Texas A&M University Women in Robotics, Engineering, and Development (WIRED) Autonomous Underwater Vehicle Team

Rebecca Bates, Letisha Chan, Ana Cruz, Rishika Desai, Anagha Dharmavaram, Adaku Duru, Alex Holmes, Azhure Landers, Mackenzie Lloyd, Adiba Mahjabeen, Gael Mamenta, Anna Miley, Jennifer Romero, Emma Stewart, Tharshini Subash, Raquel Susko, Kathy Vo

Texas A&M University, College Station, TX, USA

***Abstract*—Throughout this competition season, the Women in Robotics, Engineering, and Development Autonomous Underwater Vehicle (WIRED AUV) team has focused on creating a vehicle that balances innovative technologies with reliable functionality to increase learning and maximize the number of points scored. This year, emphasis was placed on navigation with this model of the sub. Wayfinding tools, including multiple cameras and a pinger, guide the sub through initial tasks such as the gate, buoy, and octagon. Implementing machine learning using these navigational devices allowed the team to combine the practices of object recognition algorithms with modular mechatronics, including a mechanical arm, to complete the bins and the octagon task so additional points could be earned.**

Keywords—Autonomous Underwater Vehicle, Women in Robotics, object recognition, doppler velocity logger

I. COMPETITION STRATEGY

A. General Strategy

The team's strategy for this competition cycle involves attempting tasks that do not require much physical equipment to reduce the strain on the systems of Guppy, the team's robot. With that in mind, the team's strategy was adapted to maximize the use of the technologies available.

With the addition of a working camera model and a mechanical arm, it was envisioned that more tasks could be accomplished this season. However, since the mechatronics were a recent addition, it was decided to attempt only the buoy, bin, and grabber tasks with the arm. To maintain simplicity, the arm was designed with only two degrees of freedom.

B. Coin Flip

The first task the team plans to complete is the coin flip. The AUV's front camera runs a machine-learning model trained to detect the gate, so it will first spin to the right until the model detects it.

C. Gate Task

The team will then complete the gate task. The front camera will detect the gate using the camera model mentioned, and the AUV will activate thrusters to move toward its right side.

D. Buoy Task

As the AUV passes through the gate, the front camera will detect the buoy and move towards it, allowing the AUV's mechanical arm to hit and go around it. Recent teams at A&M have not been able to hit the buoy because they lacked a camera model to detect it and an attachment to hit it. However, it was observed at past competitions that other teams used their AUV's mechanical arm or a pointer-like device to touch the buoy, so it was decided to have the AUV's mechanical arm hit the buoy.

E. Bin Task

The team's strategy involves detecting the bins with the AUV's bottom camera, prompting the AUV to move over the bin. The bottom camera will then verify the bin's position. Then, the mechanical arm will drop a marker into the side of the bin corresponding to the side of the gate that the AUV entered.

F. Octagon Task

The surfacing part of the Octagon task: would be done the following way:

First, the AUV's front and bottom cameras detect the octagon. It would then move towards the octagon and position itself beneath it. The bottom camera would then check the position of the AUV with respect to the bottom of the octagon. Once complete, the AUV will rise and surface. The introduction of a working camera model made detecting and surfacing in the octagon feasible.

For the grabbing task:

The AUV's bottom camera detects the shapes within the bottom octagon, prompting the AUV to lower. The mechanical arm will grab whichever object is the most convenient, determined through testing and analysis. This year's team had more time to develop a mechanical arm because the AUV's hull was finished earlier in the year. Additionally, the team bought waterproof servos, which allowed for a mechatronic element to be created.

II. DESIGN CREATIVITY

A. Mechanical Creative Aspect

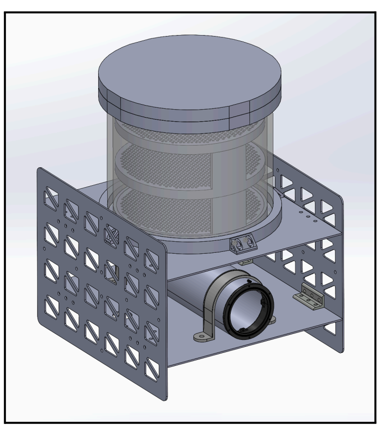

Figure 1: AUV Assembly

1) *Mechatronic Arm*

The AUV model includes a mechatronic arm that sits on the bottom plate, allowing for adequate movement and manipulation. The arm design includes two waterproof servo motors attached to the arm configuration with claw-like appendages for grabbing and holding objects [1]. The assembly therefore has two degrees of freedom, relegated to the pivoting of the arm and the closing of the claws.

It was decided that the body of the arm would be made from aluminum to accommodate the load capacity constraints of the servo motors. Aluminum supports the weight of the servos and is corrosion-resistant over time.

2) *Internal Frame*

The internal frame is a combination of perforated plastic boards and 3D-printed shelving designed for easy deconstruction and reconstruction. Each shelf houses electronic components that can be accessed by removing one of the shelves while maintaining electrical connections. The internal frame houses nearly all of the robot's internal components, including the Jetson nano, which serves as this AUV model's microcontroller.

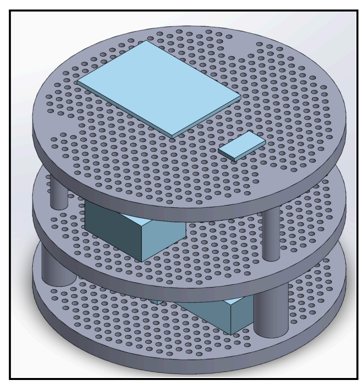

Figure 2: Isometric View of Guppy's Internal Frame

In this design, the material type was carefully considered. Some electrical components are exposed to high temperatures during consistent use, so a heat-resilient filament was necessary. ABS was chosen due to its lightweight, inexpensive material rated for temperatures well above 100°F, meaning that it can withstand any excess heat given off by the electrical equipment [2] [3].

B. Electrical Creative Aspect

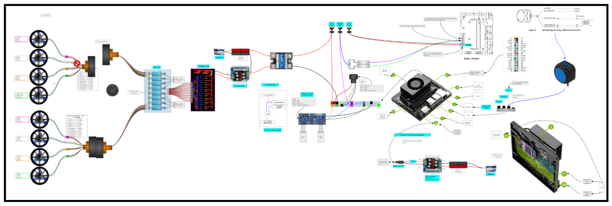

Figure 3: Full Electrical Schematic

1) *Switches*

This year, 4-pin, 12-volt button switches were used for the power, mission, and kill switches. They are push-button switches that use blue and red lights to indicate if they are on or off. This differs from the previous year's design, which used 2-pin switches that mechanically connected or broke their corresponding electrical connections by twisting and lacked a light-emitting mechanism. The additional number of pins and higher voltage requirements created some challenges when implementing the new switches, as they needed to be connected to a higher-voltage source than the Jetson Orin Nano provides and in more locations. This was resolved by adding parallel connections to the original buck converters used to power the Nano jetson. Both would be supplied by the 19 volts the buck converter outputs. The new switches make it easier for the team to determine when a switch is activated or deactivated due to its LEDs.

Additionally, last year's switches were hard to determine when switched on. The switch was a cap on a cable penetrator that activated an internal button when screwed in all the way in. To kill the thrusters, the cap would only have to unscrew a quarter turn. However, this ran the risk of unscrewing it too much and water getting into the hull. The four-pin switches have the same format: one pin for power, ground, switch 1, and switch 2. Once ground and power are connected accordingly and powered on, it would cause the pins of switch 1 and switch 2 to be bridged as one.

2) *Jetson Orin Nano*

This year, the team used a new Jetson, the Jetson Orin Nano, as the robot's microcontroller. This change enabled the implementation of a functional camera model that successfully detects objects in the water.

The new version of the Jetson changed the team's wiring. The Jetson Nano can be operated without a tether by using the wifi to send the code to the Orin Nano, unlike the Jetson TX2 [4] [5]. Not using the tether would make it less likely for the vehicle to get stuck on any obstructions underwater.

The program and data can be delivered effortlessly when the Jetson is tethered to the software laptop. However, when the team tried to connect to the Jetson through their school pool's WiFi, it struggled to connect to the AUV. Thus, the team decided to keep the AUV tethered during practice runs and pool tests to relay data consistently.

3) *Fuse Board PCB*

The Fuse Board PCB in Guppy integrates multiple fuse holders to protect the ESCs and thrusters from overcurrent. Each fuse holder is rated for specific current loads, ensuring optimal protection for connected subsystems. The board features connectors that maintain its electrical connections as the AUV moves, with a layout that includes clear labeling for each fuse, facilitating accurate and efficient installation. The decision to include a centralized fuse board PCB reduces the volume of wiring within the electrical system, preventing clutter and potential wiring errors. Compared to last year's design, where fuses were scattered throughout the electrical system, the centralized Fuse Board design significantly improves accessibility and maintenance efficiency.

4) *Camera Box*

To establish a connection to the camera, the team opted for a straightforward design by feeding a cable through a 5mm hole in the camera box to guarantee its safety. However, an issue was encountered with the USB-A to USB-C cable. Due to its vertical design, the USB-C connector was too wide to pass through the 5mm hole. The team considered separating and resoldering the wires but found that the USB-A 3.0, designed for data transfer, has more complex wiring than expected based on a USB-A 2.0. Consequently, the resoldered cable resulted in a very weak transmission. Other options, such as an adaptor, were considered, but most adaptors were incompatible with the USB-A 3.0. Therefore, the team decided to attach the camera to the cable without using the camera box.

C. Programming Creative Aspect

1) Code Structure

There are four primary sensors that send information to the Nano. With help from the pressure sensor, the pinger sends the vehicle's depth, checking it is not about to surface or hit the floor. The front camera searches for obstacles, and the bottom camera positions the vehicle above the dropper and octagon bins. The DVL tracks the global position. The Nano takes this information, and the code determines which direction the thrusters run. When it is time, the mechanical arm drops the marker and moves objects.

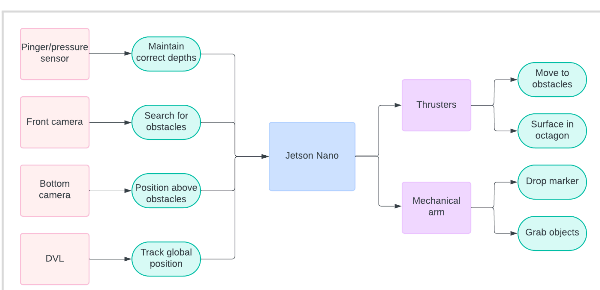

Figure 4: Structure of code for competition

2) Front Camera

A machine learning model runs on a ZED Mini to detect all the tasks the team plans to complete. The buoy images were sourced from Roboflow, and the team took and annotated the rest. The model outputs the detected object's label and its x- and y-coordinates in the image.

3) Bottom Camera

The bottom camera is used to detect the dropper bins, the grabber bins, and the grabber objects using a separate machine-learning model. It is positioned on the vehicle's bottom plate, tactically off-center to provide room for all the sensors needed on the bottom. This code was calibrated with this in mind.

4) Doppler Velocity Logger (DVL)

This year, a DVL was integrated. It utilizes sonar to determine speed, which can be used to measure the distance the AUV has traveled. This sensor provides global mapping, something the vehicle lacked in previous years.

III. EXPERIMENTAL RESULTS

A. Mechanical

The team's test strategy involved systematically testing mechanical and electrical systems as they are brought online, in conjunction with simulating the programming aspects of the sub. Initially, tests focused on verifying water-tightness and buoyancy as well as calibrating the thruster configuration.

Initial testing showed a minor leak due to a small abrasion in the surface of the cap near the pressure sensor, and Guppy exhibited positive buoyancy. To address these issues, water-rated epoxy was applied carefully around the pressure sensor to prevent further leakage, and dive weights were spaced evenly to keep the sub neutrally buoyant. Bubbling was also observed around the top cap, but there was no leak; it was decided that latches would be installed to guarantee a tight seal. The latches will also prevent pressure buildup and maintain water-tightness.

The front camera in the original design had a separate water-tight enclosure attached to the top cap. Unfortunately, neither the seal holding it to the cap nor the seal around the lid was secure. Additionally, the electrical team's attempts to splice the USB to fit through the cable penetrator were met with little success. To mitigate this, the ZED mini was placed inside the hull. Despite the hull's curved shape and blue tint, the ability to detect objects was not compromised.

Further test runs were conducted to check what speeds each thruster ran, ensuring that Guppy ran in a straight line. This, coupled with the thruster code, allows the simulation of qualification runs in advance so the team can troubleshoot any issues. The coding aspects of these trial runs are discussed in further depth in the "Programming" section.

B. Electrical

The electrical subteam performed out-of-water tests to verify that the switches worked and that the tether transferred power to the AUV. These tests showed that the Jetson couldn't connect to the internet when moving from the engineering building to the school's recreation center. Rather than being tetherless, the team returned to testing with the tether after the initial pool test.

Initially, wiring the AUV moved slowly as the electrical subteam struggled to find and configure a working buck converter to perform the proper voltage drop. Most other components couldn't be tested without fixing this issue since the batteries had a higher voltage than most components could handle. Once this issue was resolved, the focus turned to creating and testing sections of the circuit. The team worked to mimic the conditions of the entire circuit to test each component.

The team began by soldering connectors onto wires for the switch. However, the connectors were extremely loose and were susceptible to disconnections due to vibrations or movement. To address this, the wires were soldered directly onto the switch, providing a more secure connection compared to using potentially loose connectors. Additionally, connectors were added to the ends of the wires that connect to the Jetson, allowing for easier disconnection and reconnection when working on components inside the AUV. This approach ensures a stable electrical connection and enhances modularity and practicality. It accommodates the need to work inside the AUV while maintaining reliable connections, which is crucial for maintaining operational integrity.

The AUV has three switches located on the outside of the vehicle: the power switch, mission switch, and kill switch. The subteam tested each switch's functions using a breadboard connected to buck converters to simulate the same voltage the switches would receive in the full circuit. Initially, the wires were secured with tape onto the switches, but they were unreliable and would cause faulty electrical connections. Instead, they were soldered on and had to be tested to prevent potential short circuits or poor connections, especially as the switches are connected to the Jetson, a costly and essential component. The team must ensure they do not cause permanent damage or fry a part that would take time and money to replace. Once the switches performed as expected with the proper voltage input and output, the team was confident enough to add the Jetson to the test circuit.

The team utilized a power supply and a multimeter to test components like buck converters and switches. After setting each component to a specific voltage potential, the team measured the output voltage using the multimeter. To validate the component's functionality, the buck converter exhibits an output voltage lower than the input voltage. Conductivity was repeatedly assessed to ensure the component's electrical integrity.

C. Programming

Using a new computer, the Jetson Nano had to be set up from scratch. After flashing it, the next step was establishing a connection to a laptop so the Nano could run the code while the vehicle was in the water. An unknown error occurred during this process, causing the Nano to no longer connect even through HDMI. Ultimately, the team had to reflash the operating system and start over, setting up NoMachine as the connection software.

Last year, the camera model was developed using MATLAB's deep learning software, which is incompatible with the ARM processor. Therefore, the camera models for both cameras were trained using Roboflow's AutoML. The buoy photos were collected from public datasets on Roboflow. The rest of the obstacles were built by the mechanical Subteam for photos. The model is run on the Jetson Nano using OpenCV to take the images and run them through interference. The team used the code provided by Roboflow and expanded it to meet the team's needs [6].

To ensure the model's functionality, it was trained first using only buoy images, resulting in a precision of 98.7%. The detection on the Nano was tested with the ZED Mini, and the code was optimized to work with the stereovision camera available [7]. The main issue was combining the images of the two lenses by overlaying them. The code was expanded to center the camera on the buoy and drive toward it. After completing this, the team incorporated the rest of the obstacles into the models.

The team attempted to integrate the DVL but faced issues. While its purchase was confirmed in November 2023, it didn't arrive until several months later. Therefore, due to the complicated nature of the DVL and time constraints, it could not be integrated into the robot in time for competition. Other components that were more crucial for completing tasks were prioritized. While the DVL would have been incredibly helpful for mapping, it was not necessary.

IV. ACKNOWLEDGEMENTS

The WIRED AUV team would like to thank the following sponsors: Phillips 66, Williams, L3 Harris, Lockheed Martin, TC Energy, and the College of Engineering. The monetary support these sponsors provide makes travel and the vehicle's fabrication possible.

In addition, we would also like to thank the Zachry FEDC and its staff for letting us utilize its workspaces and machines and giving us a place to house our robot. Their services were vital for the success of our robot. We would also like to thank the TAMU Recreation Center for giving us a space for our pool tests.

Lastly, we would greatly like to thank our mentors, Dr. Saira Anwar and Dr. Shawna Fletcher. Their mentorship was invaluable in the supervision of project activities, encouraging the team's personal and professional growth and the re-establishment of our team following the dissolution of our sponsoring department.

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Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of Purchase
Frame	Team Storage	6061 Aluminum Plate	Additional manufacturing and drilling to the previous model	Custom	-	2023
Hull: Tube	McMaster-Carr	Polycarbonate Tube	ID: 11 3/4”, OD: 12”, L: 14”	Purchased	$185.05	2018
Top Cap	Midwest Steel Supply	6061 Aluminum Rod	Size: 14in Length: 1in	Purchased	$225	2023
Bottom Cap	Midwest Steel Supply	6061 Aluminum Rod	Size: 14in Length: 1.75in	Purchased	$179.82	2023
Waterproof Connectors	Subconn & Blue Robotics	Blue Robotics Cable Penetrators	Circular Series 12-pin	Purchased	$600	2022
Propulsion	Blue Trail Engineering	Blue Robotics T200 Thruster	T200	Purchased	$1,960	2023
Servo	Blue Trail Engineering	SER-2020	+/- 230 deg, used for manipulator	Purchased	$495	2023
Motor Controls	Blue Robotics	R3	7-26 volts, 30 amps, Spade terminals, Tinned Wire Ends, L 1.38’, W .67’	Purchased	$200	2020
CPU	NVIDIA	Jetson Nano	4 GB, 25.6 GB/s of memory bandwidth	Purchased	$148.95	2023
Inertial Measurement Unit	VectorNav	VN-100 IMU/AHRS	3-axis gyros	Team Storage	-	2016
Doppler Velocity Logger	Teledyne Marine	Wayfinder DVL	600 kHz Bottom Tracking, Long Term Accuracy ±1.15%	Purchased	$4,959	2023
Top Camera	ZED	ZED Mini	100 Hz FPS, 0.1 - 15 m depth range	Purchased	$399	2023
Bottom Camera	Blue Robotics	Low-Light HD USB Camera	Sony Exmor IMX322 / IMX323 1920(H) x 1080(V)	Purchased	$117.54	2018
Algorithm: Vision	Roboflow	Inference	Object detection model	-	-	-
Vision	OpenCV	-	Runs camera	-	-	-
Pressure Sensor	Blue Robotics	Bar30 High-Resolution	300m depth, 2mm depth resolution	Purchased	$91.50	2023

Pinger	Blue Robotics	Ping2 Sonar Altimeter and Echosounder	25-degree beam width, 300-meter depth rating	Purchased	$435	2022
Programming Language	Python	Python 3	Installed on Jetson	-	-	-
Buck Converter	ANMBest	DC 6-40V to 1.2-36V 20A 300W Buck Converter	60×53×27 [mm] 2.36×2.08×1.06 [in]	Purchased	$19.99	2022
Solid State Relay	CGELE	DC to DC Input 3-32VDC To Output 5-240VDC 25A Single Phase	58 x 45 x 32 [mm] 2.3 x 1.8 x 1.26 [in]	Purchased	$9.90	2018
Lipo Batteries	Turnigy	Turnigy High Capacity 16000mAh 6S 12C Lipo Pack w/XT90	183 x 77 x 70[mm]	Purchased	$163.83	2018
LED Switches	Generic	22mm Waterproof Push Button 12V 24V 110V 220V IP68 Momentary Latching	22 [mm]	Purchased	$27.99	2022
Fuseboard	Electronics Salon	Panel Mount 10 Position Power Distribution Fuse Module Board	150 [mm] x 72.5 [mm] x 29 [mm]	Purchased	$28.00	2018
PWM Servo Driver	Adafruit	Adafruit 16-Channel 12-bit PWM/Servo Driver - I2C interface - PCA9685	"62.5 x 25.4 x 3 [mm] 2.5 x 1 x 0.1 [in]."	Purchased	$14.95	2023
Electronic Speed Controller	Blue Robotics	Basic ESC	17.1 [mm] x 32 [mm]-	Purchased	$304 (8x$38)	2023

Appendix B: Proposed Mission Plan