Texas A&M Women in Engineering AUV Design and Development

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***Abstract*— The Texas A&M University Women in Engineering AUV project team has designed and manufactured a more durable and robust Autonomous Underwater Vehicle, Nessie, to compete at the 2018 RoboSub competition. This vehicle has been built upon past years' experience and after rigorous training of underclassmen in SolidWorks, Milling, Eagle, Soldering, Python, and Git. The goal of the team is to not only explore the field of underwater autonomy but also gain valuable engineering and leadership skills not taught in a classroom setting.**

Keywords*— Autonomous Underwater Vehicle, Women in Engineering, SolidWorks, Python, Computer Vision, PCB Design, PID Control

I. INTRODUCTION

Research into Autonomous Underwater Vehicles (AUV) has grown in recent decades due to myriad of applications for AUVs in deep sea exploration, environmental monitoring, and search and rescue. The Women in Engineering program at Texas A&M University founded the AUV project team for inexperienced underclassmen to gain real-world skills in the mechanical, electrical and programming aspects of engineering.

Over the past three years, the team has doubled in size and refined its AUV design efforts. In its third year to compete, the team aims to complete the first three competition tasks: locating the gate, entering the gate, and following the path to touch the dice buoys. In order to build a more robust vehicle, the team spent a semester learning and training underclassmen in various software and hands-on engineering skills: SolidWorks, Milling, Eagle, Soldering, Python, and Git.

The team is divided into three subteams: Mechanical, Electrical, and Programming. The Mechanical team focuses on fabricating a compact and watertight enclosure for electronics and a frame that attaches to the enclosure for thruster placement. The Electrical team focuses on power distribution, sensor integration, and circuit design for efficient data transfer. The Programming team focuses on implementing various computer vision algorithms, control algorithms, and predictive algorithms to make the vehicle move in desired trajectories.

II. DESIGN STRATEGY

A. Takeaways from Previous AUV

The mechanical structure has been drastically modified to ensure that past mistakes have been rectified. The 2017 AUV, named Sharkbait, had multiple mechanical shortcomings and broke down multiple times during the competition. Sharkbait's design poorly attempted to integrate many small parts, but this year the team resolved to create a simple design for their AUV.

The 2017 AUV's hull was formed by polycarbonate dome epoxied to a PVC tube, which resulted in corrosion of the polycarbonate. Therefore, the team has elected to not use PVC in the new AUV's design. After encountering the balance issues due to positive buoyancy from the front dome combined with a heavy aluminum endcap on the other end of the AUV, the team has chosen to manufacture a midcap as a means to attach the hull to the structure while also keeping the AUV balanced. This additionally prevents last year's issue of the endcap getting pulled into the hull, causing the AUV's density to increase, which was a result of the lack of a lip near the bore seal that kept the AUV watertight. The team is therefore also using latches over the bore seal to secure the hull in place.

As exposed wires outside of the hull enclosure caused thrusters to malfunction in water, the electrical subteam is utilizing better wire management and waterproofing all electrical connections. Lastly, the weight and compactness of the previous year's vehicle made it difficult to carry without handles, so the team made sure to add them to this year's AUV. The summation of Sharkbait's various weaknesses led the team to decide that designing a brand new AUV would be in the team's best interest for the 2018 competition.

B. Current Strategy

After the unfortunate breakdown of last year's vehicle, the mechanical subteam this year has made sure to make a vehicle that is robust, easy to manufacture and assemble, and that allows for easy access to electronics. The electrical system has been simplified to achieve reliability rather than complexity. The programming team aimed to implement efficient PID control along with reliant computer vision algorithms to detect objects and travel to desired locations without much deviation.

Keeping this in mind, the team decided to train 25 freshmen and sophomore in various design softwares and machining equipment. The goal was to create a simple yet effective design that would also leave room on the vehicle to accommodate future modifications with respect to advanced sensors and additional mechanisms.

Another goal was to be able to design, manufacture, and assemble all of the vehicle's structural components in the Engineering Innovation Center (EIC) at Texas A&M University, without the help of a third-party company. This way students gained hands on experience with milling and lathing.

C. *Design Phase*

As the team progressed through the design phase in the fall semester, the team held three design review meetings to propose ideas for the new AUV and receive feedback from industry professionals and university professors. In preparing for the first design review, the team looked back at strengths and weaknesses of the its past two vehicles, along with the vehicles built by other teams for past competitions. In doing so, the team gained a better idea of how to most effectively integrate AUV components. At the end of this phase, the team had formulated two generalized designs which its members then presented. The feedback helped the team to improve on its designs and work toward the final design to be developed in future design reviews. For the second design review the AUV had been assigned dimensions and materials. For the last design review the team presented a final Solidworks design along with a list of parts required for the manufacturing phase.

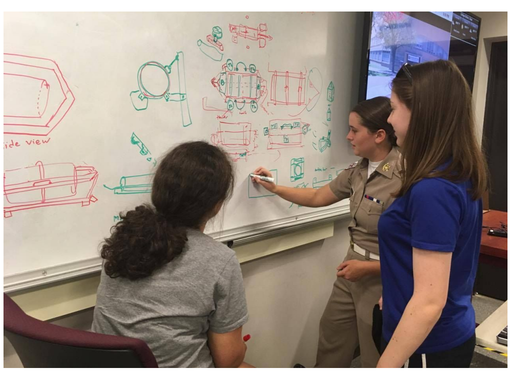

Figure 1: Design Phase I

D. *Manufacturing Phase*

The first month of the spring semester was used to train team members on fabrication and how to safely use the fabrication machines in the EIC. After becoming familiar with the machines, the team began machining the frame of the AUV using a CNC mill for the various panels and a lathe and manual mill for the midcap, endcaps, and hull rings.

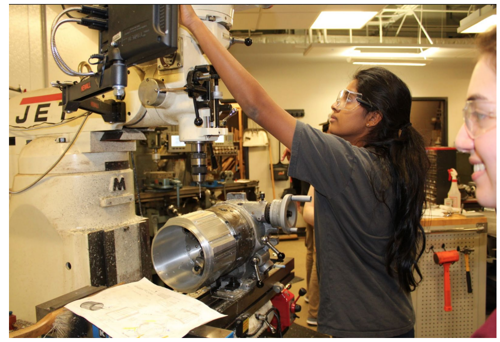

Figure 2: Manufacturing Phase - Midcap on Manual Mill

III. VEHICLE DESIGN

A. *Mechanical*

The mechanical team focuses on teaching members how to innovate by using Solidworks from the design phase into the implementation and testing phase. When designing, mechanical team focuses on the structural integrity and the protection of the electronics as well as ease of use. The various aspects of the mechanical design are discussed below:

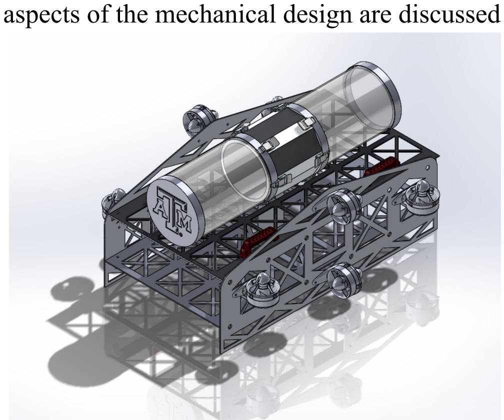

Figure 3: Full AUV Assembly

External Frame

The main goal was to create a robust and simple frame that is easy to carry, simple assembly, and structurally sound while also keeping in mind the need for viable space for future mechanisms.

Figure 4: External Frame Assembled

In order to do this a simple frame was created with 4 panels made out of ⅛" thick sheets of 6061 aluminum. The two Side Panels mount the thrusters in the correct orientation and allow for convenient accessibility the battery box from the sides without them being exposed to impact. The Base Panel was created to attach the hull securely onto the frame and to be able to mount handles for ease of transport as well as the watertight forward facing cameras. The Rack Panel was implemented to hold the battery boxes in place and to give us space for weights to be added and for future mechanisms. The details and holes made on the panels were machined with a CNC mill. The frame is assembled with L-brackets ordered from McMaster-Carr and ¼ inch bolts are used on the entire frame in order to standardize the parts and ease of replacement if needed.

Main Hull

One of the main objectives for the hull is to securely attach it to the frame without the use of straps as had been the case in the past; this was avoided with the implementation of the midcap. The midcap, made from a 6061 aluminum 10" diameter round, can be mounted directly onto the base panel and keeps the center of gravity central to the vehicle, therefore keeping the buoyancy force and the weight of the hull balanced so that the forces are evenly distributed throughout the vehicle. In the past, opening and closing the hull has been inefficient, making electronics difficult to access. Latches ordered from McMaster-Carr alleviated this issue.

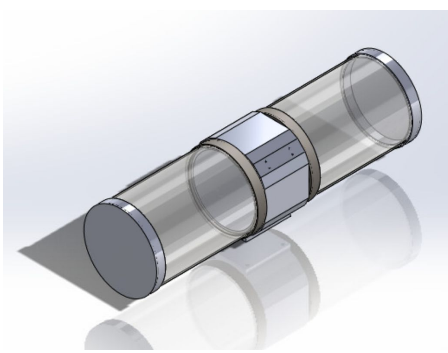

Figure 5: Hull

To keep the Hull watertight by using a double bore seal on both sides of the midcap. The O-rings used were selected from the Static O-Ring Section from the Parker O-Ring Handbook. An O-ring is also used as a buffer to keep a space between the hull ring midcap, enabling easy removal of the tube from the midcap when accessing electronics. Therefore the AUV uses six O-rings in total. There are four latches on each side of the midcap that are used to enclose the midcap. These latches come with a safety catch in order to ensure that the hull only becomes unlatched when intended to.

Internal Frame

The goal for the internal frame is to enable heat distribution. The Intel NUC produces more heat than any other electrical component, therefore it is located directly inside of the midcap to allow for heat transfer through the aluminum and to the water. For the internal frame to be structurally sound, a 3D-printed base was created to hold 2 aluminum L-beams with ¼" holes spaced 1" apart. This 3D print will be secured by the plugs made for the Subconn connectors. The acrylic panels on the internal rack also have ¼" holes in a 1" x 1" matrix so that they can be mounted onto L-beams. The electronics each have custom 3D-printed mounts to secure them onto the internal rack.

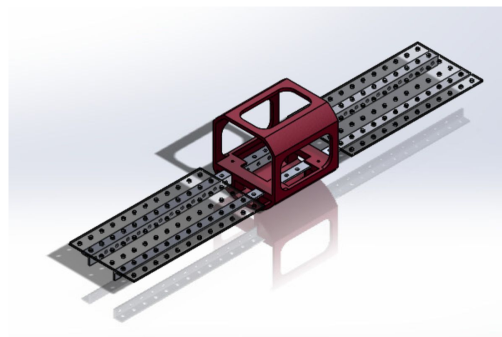

Figure 6: Internal Frame

Battery Boxes

Last year the battery boxes were retrofitted by drilling holes to a watertight container to allow for wires to pass through cable penetrators. Four screws were used to close the battery boxes and make them watertight, but in some instances, the screws would unexpectedly strip. As a result, the current team decided to use watertight boxes with latches that are easier to open and close, while still retrofitting cable penetrators for wire passage as before.

B. Electrical

The electrical system has been mostly retained from last year's attempt due to its simplicity and reliability. Few changes were incorporated to improve kill switch accessibility and software modification during pool testing by integrating a tether. Efforts were also made to make rudimentary hydrophones to attempt any acoustic-based tasks. The various aspect of the electrical setup is discussed below:

Power Distribution

Four 14.8 V 10000mAh LIPO batteries power the entire vehicle. Two batteries connected in parallel power the eight thrusters. The batteries are connected in parallel to double the current supplied to the thrusters. The other two batteries power the remaining electronic on board which include the Intel NUC, an Arduino Mega, three cameras, a pressure and a temperature sensor. An ATX power supply is used to step down 14.8V to 12V and 5V rails to power the Intel NUC and cameras respectively.

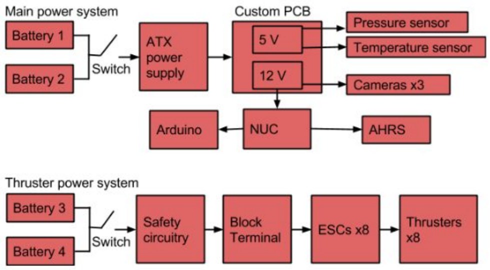

Figure 7: Power Distribution Flow Chart

The thruster are powered separately since in case of an emergency shut down, it is not desirable to shut down the entire system but cut power to the thrusters alone.

Thruster and Sensor Circuitry

Thrusters are controlled via PWM pins on the Arduino Mega. A custom arduino shield PCB provides connections for the ESC signal and ground wires. Analog data from the pressure sensor and temperature sensor is received on the Mega. The Intel NUC uses a serial interface to receive the sensor readings as part of control algorithms. The PCB also incorporates a mission switch which helps start and terminate program execution.

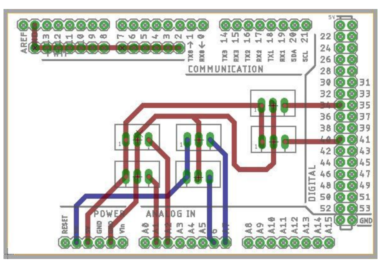

Figure 8: Custom Arduino Shield for Thruster Control

Computer, Camera and Sensors

The vehicle uses three analog waterproof SS AquaCam to detect objects underwater. The Intel NUC receives camera data through the A2D convertors. An AHRS (Attitude and Heading Reference System) is connected to the Intel NUC to provide yaw, pitch and roll data. The Intel NUC talks to the Arduino Mega through a USB connection and receives pressure and temperature data. The NUC also communicates to the Arduino which thruster to

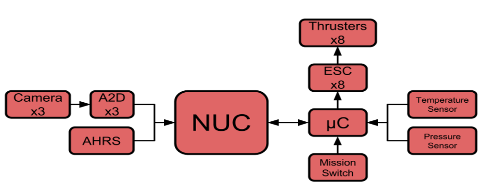

Figure 9: Data Transfer Flow Chart

Kill Switch and Mission Switch

The kill switch is connected in series with the power line for the thruster, so the Thruster immediately lose power and stop when the switch is flipped. The mission switch is connected to the arduino shield PCB and acts as a digital high or low used to determine when to start the program.

Tether

Ethernet connectors were put on a Blue Robotics Fathom tether to act as a communication interface between the Intel NUC and another computer while the vehicle is underwater. The content on Intel NUC is modified by using Windows Remote Desktop application. A SubConn connector is used to plug in the tether when needed.

C. *Programming*

The AUV's software coordinates the data transfer between the main computer, the sensors, the cameras and the thrusters.. The main computer - an Intel NUC, communicates with an Arduino Mega through a serial interface to transmit thruster control data and receive pressure and temperature sensor readings. Due to hardware restrictions, the AUV's software was not build on top of ROS as originally planned. The cameras require ADC adapters to help convert analog feed into digital stream for image processing using OpenCV and Python. The ION VIDEO 2 PC adapters had device drivers only compatible with Windows OS and hence, the AUV's software is implemented on a Windows platform. The various aspect of the AUV's software is discussed below:

Thruster Motion Control with PID

An Arduino script helps control the speed and direction of the eight thrusters by sending the right PWM signals to the Electronic Speed Control units for individual thrusters. The cameras, IMU and pressure sensor acts as feedback to correct the deviations encountered while navigation due to drift.

Image Processing

A combination of color thresholding, contour detection and image segmentation is used to identify the gate, orange ground path and dice buoys [1]. A depth map is also created using two front-facing cameras to determine the distance of the object from the vehicle.

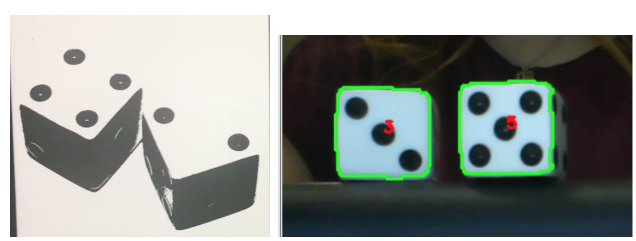

Figure 10: Dice Buoy Detection

Localization and Mapping

A Kalman filter was incorporate in the previous year to aid object tracking and make up for shaky camera input and rare faulty sensor reading. An extension on Kalman filter is currently being implemented to harness the power of Monocular SLAM which will help localize and track the movement of the vehicle along the course using cameras and IMU [2]. Monocular SLAM is experimented since stereovision is not completely reliant in the current state.

IV. EXPERIMENTAL RESULTS

As of the submission of this paper, the finished AUV has completed approximately 20 total hours of water-testing. The hull and the battery boxes have been confirmed to be watertight. The electrical system has also completed testing by analyzing the connections between ESCs to determine whether power is evenly distributed to the thrusters. However, preliminary calculations have not been calculated to determine the AUV's maximum runtime. The AUV's software is currently under test to tune its performance. Parameters for the PID need to be figured experimentally and IMU-Camera calibration is underway to perform Monocular SLAM.

With rigorous training in SolidWorks, Manual Mill, Eagle, Soldering Microcontroller Programming and Computer Vision using Python, the underclassmen of the team are ready to face any issues that might arise during testing and competition runs.

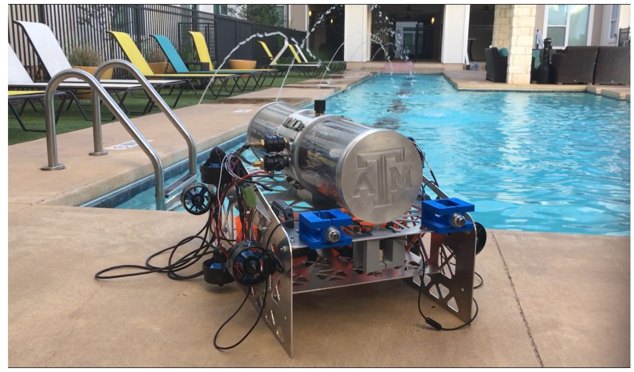

Figure 11: Nessie Pool Testing

V. ACKNOWLEDGMENT

The REAF team would like to thank the following sponsors: The Texas A&M University Women in Engineering program, the Engineering Innovation Center, and ViaSat. Without the support of these sponsors, the new advancements in the overall design and manufacturing process for the AUV would not have been possible.

References

[1] P. Arbelaez, M. Maire, "Contour Detection and Hierarchical Image Segmentation," IEEE Transactions on Pattern Analysis and Machine Learning, vol. 33, pp. 898–916, May 2011.

[2] A. J. Davidson, I. Reid, "MonoSLAM: Real Time Single Camera SLAM", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 29, pp.68–73, June 2007

Appendix A

Component Specifications

Component	Vendor	Model/Type	Specs	Cost
Frame	Midwest Steel & Aluminum	Aluminum 6061 T6	34" x 19"	$197.72
Hull: Tube	Cope Plastics	Polycarbonate Tube	ID: 7 ¾", OD: 8", L: 8'	$185.05
Hull: Midcap	In house		ID: 7"	
Waterproof connectors	Subconn	BH12,	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
Battery	HobbyKing	Multistar	4S 10000mAh	$50 each
Converter	Mini-Box.com	M4-ATX	250W, 6-30V	$79 each
CPU	Intel NUC	NUC6i7KYK	Core i5	$350
External Comm Network	Blue Robotics Fathom Tether	Cat5 Ethernet Cable	100 m long Crossover Ethernet	$900
Programming Lang 1	Python	Python 3	Implemented on NUC	$0
Programming Lang 2	Arduino	C programming - Register level	Implemented on Arduino Mega 2560	$10
Inertial Measurement Unit	VectorNav	TN-100	800 Hz IMU data	Donated
Cameras	Lights Camera Action	SS-AquaCam, Analog	Quantity: 3, Waterproof H 1.5', W 2.1', L 2.6'	$1485
Algorithm: Vision	OpenCV	3.2	Color Thresholding, Contour Detection	$0
Algorithm: Autonomy	PID control and MonoSLAM		Extended Kalman Filter	$0
Open Source Software	Github		Currently getting organized	$0
Team Size	32 members			
HW/SW ratio	3:1			
Testing time: in-water	20 hours			

Appendix B

Through the team's participation in the Grand Opening of the Girl Scouts STEM Center of Excellence in Dallas, Texas, REAF has inspired young girls interested in the fields of science, technology, engineering, and mathematics (STEM). The team has also been a part of events such as Engineering Project Showcase and Student Research Week at Texas A&M University, allowing the team to demonstrate and promote the applications and extensive research work achieved by the team over the past 3 years. Additionally, the REAF AUV project team won first place in the non-Capstone category of the Virtual Project Showcase at Texas A&M University for its video submission capturing the work and overall objective of the project team.

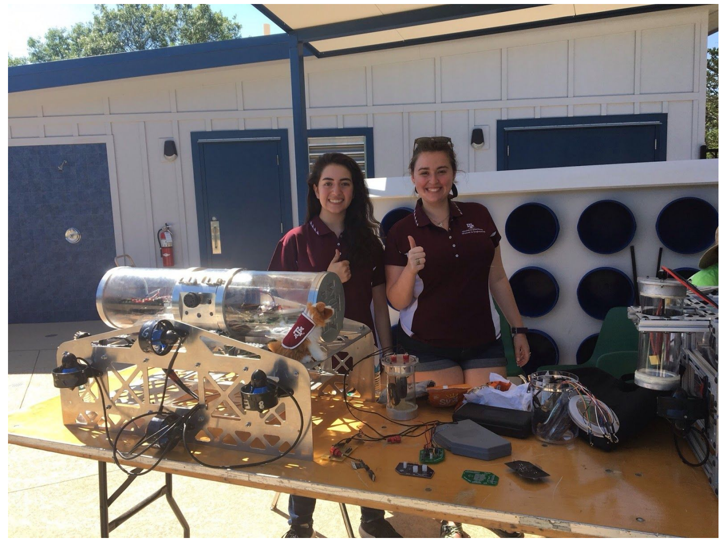

Figure 11: Grand Opening of the Girl Scouts STEM Center