *lbf*	Purchased	• $119.00 x10 • $169.00 x6	2021
Power Systems	Blue Robotics	LiPo batteries x2	4 cell, 18 *Ah*, 16.8 *V*	Purchased	$289.00 x2	2021
Motor Controls	Blue Robotics	Basic ESC x16	30 *A* brushless ESC	Purchased	$25 x16	2021
CPU	NVIDIA	Jetson Xavier	6-core NVIDIA Carmel ARM®v8.2 64-bit CPU 6 MB L2 + 4 MB L3	Purchased	$399.00	2021
Teleoperation	Microsoft	Xbox controller	Series X/S	Purchased	$26.00	2019
Compass	N/A	-	-	-	-	-
Inertial Measurement Unit (IMU)	KVH Industries	DSP-1760	3-axis	Purchased	$17,000.00	2021
Doppler Velocity Log (DVL)	Nortek	DVL 1000	300 *m* max operational depth	Purchased	$14,960	2021
Camera(s)	Leopard Imaging	LI-IMX274-MIPI-M12 x2	1/2.5" 8.51M CMOS HD digital imager	Purchased	$365.55 x2	2021
Hydrophones	Advanced Navigation	Subsonus	1000 *m* range	Purchased	$12,000.00	2021
Algorithms: Vision	-	MobileNet, Gaussian, Canny, approxPolyPD, Dilate	-	-	-	2019
Algorithms: Localization and Mapping	-	Waypoint navigation	-	Custom	-	2019
Algorithms: Autonomy	-	Linear state machine	-	Custom	-	2019
Open Source Software	OpenCV	HSV and machine learning	-	-	-	2021