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

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***Abstract*—In preparation for the 2021 RoboSub competition, the Texas A&M University Women in Engineering Team researched, designed, and updated Ray; our multifunctional and versatile Autonomous Underwater Vehicle. Through increased training of underclassmen members and application of engineering principles, our current design builds upon the foundation of our previous vehicles. Overall, the Texas A&M University Women in Engineering AUV Team aims to build technical and leadership skills outside of the classroom while building a community of like minded individuals interested in the exploration of autonomous control and aquatic engineering.**

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

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) pioneer a new field of underwater discovery. At Texas A&M, Women in Engineering sponsors an AUV team to help underrepresented students in the Texas A&M College of Engineering develop technical skills in a supportive environment. The team focuses on recruiting and training students in their first and second years and providing ample opportunities to learn hands-on skills and grow through leadership positions. This year was the teams' sixth year and was conducted entirely in a virtual environment. The team adapted through virtual workshops and meetings and reached an impressive size of 82 members despite the challenges of the pandemic.

The team consists of three subteams: mechanical, electrical, and programming. The mechanical team focuses on creating both the outer and internal frame of the vehicle, as well as mechanisms to accomplish competition tasks. The electrical team works on power distribution and circuitry for sensors. The programming team examines machine learning algorithms and creates code to direct the thrusters and other vehicle sensors in order to maneuver the vehicle effectively. Each subteam has their own lead to organize their members and weekly assignments. The subteam leads work with the AUV admin team which consists of the project lead, project manager, and team assistant. Multiple tiers of leadership allow the entire team to be on the same page and ensure that communication between subteams is smooth.

II. DESIGN STRATEGY

A. Takeaways from Previous AUV

This year's vehicle, Ray II, is largely modelled after 2020's submarine, Ray, which was unable to be completed due to the pandemic. Ray II has been downsized from previous years' models, sporting a smaller hull that will reduce the volume of the vehicle's fluid displacement, which will in turn lessen the additional mass required to approach neutral buoyancy.

The team also added two custom mounting installments: a camera mount and an internal frame. The internal frame aimed to reduce the clutter of previous years' vehicles and improve the organization and accessibility of internal electrical components.

Additionally, the team focused on simplifying and consolidating computing modules in order to improve performance and reduce clutter in comparison to previous years. This was done through the incorporation of the Jetson TX2, as well as a new Zed Mini Stereo-IMU camera. The introduction of this camera reduced the electrical system volume from the previous model with an upgraded digital output, which removed the necessity of the previous analog to digital converter.

This year we reshaped the endcap, getting rid of the earlier dome design that was intended to allow for more hydrodynamic propulsion of the vehicle. However, the dome was damaged during competition due to extreme water pressure. Because of this, we replaced the dome with a flat endcap that can be easily slid and secured on and off, making the internal components more accessible. With this, our team is able to make adjustments to inner components with ease, as well as give our newer members opportunities to learn more about each component's function, both visually and kinesthetically.

Comprehensive review of the past six years of the team's development was primarily applied through an interdisciplinary effort towards reducing the volume and increasing the longevity of the main hull. The team collectively assessed the strengths and weaknesses of previous years in order to design a more functional and competitive vehicle for this years' competition.

B. Current Strategy

Several improvements were made to the vehicle this year in order to increase capabilities and improve functionality. These improvements aimed to maximize our vehicle's ability to earn points at competition through the creation of a more maneuverable and capable AUV. The mechanical team focused on hull modifications and two custom mounting systems to improve the internal organization of the vehicle. The electrical team explored hydrophone systems as a way to improve the vehicle's movement. The programming team primarily worked on machine learning algorithms to control the camera and pressure sensor in order to further aid in the maneuverability of the vehicle. The team aimed to design and manufacture most parts in order to allow members to develop a practical engineering skill set.

C. Design Phase

This phase took up the majority of the year due to the COVID-19 pandemic restrictions. During the design phase all three subteams teams focused on assessing the progress of last year and designing new parts and systems to improve the previous vehicle. The team also had a design review during the Spring semester to discuss our progress and get advice from industry professionals. From this design review we were able to improve the materials and structural plans of many designs while gaining valuable presentation and networking skills.

D. Manufacturing Phase

Due to pandemic restrictions the team was unable to manufacture any parts for the vehicle this year. However, the team did host several workshops to learn about the various manufacturing processes so that the vehicle can be more efficiently manufactured once the manufacturing lab space is open.

III. VEHICLE DESIGN

A. Mechanical

<u>Endcap</u>

Our submarine will have an endcap on each side of the hull holding the internal frame components. On one side of the hull, the endcap team worked to design the front endcap so that a camera could see through it. Since last year, we have not made any key adjustments to the previous year's endcap design.

Figure 1: Endcap

This year, we focused on designing and fabricating prototypes of an acrylic piece and related parts that will fit into the rectangular-shaped hole in the front endcap. This will allow a clear window for the Zed Mini camera to see through and record footage, allowing the submarine to position itself and navigate through the obstacle course. When designing the acrylic piece, we created a formula to determine the figure of merit. We took into account size, cost, efficiency, as well as other properties. This process allowed us to see objectively which of our designs would work best for our team. To prevent water leakage into the hull from around the acrylic insert, a gasket will be placed on the outer rim of the acrylic piece to ensure a tight face seal. We are not using an adhesive sealant to allow for replacement of the acrylic, should it get cracked or overly scratched during testing.

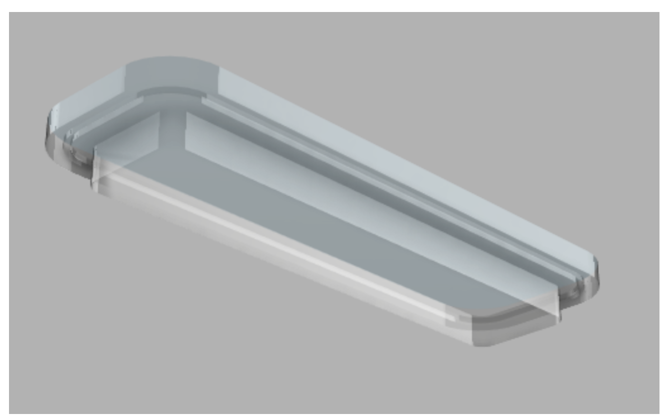

Figure 2: Rectangular Acrylic Piece

In order to ensure a watertight seal between the endcap and the acrylic insert, our team plans to secure the acrylic piece to the endcap using a pressure collar as shown in the design below. This pressure collar will be made from the same metal as the endcap to ensure even thermal expansion as the inside of the submarine's body increases in temperature.

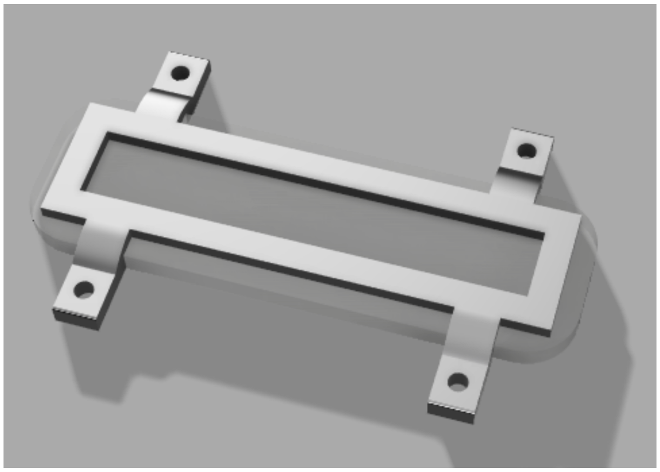

Figure 3: Metal Pressure Collar

The collar consists of a slim metal structure that will secure the acrylic piece to the hull firmly, while also allowing maximum visibility through the front of the craft. This collar will be attached to the hull using screws to ensure a watertight seal with the gasket and minimum movement as the AUV navigates.

Mechanisms

The mechanism team decided to pursue a torpedo launcher design to gain points in a portion of the competition our vehicle had not had capabilities in before. After brainstorming and sketching several different designs, we settled on a rubber band model where the rubber bands are wound up and held in place by a servo which can release the torpedo when desired. The basic design is seen below. This design was chosen to maximize the distance and accuracy of the torpedoes while minimizing the cost of materials.

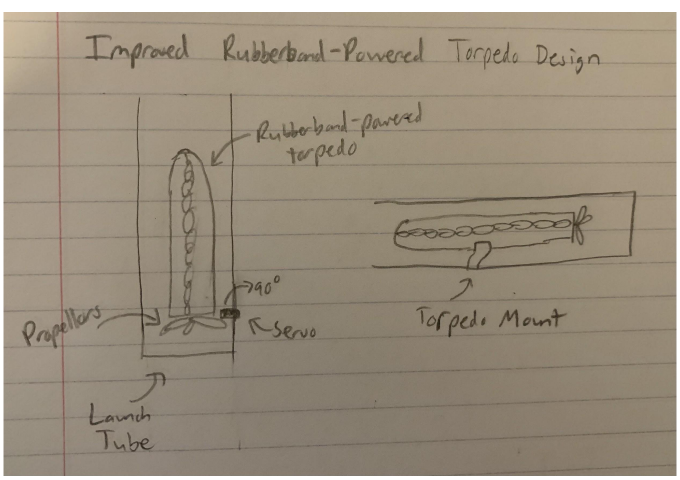

Figure 4: Torpedo Rough Design

Midcap

The midcap on the submarine functions to connect many parts of the vehicle together, including the midcap panels, polycarbonate tubes and their latches, the AUV body, and the SubConn. A large focus for the midcap team this year was creating the attachment for the SubConn tether, which is centered on the top face of the part. This tether allows us to connect the programming iteration interface through convenient, robust, and reliable pins on the outside of the submarine to the Jetson and power supply while ensuring the inside stays watertight. In order to attach it, we researched threads and hole types that would be compatible with the tether.

Figure 5: Midcap

Internal Frame

This year's internal frame team focused on two key improvements: optimizing the material of the frame and reconfiguring the design to most efficiently store the robot's interior electrical system. To begin, we focused on researching 3D printed materials that could withstand the heat of the electrical components (a maximum of 200°F). In the end, we settled on prototyping the internal frame out of ABS which can withstand temperature of up to 185°F with plans to print the final frame out of PEEK filament which is more heat resistant (it can withstand up to 480°F), but is also approximately 4 times as expensive as ABS [1].

In order to optimize the structure of the internal frame, we consulted the electrical subteam to determine the exact dimensions and placement of the electrical components. We then utilized a top-down design approach and structured the frame around dimensioned "blocks" of each electrical component. Major changes to the internal frame included expanding the center section to fit the Jetson TX2 and adding a shelf on the lower part of the frame so the VectorNav could lay flat in a centralized location.

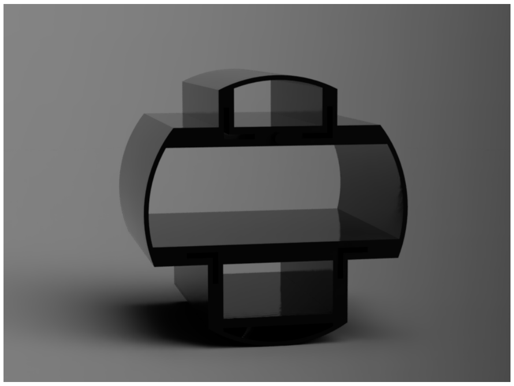

Figure 6: Internal Frame

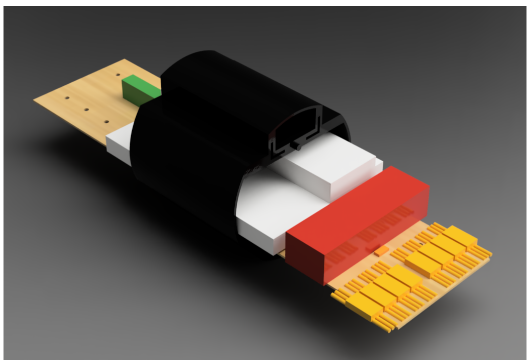

Figure 7: Internal frame with electrical component "blocks"

B. Electrical

The core of the electrical system this year has minimally changed since the past year. The team was impaired and could not work in person, so they focused on researching minor improvements to the previous system. The team also researched hydrophones and how to implement them.

Current System

The current system consists of a Jetson TX2 as the main computer, with an Arduino MEGA and a Teensy 3.5 as microcontrollers for the thrusters/ESCs and sensors respectively. A custom shield was designed to fit on the Arduino to distribute the signal to the ESCs appropriately as seen in figure 8.

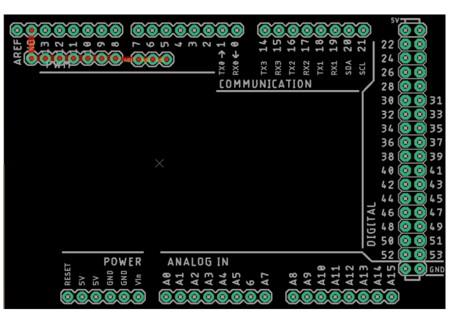

Figure 8: Arduino MEGA Shield for ESC control

Power in the system is supplied by two 22 V 1600 mAh batteries. One of the batteries purely supplies power to the thrusters/ESCs, and the other battery supplies power to the Jetson TX2 and other elements of the system.

Hydrophones

The hydrophones were the first decision the team focussed on. The hydrophones needed to pick up frequencies within a range of 18 kHz to 52 kHz. This was decided by previous competition standards. The team ultimately had the choice between various products, but the final decision was to build a hydrophone. A thesis done by Miguel Alvarado Juarez over low noise hydrophones includes the process to build these cheaper hydrophones.

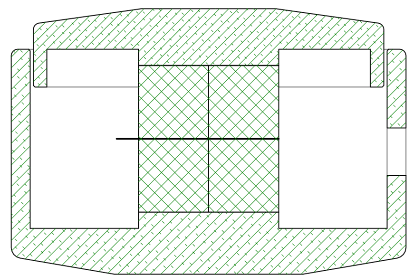

Figure 9: MiniCan 6 cross section

The design chosen to be built later in the year is the MiniCan 6, which had the capability to pick up the desired frequencies within the desired resolution. This will be built with two piezoelectric ceramic discs glued together with epoxy. Thin copper film will be placed between the plates, and the different pressures between the ceramic discs will change the voltage across the copper film.

Amplifier

The signals picked up by the copper film in the hydrophone need to be amplified to become analog signals that can be converted into digital accurately. Various amplifiers of different types were taken into account, but the final decision ended up being a 2 stage single-ended JFET with resistors, capacitors, and potentiometers. This can be set to amplify certain frequencies over others in order to operate well in competition.

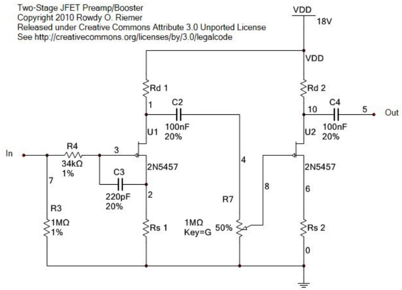

Figure 10: JFET Amplifier Circuit

<u>Bandpass Filter</u>

A third component on the system will be added in the future. The bandpass filter helps with reducing the amount of noise in the system. By cutting off frequencies below 18 kHz and above 52 kHz, the microcontroller will have an easier time reading and understanding the signal. The specific bandpass filter is a Chebyshev active bandpass filter. This filters a single frequency and removes all others in the range. Unfortunately, this filter does require an external power supply, as it is not a passive filter, and this will further complicate the entire system.

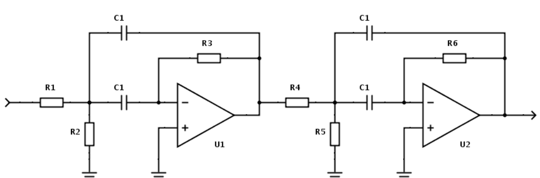

Figure 11: Chebyshev Active Bandpass Filter

<u>Microcontroller</u>

The microcontroller for the whole system is the main computer--a Jetson TX2. This computer has the capability to run these calculations. Once the system is physically built, testing can be done, and the team can determine whether this computer in practice will work. As a backup plan, other microcontrollers with ARM capabilities are being considered, in case the Jetson TX2 does not work. This decision will be made later.

C. Programming

The software allows for the data to transfer between the main elements of the robot including the sensors, cameras, thrusters, and the Nvidia Jetson TX2. The Jetson serves as the main communication tool from the Arduino Mega through the serial interface to transmit thruster data and receive readings from the pressure and temperature sensors. The 5 sections of software data are discussed below:

<u>Camera</u>

The main objective of the camera is to detect and label objects in a video in both real-time and through the recorded video feed. The camera applies image processing using Machine Learning principles, where a model is created and trained to aid in object detection. Image Processing is a set of computational techniques that allows a model to analyze, enhance, compress, and reconstruct images. Its main components consist of importing, analyzing, and manipulating an image using various specialized software applications. The process is then completed when a desired result is outputted. The general idea of image processing is analyzing an image through the use of complex algorithms. In Machine Learning (ML), the machine can be trained to process images by providing a set of training data. Without ML, image processing can only suggest examining the discrete targets in an image. Now with ML and AI, image processing can find many differences among numerous images. One example of this is Google Lens, which incorporates image processing with Machine Learning. With Google Lens, one can point a device, such as a phone, at a plant and it will automatically identify the key features and determine the species of the plant.

<u>Machine Learning</u>

There are many different types of Machine Learning techniques including Supervised Machine Learning and Unsupervised Machine Learning. The AUV utilizes Supervised Machine Learning, which takes in a labeled set of inputs. The model is then trained using the labels and can predict future inputs. On the contrary, Unsupervised Machine Learning takes unlabeled inputs and works to analyze the data [2].

TensorFlow is a Python, Machine Learning platform that can be used to solve a variety of problems [5]. Keras is a Python API [6], used for Deep Learning, which can be used in conjunction with TensorFlow to solve many Deep Learning and Machine Learning problems, such as the classification of objects. TensorFlow includes a library called COCO for object detection, which stands for Common Objects in Context and is a dataset that helps with large-scale object detection. It contains images, bounding boxes, and labels [7]. For the AUV, the camera needs to classify an image as “an orange marker” or “not an orange marker”, so the AUV knows where to move. Deep Learning is a subsection of Machine Learning, modeled after the human brain. Deep Learning utilizes neural networks, designed after the neurons in the human brain, to solve many different problems. Through Deep Learning, models can learn information to perform tasks, such as recognition and classification [3] [4].

Google Teachable Machine

Google's Teachable Machine is a Web-based tool that can be used to create Machine Learning models based on an input of photos (i.e. cat vs. dog), audio clips (i.e. sneezing), or actions (i.e. tapping your hand). Google's Teachable Machine takes in these sets of inputs, separated into different classes; for example, one class might be 'Cat', and a second class might be 'Dog'. The machine creates and trains the model, and then when given new inputs, predicts which class the current input belongs to. (See Figure 8). For example, after training the model on various images of cats and dogs, one can input another picture of a dog (i.e. a pug), which may not have been included in the initial set of inputs, and the model will be able to classify this image of a pug, as either a dog or a cat, listing the accuracy of this model's classification.

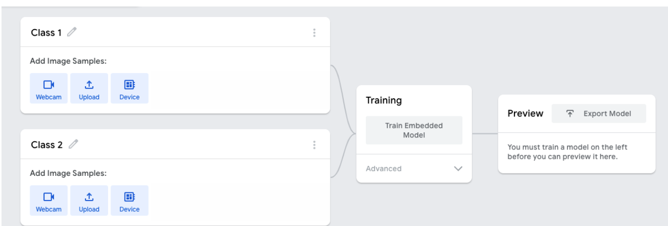

Figure 12: Google Teachable Machine

ROS

ROS stands for Robot Operating System and is an open-source software (See Figure 9). It allows robots to receive commands from the sensors, interact with the camera and thruster, and coordinate data transfer among the entire software system (main computer, sensors, camera, and thrusters). The AUV implements ROS using a three-part integration system. First, list all the components that will be used; this includes sensors, computers, and microcontrollers. Second, create nodes that communicate data and publish the topics for different components [11]. Third, create controllers for any hardware that moves; this includes thrusters. Controllers act when they are called upon by other nodes.

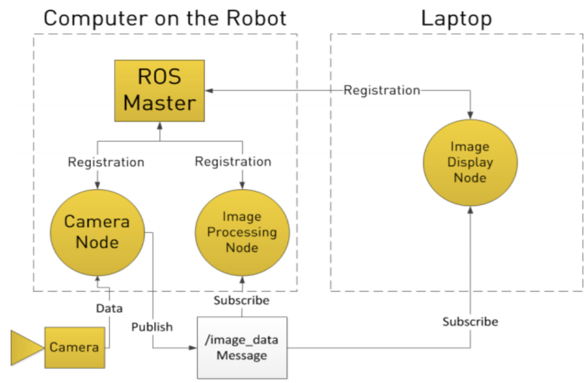

Figure 13: Robot Operating Systems (ROS)

Pressure Sensor

The purpose of a pressure sensor is to monitor the pressure surrounding the AUV to ensure that it does not enter an environment with higher pressure than it is designed to handle. With the pressure sensor and the use of Python Machine Learning and Deep Learning, the AUV will be able to make decisions based on its surroundings. The pressure sensor provides a 3.3V logic signal, instantaneous measurements of current depth below the surface of the water, and can measure up to 10 m or 2 bar in pressure. The sensor can be wired to the Teensy (a development board), and the Teensy can communicate to the Jetson through the USB port of the Teensy. The sensor is a device used for measuring physical quantities. The sensor detects the physical changes in the surroundings and converts it into a readable quantity and the transducer transforms the non-electrical signal into an electrical signal to be easily measured by the digital meters. The I2C cable of the pressure sensor can be directly wired to the Teensy (if 3.3V logic, else an I2C converter is needed if Teensy takes 5V logic signals).

IV. EXPERIMENTAL RESULTS

Due to the global COVID-19 pandemic and the inability to meet in-person, the vehicle has not yet gone through the testing phase. Once the team is able to return to the lab and work on the vehicle in-person, there are plans to train and test the Deep Learning model implemented for the camera with various images to ensure optimal accuracy and connect the pressure sensor with the camera to ensure optimal pressure output. Once back in our testing facilities, the mechanical subteam will ensure waterproofing of the hull, optimal pressure on the acrylic face seal, and testing/implementation of our newest torpedo mechanism. As we have designed and developed custom parts for the endcap, the endcap team would like to test the optics of the acrylic to ensure any optical warping is minimized. Additionally, the electrical team plans to test the new hydrophone system and fine tune its accuracy. These tests would allow us to better hone our designs to increase effectiveness in live competition.

V. ACKNOWLEDGMENTS

The WE AUV team would like to thank the following sponsors: The Texas A&M Women in Engineering Program, The Fischer Engineering Design Center, L3 Harris, Qualcomm, Accenture, and Blue Origin. The team is extremely grateful for the financial support of all sponsors, as well as the technical and professional expertise from L3 Harris mentors. The new mentorship relationships this year allowed the team to improve upon designs at design reviews in addition to gaining invaluable professional skills and advice through networking sessions.

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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, 1600mAh	$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 4.1	IMXRT1062DVJ6A processor, Cortex-M7 Core, 1024 kb	$0
Pressure Sensor	Blue Robotics	Bar 02 Ultra High	3.3V, 10 m depth, 0.16 mm depth	$88

		Resolution	resolution, 13 cm in-air altitude resolution	
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	-	-	82 Members	-
HW/SW ratio	-	-	3:1	-
Testing Time	-	-	Due to unforeseen circumstances the AUV was unable to be tested	-

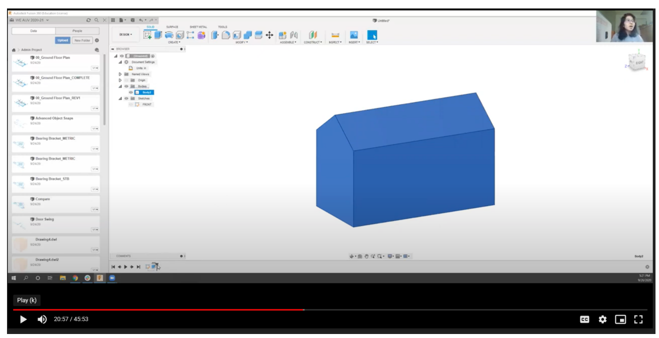
Appendix B

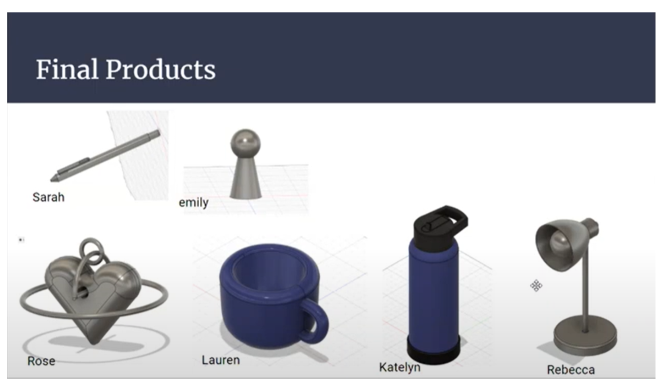
<u>Project Team's Workshops</u>
Supported by the Women in Engineering Program
At Texas A&M University

This year the team shifted focus to virtual workshops as a way for both members of the team, as well as underrepresented students in the College of Engineering to continue developing technical skills, even in a virtual environment. 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. Additionally, the team placed a new emphasis on professional development through both workshops and networking events with our sponsors. We particularly focused on our relationship with L3 Harris, a nationwide defense contractor. The team worked with mentors from L3 Harris and presented our progress at a design review, gaining invaluable advice that was utilized to improve our vehicle design. In addition, the team hosted its first Entry to a Major (ETAM) event to assist freshmen across the college of engineering in choosing what engineering major to apply to for their sophomore year at Texas A&M.
The following workshops were hosted this year:

- Mechanical
  - Introduction to CAD
  - Fusion 360 Certification
  - Materials Science
- Electrical
  - Electrical Component Basics
- Programming
  - Intro to C++
- Professional Development
  - Resume and Career Exploration
  - Entry To a Major Q&A Session
  - Industry Networking Events with sponsors
  - Design Review with sponsors

Screenshot of professional development resume workshop


Screenshot of mechanical sub team's Fusion 360 workshop. All workshops were recorded to allow for asynchronous participation and maximize the number of students reached.



Examples of Fusion 360 models created during Mechanical sub team's workshop