Texas A&M University Women in Engineering Autonomous Underwater Vehicle Team

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***Abstract*—The Women in Engineering Autonomous Underwater Vehicle team aimed to create a vehicle that balanced complexity and reliability in order to earn the maximum number of points at competition. The team's focus lay in the tasks at the beginning of the course including the gate, buoys and bins. Through the use of machine learning and object detection algorithms, the task's locations could be identified and navigated to. The use of novel mechanisms including a rotating dropper and mechanical arm will allow the AUV to complete these tasks. In addition to this core strategy, a three hydrophone array was developed to allow the vehicle to navigate the octagon task and earn additional points.**

Keywords—Autonomous Underwater Vehicle, Women in Engineering Program, hydrophones, machine learning

I. COMPETITION STRATEGY

A. General Strategy

This year the team aimed to add additional capabilities while maintaining the reliability of the core designs developed in previous years. The major addition was the implementation of a hydrophone system, which would allow the team to reach additional tasks and earn more points. It was decided to focus on the gate, buoy, and bin tasks as the core of the team's goals since these tasks fell within the engineering expertise of our members. The team's additional goal was to implement the hydrophone system once the rest of the vehicle was functioning reliably, allowing the vehicle to reach the octagon task at the end of the pool and earn additional points.

B. Gate Task

With the gate task being mandatory for qualification, this was the highest priority task for the AUV to be able to complete. Eight thrusters positioned symmetrically along parallel side panels are divided equally between surge and heave orientations to allow the AUV to maneuver through the gate.

C. Coin Flip Task

In order to accomplish this task, the programming team plans to use spatial mapping, localization, and Machine Learning (ML). First, ML can be used to determine that the gate is present (object detection). Then, in order to figure out the position of the gate, we can use localization and move appropriately towards the gate or angle and then move towards the gate.

D. Buoy Task

The buoy task can be reached by navigating using the path markers on the bottom of the pool. This is accomplished by utilizing our ML model to determine that buoys are present, and then we can use localization to appropriately navigate through the path. Once the buoys are detected, an aluminum arm attached to the AUV will be used to touch the appropriate buoy.

E. Bin Task

Once the buoy task is completed, the path will be followed using the same techniques outlined in the buoy task section. The lids of the bins will be lifted using the hooked ends of the aluminum arm. The dropper design consists of a 3D printed holder connected to a servo that will rotate, thus pushing the markers (golf balls) out of the apparatus.

F. Torpedo Task

The team decided to skip the torpedo task and focus on gaining the maximum number of points from the other tasks. This decision was made based on time constraints and a desire to focus on minimizing the complexity of the system, which would in turn limit potential malfunctions.

G. Octagon Task

The newly implemented hydrophone system will be used to reach this task. In order to complete this, sound localization will be used to determine the offset between the hydrophone signals from the AUV to the pinger[1]. In order to surface the octagon, object detection will be used to detect the octagon, and spatial localization combined with depth perception will help the AUV understand how far it needs to move to surface the octagon.

II. DESIGN CREATIVITY

A. Mechanical Creative Aspects

1) *End Caps*: An end cap on each side of the hull secures the internal frame components. The front end cap contains a cut out for the Zed Mini camera to see through.

Fig. 1: Front End Cap

An acrylic panel was selected to cover the cut out to minimize image distortion, and a gasket in a channel along the outer rim of the piece ensures the AUV stays watertight.

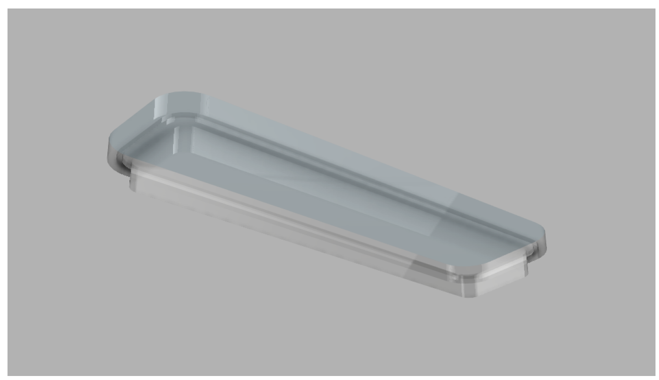

Fig. 2: Rectangular Acrylic Piece

2) *Midcap Panels*: The midcap panels secure two side gaskets on the midcap for the AUV, ensuring it is watertight. One-eighth of an inch neoprene rubber was selected for the gaskets as part of a compressive face seal. This design was chosen to allow for the reuse of the expensive main midcap year after year while allowing easy replacement of the midcap panels. This is important as the electrical system changes, which then requires different holes for running wires between the inside and outside of the vehicle.

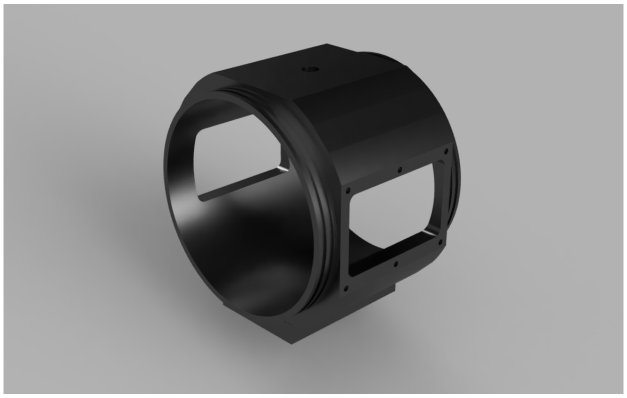

Fig. 3: Midcap

3) *Internal Frame*: Housing the majority of the AUV's electrical components, the internal frame was designed with space for each board and its air flow and wire requirements using different colored "blocks". The Jetson TX2 was the largest component and defined the minimum dimensions. Components interfacing most with the Jetson TX2 are positioned central to it, and additional components are placed on shelves extending from the central frame on aluminum L brackets.

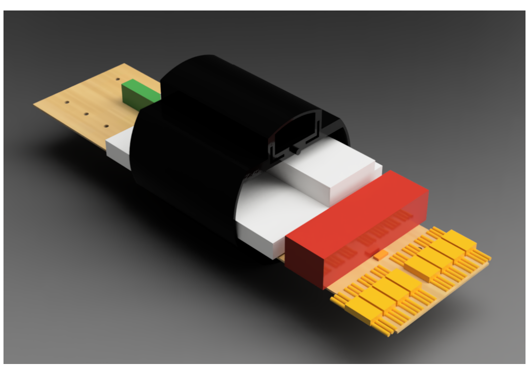

Fig. 4: Internal frame with electrical component "blocks"

An additional consideration for the internal frame was its material. It needed to be lightweight, inexpensive, and capable of withstanding the heat from the electrical components (a maximum of 200°F). The selected material was ABS at 1.03 g/cm^3, $1.50/ lb, and a rating for being able to withstand 185°F [2].

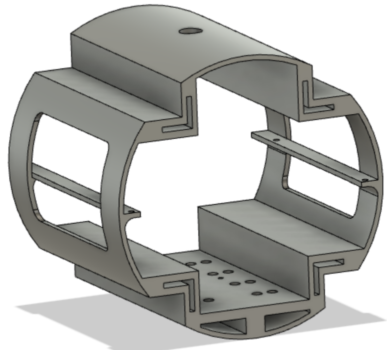

Fig. 5: Internal Frame

4) *Aluminum Arm:* The arm was designed with the goal of assisting in accomplishing the buoy and bin tasks. It was designed with cutouts to minimize weight and improve the vehicle's hydrodynamics.

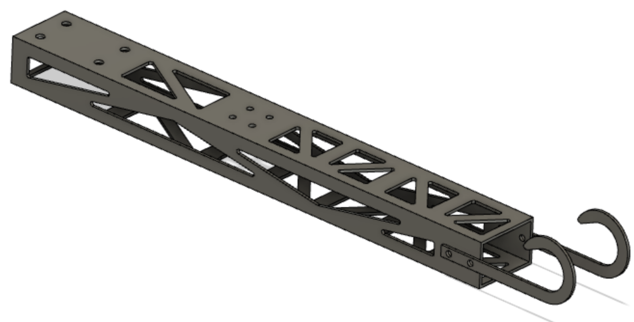

Fig. 6: Arm

5) *Dropper:* The dropper is a 3D printed design consisting of a cylindrical holder and a four-winged fan in the center. The fan is controlled by a servo and pushes the markers (golfballs) through an opening.

B. Electrical Creative Aspects

1) *Hydrophone Array:* For the first time, the electrical team will be creating a microphone array. The array consists of three hydrophones placed equally apart from each other in a triangular pattern. The exact placement of the hydrophones allows for the three hydrophone signals to be compared in set to determine the position and angle of the

pinger. By creating a custom PCB allows for the hydrophone signal to be filtered using hardware, then later using software in the Teensy 3.5.

C. Programming Creative Aspects

1) *Camera*: The AUV will utilize the Zed Mini Camera, which has built-in depth perception, in order to detect objects underwater. Connecting this camera with our Machine Learning (ML) model will allow us to use object detection to identify the item detected by the camera and perform the appropriate task. The ML model utilizes Python and the *Detecto* library to learn certain features of the underwater object. The correct detection of the object will lead the AUV to perform the appropriate task.

2) *Detecto*: Detecto is an object detection library created by students at Duke University. The AUV utilizes this library along with built-in libraries in Python, namely TensorFlow, to create a Machine Learning (ML) model that can detect underwater objects. This ML model analyzes the characteristics of the images and classifies them as one of many labels (Bottle, G-man, etc.). Once the model has successfully detected the image, it can then perform the appropriate task.

```
for image in training_dataset_images:
    print(image)
```

```
print("The length of the dataset is: ")
print(len(training_dataset)) #Check that there is information in the dataset

#Possible predict files
AUV_model = Model(['Bootlegger', 'bootlegger', 'bottle', 'phone', 'tommygun', 'badge', 'barrel', 'gman', 'octagon', 'Pape
```

Fig. 6: Code from ML Model

3) *ROS*: ROS stands for Robot Operating System and is an open-source software that allows robots to receive commands from the sensors, interact with the camera, and coordinate data transfer among the entire software system. ROS is used to simulate an environment for the AUV and connect all of the various components together, including sensors, computers, and microcontrollers. Another main part of integrating ROS with the AUV involves creating nodes that communicate data and publish the topics for different components as well as creating controllers for any hardware that moves.

4) *Spatial Mapping and Localization*: The AUV will utilize spatial mapping and localization (through the use of SLAM Matlab) in order to determine the position of the object to be detected. We will be utilizing the lidar data we acquire from the ZED Mini camera and SegMatch (plane recognition algorithm based on segment matching) to build a map and localize the position of the AUV on the map.
SLAM MatLab utilizes signal processing and pose-graph optimization to determine the amount of movement needed (localization) and to create a map of the robot's surroundings (mapping).

III. EXPERIMENTAL RESULTS

A. Electrical

The overall setup of the electrical system is seen in Fig. 7, where the internal components are listed within the dotted line, and everything else is placed outside the vehicle. The flow of power and/or data is identified by the arrows in the schematic.

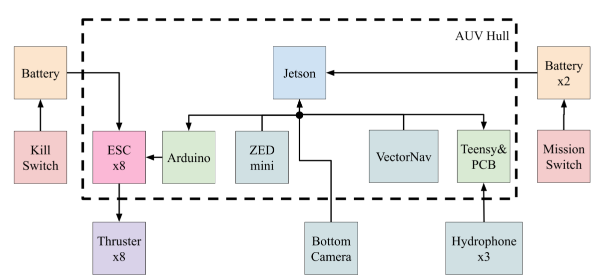

Fig. 7: Simplified System Schematic

The process of filtering the raw data from the hydrophone is a multistep procedure, seen in Fig. 8 to the right. The first step is to use a custom PCB to amplify the signal received from each of the hydrophones, then pass the signal through a bandpass filter to block out the unwanted frequencies.

The waveform is then sent to the Teensy, which computes the digital signal conditioning and processing of the hydrophone data. The signal is conditioned to reduce noise in order to isolate the frequency of the pinger. When each of the hydrophones have isolated the pinger, the filtered signal is sent back to the Jetson for further computation.

The final signal of the hydrophone will have been processed in a way to isolate the frequencies in the 25-40kHz range and to reduce noise within the signal. Using this information, sound localization can be calculated to determine the distance and direction of the pinger from the AUV. The hydrophones are placed in a triangular pattern, and calculated using a cross correlation time delay estimation method.

B. Programming

After creating our initial Machine Learning model, our team tested the model by uploading an image (e.g. a picture of g-man or badge or phone, etc.) and observed the recorded label (‘g-man’, ‘badge’, ‘phone’) to see if the model was successfully able to classify the image, in order to understand which tasks to complete in the future. In an earlier phase, we found that images were classified correctly with the first outputted label.

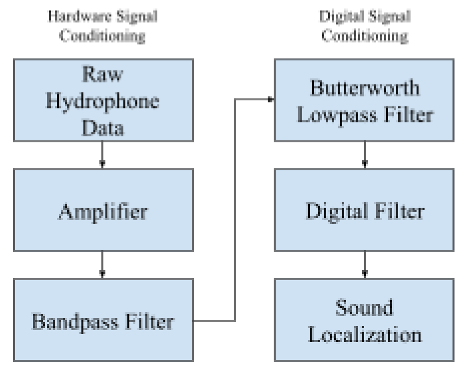

Fig. 8: Signal Conditioning Process

IV. ACKNOWLEDGMENTS

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V. REFERENCES

[1] "Sound Localization for Ad-Hoc Microphone Arrays," Energies 14, no. 12: 3446. Liaquat, Muhammad U., Hafiz S. Munawar, Amna Rahman, Zakria Qadir, Abbas Z. Kouzani, and M. A.P. Mahmud. 2021.

[2] “Best Heat Resistant 3D Printing Materials,” BCN3D Technologies. Barcelona, Gava, Spain. June 5, 2020.

Appendix A: Component Specifications

Component	Vendor	Model/Type	Specs	Cost
Frame	Metal Supermarkets	Aluminum 6061 T6	Additional bottom frame panel added to 2018-2019 AUV Frame	$50
Hull: Tube	McMaster-Carr	Polycarbonate Tube	ID: 7 ¾", OD: 8", L: 8'	$185.05
Hull: Midcap	In House	Aluminum 6061 T6	Reused from 2017-2018 vehicle	
Endcap	Online Metals	Aluminum 6061 T6	D:8 in H:1 in Thickness: ¼ in	$405
Endcap Window	Home Depot	Clear Plexiglass Acrylic Sheeting	L: 8 in W: 2.5 in Thickness: ¾ in	$24.29
Waterproof connectors	Subconn & Blue Robotics	Blue Robotics Cable Penetrators	Subconn: Circular series 12 pin	$600
Thrusters	Blue Robotics	T200	T200	$1,352
Motor Control: ESCs	Blue Robotics	R3	7-26 volts, 30 amps, Spade terminals, Tinned Wire Ends, L 1.38',W .67'	$200
Batteries	Hobby King	Lipo	22V, 16000mAh	$90
Converter	Mini-Box.com	M4-ATX	250W, 6-30V	$79
CPU	NVIDIA	Jetson TX 2	8 GB, 59.7 GB/s of memory bandwidth	Donated
Kill Switch	Grainger	Waterproof Switch	5A @ 28VDC	$99.2
External Comm Network	Blue Robotics Fathom Tether	Cat5 Ethernet Cable	100 m long Crossover Ethernet	$900
Inertial Measurement Unit	-	-	IMU is embedded in the stereo vision forward facing camera. See below.	-
Camera	ZED	ZED Mini	100 Hz FPS, 0.1 - 15 m depth range	$399
Programming Lang 1	Python	Python 3	Implemented on NUC	$0
Programming Lang 2	Arduino	C programming - Register level	Implemented on Arduino Mega 2560	$10
Application Programming Interface	Keras	Keras 2.3.0	API built on top of TensorFlow 2.0	$0
Development Board	Teensy	Teensy 3.5	MK64FX512 processor, Cortex-M4 Core	$0
Pressure Sensor	Blue Robotics	Bar 02 Ultra High Resolution	3.3V, 10 m depth, 0.16 mm depth resolution, 13 cm in-air altitude resolution	$88
Algorithm: Vision	OpenCV	3.2	Color Thresholding, Contour Detection	$0
Algorithm: Autonomy	PID control MonoSLAM	-	Extended Kalman Filter	$0
Open Source Software	Github	-	Currently getting organized	$0
Open Source Software	TensorFlow	TensorFlow 2.0	Python Library	$0
Team Size	-	-	64 Members	-
HW/SW ratio	-	-	3:1	-
Testing Time	-	-	10 hours	-

Appendix B: Project Team's Workshops

<u>*Project Team's Workshops*</u>
Supported by the Women in Engineering Program at Texas A&M University

This year the team hosted a variety of in-person and hybrid workshops centered on developing technical skills and promoting professional development. These workshops were led by senior members of the team and aimed to provide introductory skills as a way to build confidence in members and provide a base level of knowledge to utilize in the design of our vehicle. A central focus of the professional development workshops was creating a safe space for team members to ask questions and share their experiences. Senior members of the team hosted an internship experience panel, an undergraduate research panel, and an Entry to a Major Panel, all of which were used to create a platform for sharing advice, mentorship, and experiences. In addition to these workshops, the team conducted two design reviews with Texas A&M professors and industry sponsors. These events were critical for receiving feedback and mentorship on our designs.

The following workshops were hosted this year:
Mechanical

- Introduction to Fusion 360
- Mill Basics
- Lathe Basics

Electrical

- Circuits and Components Basics
- Multisim Basics
- Active and Passive Filters

Programming

- Introduction to Python and C++
- Introduction to Git and GitHub

Professional Development

- Internship Experience Panel
- Entry to a Major Q&A Session
- Getting Involved in Undergraduate Research Panel
- LinkedIn Workshop
- Industry Networking Events with sponsors
- Design Review with sponsors

Presentation at design review with industry sponsors

Presentations at Introduction to Git and GitHub Workshop