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

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***Abstract*— The Texas A&M University Women in Engineering AUV project team has designed and manufactured a more compact and lightweight Autonomous Underwater Vehicle, named Minnow, to compete at the 2019 RoboSub competition. This vehicle builds upon past years' experience and rigorous training of underclassmen in various software and hands-on engineering skills. The team aims to explore the field of underwater autonomy while gaining 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 (AUVs) has grown in recent decades due to a myriad of applications 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 to allow inexperienced underclassmen to gain real-world skills in mechanics, electronics, and programming.

In the time since its inception, the team has doubled in size and refined its AUV design efforts. In its fourth year, the team aims to complete the competition tasks of entering the gate, touching buoys, launching torpedoes, and dropping markers in a designated spot. To increase effectiveness, the team also focused on training new members in SolidWorks, milling, Eagle, soldering, Python, and Git.

The team consists of four subteams: mechanical, electrical, mechatronics, and programming. The mechanical team focuses on fabricating a watertight enclosure for electronics attached to a frame allowing 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 move the vehicle in desired trajectories. The new mechatronics team develops our AUV's torpedo launcher and marker dropper mechanisms while researching hydrophone integration.

## II. DESIGN STRATEGY

### *A. Takeaways from Previous AUV*

The AUV's mechanical structure has been refined to eliminate unnecessary bulkiness. The 2018 AUV, Nessie, proved stable yet difficult to transport and excessively buoyant. Previously exposed wires outside of the hull enclosure, causing thrusters to malfunction, will be resolved by improved wire management and waterproofing of all electrical connections. The decision to optimize the design is a result of the success of last year's AUV.

### *B. Current Strategy*

The mechanical subteam sought to construct a smaller, more transportable AUV with easier access to electronics systems. The electrical system has been simplified to achieve reliability over complexity. The programming team aimed to implement efficient PID control along with reliant computer vision algorithms to detect objects and effectively travel to desired locations. The mechatronics team emerged to develop mechanisms to complete additional competition tasks.

The team aims to independently design, manufacture, and assemble all structural AUV components in the Fischer Engineering Design Center at Texas A&M University, ensuring the acquisition of milling and lathing skills.

### *C. Design Phase*

During the design phase of the fall semester, the team held three design reviews to discuss and propose design changes while receiving feedback from industry professionals and university professors. The team reviewed strengths and weaknesses of past vehicles belonging to the team and other teams. Feedback helped the team to improve upon and work toward the final design. Upon the conclusion of the design phase, the team had developed a detailed Solidworks design along with a list of materials required for prototyping.

*D. Manufacturing Phase*

The team began the manufacturing phase of the spring semester by undergoing fabrication training. After becoming familiar with the machines, the team produced the frame panels on a water jet cutter. The team also used a CNC mill, manual lathe, and manual mill to create the midcap, endcaps, and hull rings.

## III. VEHICLE DESIGN

### *A. Mechanical*

The mechanical team teaches members to use Solidworks, from the design phase and into the implementation and testing phase. When designing, the mechanical team prioritizes the structural integrity, protection of electronics, and ease of manufacturing. The various mechanical design components are detailed below:

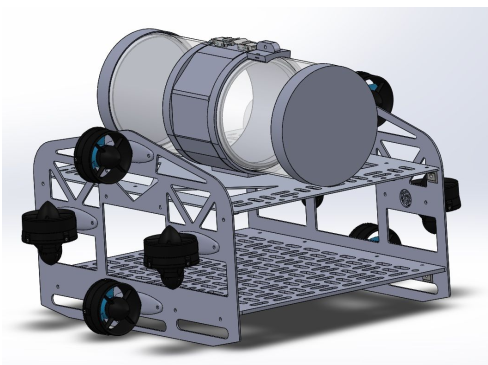


Figure 1: Full AUV Assembly

<u>External Frame</u>

The frame is made to be robust yet simple and therefore easy to carry and assemble. The team also increased hole sizes on the frame for functionality and standardization of mounting.

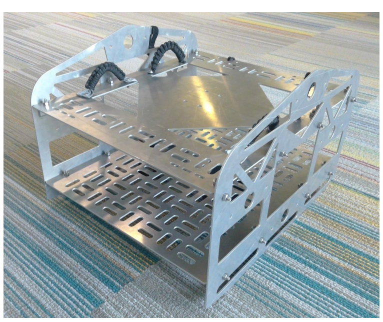


Figure 2: External Frame Assembled

The frame consists of four panels of ⅛” thick sheets of 6061 aluminum machined using a water jet cutter. Two side panels provide mounting space for thrusters and along with a circular cut-out to allow for changing of thrusters without removing the entire mount. Additional large holes allow for easy access to the battery boxes within the frame structure. The top panel was created for secure attachment of the hull onto the frame, placement of handles for transportation, and mounting of forward-facing cameras. The bottom panel has tessellating oblong holes to standardize attachment points for the battery boxes and mechanisms. The frame is assembled with L-brackets ordered from McMaster-Carr and ¼” bolts for further standardization and ease of replacement.

<u>Main Hull</u>

One of the main objectives for the hull is secure attachment to the frame allowed by the implementation of the midcap. Made from a solid 6061 aluminum 8.5” diameter round, the midcap attaches directly onto the base panel and aids vehicle symmetry and balance. Latches ordered from McMaster-Carr resolved the previous issue of a laborious process to access electronics.

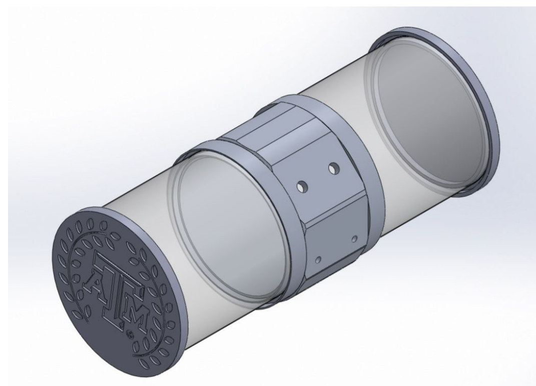


Figure 3: Hull

A double-bore seal on both sides of the midcap ensures a watertight seal. O-rings were carefully selected using the Static O-Ring Section from the “Parker O-Ring Handbook.” Therefore the AUV uses a total of four O-rings. Three latches on each side of the midcap are used to close the hull. A safety catch on the latches ensure that the hull does not become unlatched.

<u>Internal Frame</u>

The goal for the internal frame is to enable heat distribution. The Intel NUC produces more heat than any other electrical component and is therefore 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 4 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 ⅛ inch holes in a 0.5” x 0.5” matrix throughout the panel except for four larger ¼ inch holes towards the center that allows mounting onto the L-beams. Towards the endcaps the panels are rounded in order to allow for the hull to be easily closed without interference from the internal rack.

The electronics each have custom 3D-printed mounts to secure them onto the internal rack.

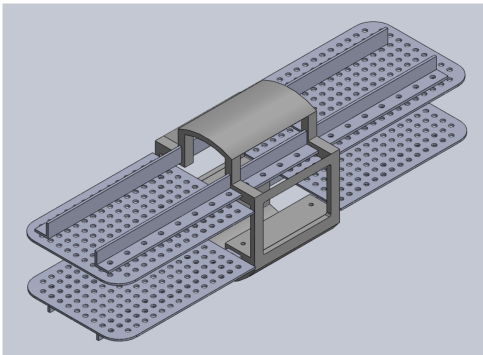


Figure 4: Internal Frame

*Battery Boxes*

Last year, inexpensive waterproof boxes were used to store the batteries. Although this allowed for easy access when switching out the batteries, the box's seal began to crack after use and the latches became brittle. This year, the team invested in better watertight boxes that each hold only one battery, reducing the buoyancy of the robot. These new boxes are easier to open and seal with their single large latch. Cable penetrators were retrofitted and sealed onto the sides of the waterproof boxes to allow for wire passage.

### B. Electrical

The electrical system has been mostly retained from last year's attempt due to its simplicity and reliability. The team did however attempted to change the ATX converter to a 12-volt converter as well as adding three servos and a pressure sensor plus a mosfet-based kill switch. The various aspects of the electrical setup is discussed below:

*Power Distribution*

Two 14.8 V 10000mAh LIPO batteries power the entire vehicle. One batteries connected in parallel power the eight thrusters. The batteries are connected in parallel to double the current supplied to the thrusters. The other battery power the remaining electronic on board which include the Intel NUC, an Arduino Mega, three cameras, and a pressure sensor. The thrusters 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.

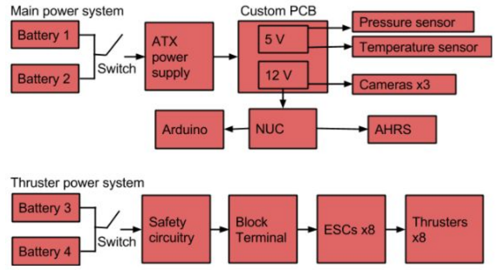



Figure 5: Power Distribution Flow Chart

*Thruster and Sensor Circuitry*

Thrusters and servos are controlled via PWM pins on the Arduino Mega. A custom Arduino shield PCB provides connections for the ESC signal and ground wires. Communication data, serial clock and serial data, is received from a Blue Robotics pressure sensor and read 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.

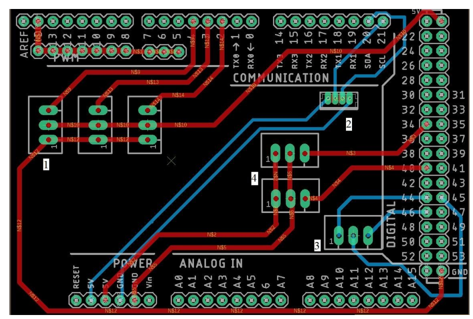


Figure 6: Custom Arduino PCB for Thruster Control

*Computer, Camera and Sensors*

The vehicle uses two analog SS AquaCam and one Blue Robotics digital waterproof to detect objects underwater. The Intel NUC receives camera data through the A2D converters. 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 for communication with the thrusters ESCs.

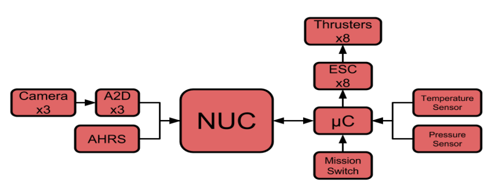



Figure 7: Data Transfer Flow Chart

<u>*Kill Switch and Mission Switch*</u>

The kill switch used in previous years consisted of a mechanical toggle switch filled with epoxy inside to prevent any water leaking in, unfortunately, water sneaked in anyways and provided potential danger. This year, a MOSFET-based kill switch is used to help efficiently and effectively shut down power the thrusters. The MOSFET intercepted the power supply wire from the LIPO batteries to the thruster. Since the LIPO batteries are carrying high current to the MOSFET needs a heat sink to provide heat dissipation at a safe rate. To trigger the MOSFET, a magnetic reed switch is used to turn the thruster on and off by bringing a strong enough magnetic to the outside of the hull. 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.

<u>*Tether*</u>

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 built 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 aspects of the AUV's software are discussed below:

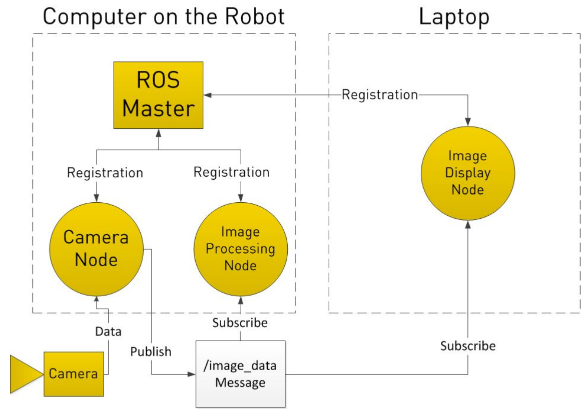



Figure 8: ROS Example

<u>*Thruster Motion Control with PID*</u>

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.

<u>*Image Processing*</u>

A combination of color thresholding, contour detection and image segmentation is used to identify the gate, orange ground path and targets [1]. A depth map through stereo vision is also created using two front-facing cameras to determine the distance of the object from the vehicle. This year, the team changed the color spectrum to receive more accurate contours as well as considered the possibility of adding a physical filter to the AUV camera to filter out sunlight and the blue from the water. As our foundation, they took last year's code from Image Processing and made some alterations in order to further better the code. To test our edited code, they used previous videos from last year in the PyCharm software.

<u>*Machine Learning*</u>

Machine learning is a task the team decided to implement in order to better the autonomous aspect of the AUV. This is a new objective that the team did not have in last year's design; they decided to implement it this year due to the much larger size of our team. They have done research into You Only Look Once (YOLO v3) as a system to provide better object detection which is part of the RoboSub tasks. Throughout the course of the year, the team focused on researching and understanding machine learning software, features and algorithms. The work done this year laid a solid foundation for next year's design and implementation.

### *D. Mechatronics*

The mechatronics team was created for the sole purpose of brainstorming and creating mechanisms to accomplish tasks at the Robosub competition. The team focuses on the design, manufacturing, and implementation of creative solutions for the torpedo launcher and dropper obstacles. In doing so, each member of the team was challenged to call upon their mechanical, electrical, and programming skills to bring the following ideas to life:

*Torpedo Launcher:*

The main objective kept in mind when designing the torpedo launcher system was to keep it as compact and simple as possible. The finalized design featured a cantilever beam system created to sustain a spring in its compressed state. The torpedo was kept atop the spring using a spring endcap attachment that helps keep the torpedo in place until needed. The system is driven by a TRAXXAS waterproof servo that rotates the cantilever beam away from the spring once the obstacle is approached. The entire system was 3D printed using ABS filament and is attached to the AUV using the bottom rack panel.

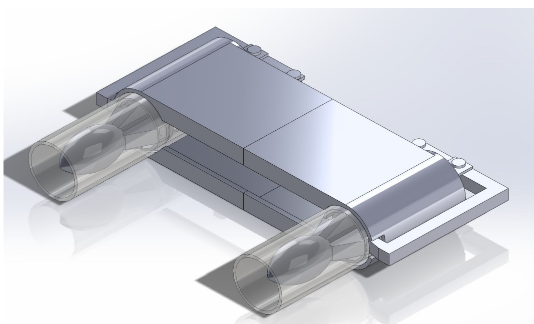


Figure 9: Torpedo Launcher

*Dropper:*

The dropper was created to contain an item until approaching an obstacle that requires the AUV to release it. The dropper system is made up of a simple cup-shaped component with an opening on the bottom to release the object, which is pushed through using fan blades powered by a TRAXXAS waterproof servo. When the AUV is above the dropper task, the fan blades will rotate, pushing the item through the opening. This system is attached to the bottom of the torpedo launcher housing and was 3D printed using ABS filament as well.

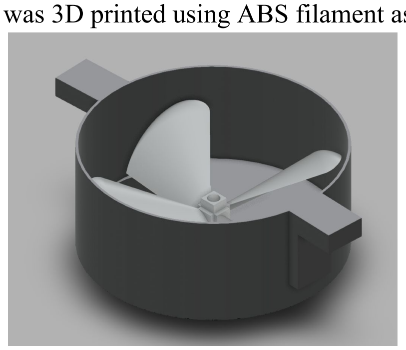


Figure 10: Dropper

*Hydrophones:*

To allow for the AUV to navigate to the desired tasks, hydrophones were to be used to create a frequency filtering system. The AUV was to have three hydrophones: a reference, an x, and a y hydrophone. This created a coordinate system that could be used to assist the AUV in determining the appropriate direction to steer towards. To filter the undesirable frequencies, a Fourier Transform algorithm was used before converting the acquired data from analog to digital using the Arduino UNO board. Once the data is converted to digital, the Python code instructing the AUV's movements is initiated.

## IV. EXPERIMENTAL RESULTS

As of the submission of this paper, the 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 on the team are ready to face any issues that might arise during testing and competition runs.

## 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 200

# Appendix A

Component Specifications

| Component | Vendor | Model/Type | Specs | Cost |
|---|---|---|---|---|
| **Frame** | Midwest Steel & Aluminum | Aluminum 6061 T6 | 34" x 19" | $240 |
| **Hull: Tube** | Cope Plastics | Polycarbonate Tube | ID: 7 ¾”, OD: 8”, L: 8’ | $185.05 |
| **Hull: Midcap** | In house | Aluminum 6061 T6 | ID: 7” | $260 |
| **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 / Turnigy | 4S 10000mAh | $90 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<br>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<br>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** | 40 members | | | |
| **HW/SW ratio** | 3:1 | | | |
| **Testing time: in-water** | 20 hours | | | |

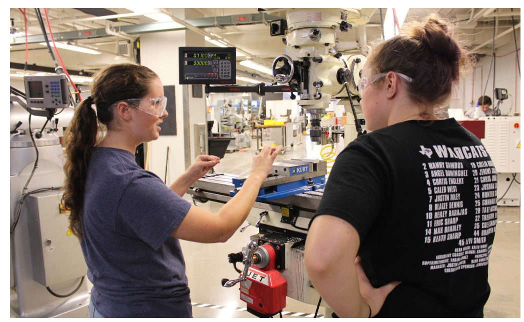
# Appendix B

<u>*Girl Scout STEMFest*</u>
*Sponsored by the Society of Women Engineers*
*At Texas A&M University*

Through the team's participation in STEMFest, an event hosted at Texas A&M University for Girl Scouts of varying ages, the team has inspired young girls interested in science, technology, engineering, and mathematics. In a session at the event, volunteers prompted teams of Girl Scouts to design and build a robot using a LEGO Mindstorms kit. Each team was also required to document the robots's construction process. The teams then exchanged instructions and attempted to rebuild other teams' robots. Overall, the session was an exercise in communication and teamwork.

Figure 11: Girl Scout STEMFest

<u>*Women Teach Women Workshops*</u>
*Sponsored by the Women in Engineering Program*
*At Texas A&M University*



In the past, team members would only be able to learn technical skills in their individual subteams. This year, the team has decided to open up workshops so that people can develop skills across different subteams. These workshops were opened up to all of the university. This has given other women who are not on the team a chance to learn skills they wouldn't have learned in the classroom. This has also helped advertise the team to other women who may be interested in joining the team.
These workshops include:

- Mechanical
  - SolidWorks
  - Mill
  - Woodworking and Basic Hand Tools
- Electrical
  - Intro to PCB Design
  - Electrical Connections & Soldering
  - Breadboard and Soldering PCBs
- Programming
  - Micocontrollers

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 4 years. Additionally, the REAF AUV project team won second place in the non-Capstone category of the 2018 Virtual Project Showcase at Texas A&M University for its video submission capturing the work and overall objective of the project team.