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 versatile and maneuverable Autonomous Underwater Vehicle, named Ray, to compete at the 2020 RoboSub competition. This vehicle builds upon past years' experience and rigorous training of underclassmen in various software and firsthand 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, Fusion 360, Python, PCB Design, PID Control, Machine Learning, ROS

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 undergraduates to gain real-world technical skills in mechanics, electronics, and programming.

In the time since its inception, the team has grown tremendously in size and refined its AUV design efforts. In its fifth year, the team has worked towards the competition tasks of entering the gate, touching buoys, following the bottom markers, and dropping objects in a designated spot. To increase effectiveness, the team also focused on training new members in CAD programs, soldering, Python, and ROS.

The team consists of three sub-teams: mechanical, electrical, and programming. The mechanical team focuses on fabricating a watertight enclosure for electronics that are attached to a frame allowing for thruster placement while developing various mechanisms. 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 the desired trajectories.

II. DESIGN STRATEGY

A. Takeaways from Previous AUV

The AUV's mechanical structure has been refined to eliminate unnecessary bulkiness. The 2019 AUV, Minnow, provided a stable yet rigid external frame that has been reused for this year. For the past two years we have utilized a midcap which we will be reusing the first iteration of this component in this year's design. Various components will be moved inside the watertight hull including the forward facing camera in order to reduce drag and eliminate wire splicing from many of our critical components. The decision to optimize the design is a result of the success and challenges of last year's AUV.

B. Current Strategy

The mechanical subteam sought to construct a more functional frame and easier access to electronics systems. To increase the organization of the electronic system, custom compartments and holders were designed for many internal components. The team also added interchangeable midcap panels for varying connections that may be needed. 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. In a joint effort, mechanical and electrical members also worked on developing and designing 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. This ensures that members gain valuable project management and hands-on manufacturing skills.

C. Design Phase

During the design phase of the fall semester the team selected various components and systems to redesign and discussed the proposed design changes with industry professionals and university professors. The team reviewed the strengths and weaknesses of past vehicles and discussed how to create a more reliable vehicle. The feedback we received from our mentors and professionals we reached out to helped the team to improve upon our components and systems' redesign. Upon the conclusion of the design phase, the team had developed a detailed CAD design along with a list of materials required for manufacturing.

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 redesigned bottom frame panel on a water jet cutter. The team also used a CNC mill, manual lathe, and manual mill to redesign the midcap, and produce the midcap panels, and end caps.

III. VEHICLE DESIGN

A. Mechanical

The mechanical team teaches members to use both Solidworks and Fusion 360, from the design phase and into the manufacturing and testing phases. When designing, the mechanical team prioritizes the structural integrity, protection of electronics, and ease of manufacturing. The various mechanical design components are detailed below:

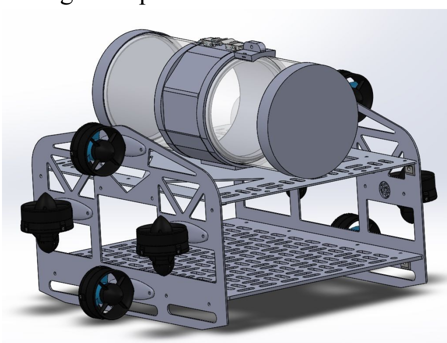

Figure 1: Full AUV Assembly

<u>External Frame</u>

The frame is made to be robust yet simple and therefore easy to carry and assemble. This year the team also redesigned hole placement on the bottom panel to allow for more purposeful mounting of mechanisms and sensors.

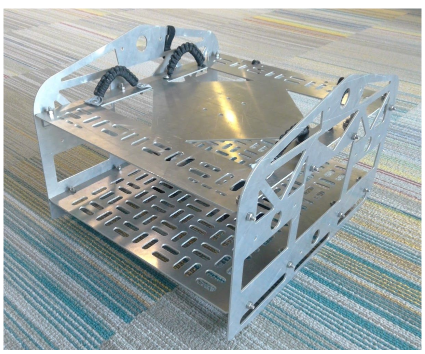

Figure 2: External Frame Assembled

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, 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 the attachment of an arm mechanism. The bottom panel has specially sized holes for the mounting of a dropper, bottom-facing camera, and a battery box. Both top and bottom panels feature tessellating oblong cut-outs in the spaces between specialized holes to reduce the overall weight of the AUV and allow for water flow. The frame is assembled with L-brackets ordered from McMaster-Carr and ¼" bolts for further standardization and ease of replacement.

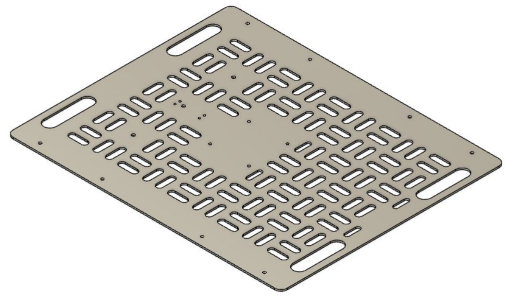

Figure: Bottom Panel

<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 top panel and aids with vehicle symmetry and balance. Latches allow easy access to electronics.

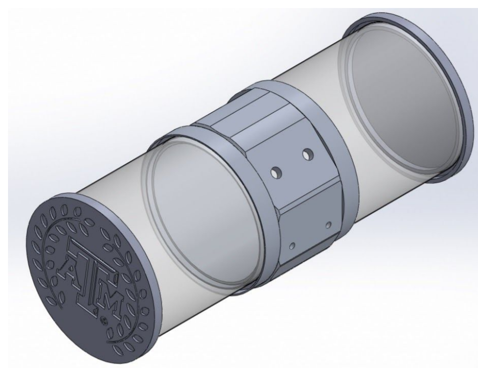

Figure 3: Hull

Both sides of the midcap have a double-bore seal and a face seal, ensuring water tightness. A total of six O-rings were carefully selected with guidance from the Static O-Ring section of the "Parker O-Ring Handbook." Four latches on each side of the midcap are used to close the hull, and safety catches on the latches ensure that the hull does not become unlatched. Two removable panels on opposite sides of the hull are secured with a gasket seal and allow easy changes to wire hole configuration.

The camera configuration was upgraded from two external analog cameras to a singular digital stereo vision unit. This altered the hull end cap specifications as it requires a watertight enclosure that would minimize distortion. The upgrade is projected to improve camera longevity and improve vehicle buoyancy as there is now a minimization of wire splicing and required volume.

Figure : Modified Hull End Cap

Internal Frame

This year's alteration to the internal frame accommodates the transition from the Intel NUC to the Jetson TX2. Rather than the previous modular acrylic sheets, custom-fitted 3D printed parts were designed. The custom fit was required as the introduction of the Jetson and removal of the analog to digital converter drastically altered the internal configuration. This modification allowed for increased space efficiency, accessibility, and display options for visual feedback. Due to the Zachry Engineering Design Center's role in manufacturing PPEs for the Brazos County hospitals, these components were unable to be manufactured.

B. Electrical

The electrical system has undergone many updates from last year to assure reliability. The team got a new Jetson TX2, replacing the previously used Intel NUC. The ATX converter was also changed to a 12-volt converter. A teensy was added for servos and a pressure sensor. A more reliable mission switch and kill switch were attached, and the power distribution system went through a complete overhaul. The various aspects of the electrical setup are discussed below:

Power Distribution

This year the power distribution was completely new. The main power supply is two 22 V 1600mAh batteries. One battery is connected in parallel across a new PCB to replace the large block terminals used previously. This allows power to be evenly distributed to the eight thrusters. Additionally, multiple fuses were added to the system as a precautionary measure. The second battery powered all of the remaining electronics, this included the Jetson TX2. The Jetson received 19 volts by use of a voltage converter connected to the battery. The Jetson then ran an Arduino Mega, three cameras with an integrated IMU, a pressure sensor and a teensy via different ports. The thrusters are powered separately in case of an emergency shut down. Shutting down the entire system is not as desirable as cutting power to the thrusters alone. The new waterproof kill switch is directly attached to the thruster system and can easily be switched off. The team did not use an ATX this year and instead distributed the power individually, greatly improving the system. Instead of the ATX, voltage converters were used as needed to achieve this.

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. Communication data, serial clock, and serial data are received from a Blue Robotics pressure sensor and read on a Teensy 3.5. The Jetson TX2 uses a serial interface to receive the sensor readings as part of the control algorithms. The Arduino shield PCB also incorporates a Blue Robotics mission switch which helps start and terminate program execution.

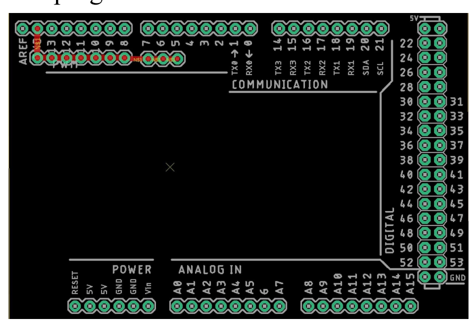

Figure 5: Custom Arduino PCB for Thruster Control

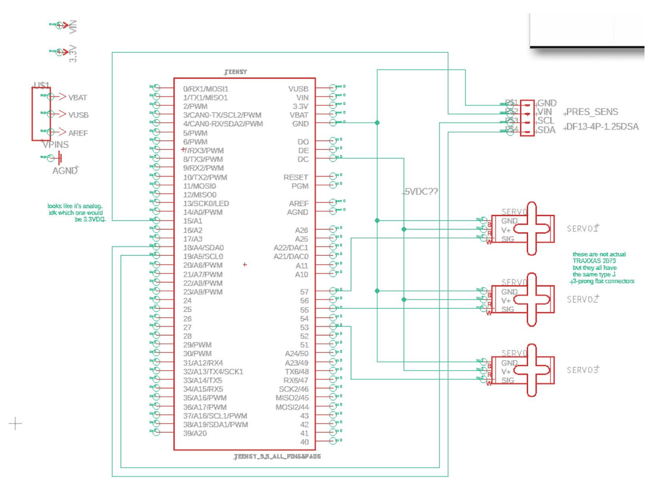

Figure 6: Custom Teensy PCB for sensor control

Computer, Camera, and Sensors

The vehicle uses a Blue Robotics digital camera for our bottom facing camera inside a separate waterproof structure. The vehicle's forward facing camera is a ZED Mini stereo vision camera with an embedded IMU (Inertial Measurement Unit). The camera system is used to detect objects underwater, in addition to monitoring the position of the vehicle. Our cameras connect directly to the Jetson TX2 via USB. The Teensy 3.5 Microcontroller also receives pressure and temperature data from the Blue Robotics pressure sensor. All of this data is fed from the Teensy to the Jetson through a USB connection. The teensy is also able to provide servo control for added mechanisms. Additionally, a VectorNav connects to the Jetson to provide yaw, pitch, and roll data. The Jetson also connects to an Arduino Mega which controls the ESC's and the thrusters and allows for access to the mission switch.

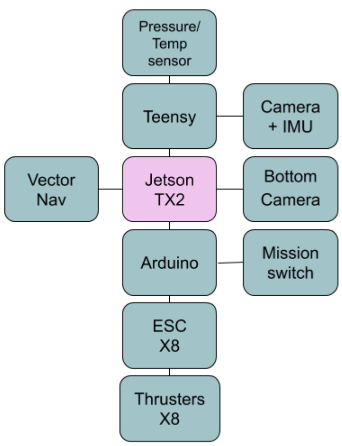

Figure 7: Data Transfer Flow Chart

Kill Switch and Mission Switch

The MOSFET-based kill switch used last year failed to terminate high current from entering the electrical system. This year the vehicle is upgraded with an on/off kill switch with wire lead terminals. The switch is connected in series to a PCB that connects our ESCs in parallel. At high current, the switch will turn on and cut off the 22V battery which is used to power the thrusters. A Blue Robotics switch which is connected to the Arduino shield PCB detects high and low currents 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 Jetson TX2 and another computer while the vehicle is underwater. The content on the Jetson is modified by using Windows Remote Desktop application. A SubConn connector is used to plug in the tether as 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 Nvidia Jetson TX2, communicates with an Arduino Mega through a serial interface to transmit thruster control data and receive pressure and temperature sensor readings. The various aspects of the AUV's software are discussed below:

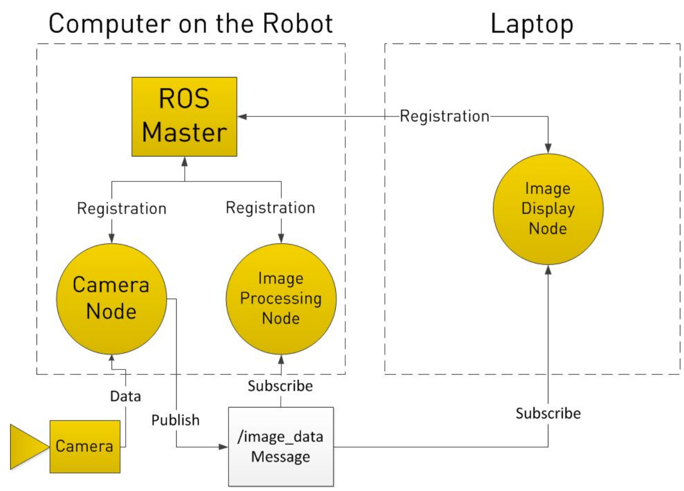

Figure 8: ROS Example

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 act 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 targets [1]. A depth map is also created using stereovision from the ZED Mini camera to determine the distance of the object from the vehicle. This year, the team changed the color spectrum to receive more accurate contours and researched adding physical filters to the AUV camera to filter out sunlight and the blue color from the water. Last year's image processing code was built upon to create this year's code.

Machine Learning

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 the team did not have in last year's design.. Research was done to provide insight into You Only Look Once (YOLO v3) as a system to provide better object detection for 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.

<u>ROS</u>

The AUV's software coordinates the data transfer between the main computer, the sensors, the cameras and the thrusters. The stack has been developed on top of the Robot Operating System (ROS Kinetic) written in C++ and Python. The segregation of work is based on nodes with each node responsible for handling tasks specific to that node. The main distinctions between the nodes are the Visual Odometry, Trajectory Planner, Control/Logic, and the Hover/Thruster Node. The Trajectory Planner Node is in charge of publishing the directive on where the AUV goes, and the Logic/Control Node will be the node that uses that information to control the thrusters. All nodes in the package begin running when the Mission Switch is enabled, and will run toward a default state until the Trajectory Planner Node decides on a course of action.

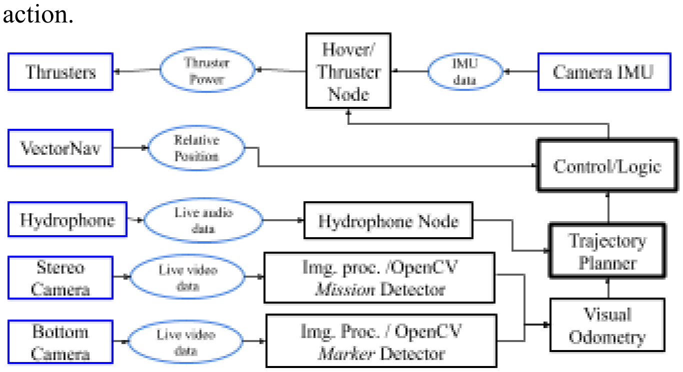

Figure 9: ROS Layout

D. Mechanisms

<u>Maneuvering Arm:</u>

The team designed a stationary arm in order to pull levers and make contact with buoys. It is created out of Aluminum 6061 and will be with the hooks attached at the bottom. The team has planned to prototype this arm through 3D printing and then manufacture the metal arm with CNC mill. The arm will be attached to the bottom panel on the mainframe through multiple bolting points.

Figure 10: Arm

<u>Dropper:</u>

The dropper was created to hold two golf balls until approaching an obstacle that requires the AUV to release it. The dropper system consists of two storage and dispensing areas. Golf balls are pushed between the aforementioned areas by fan blades powered by a digital waterproof stepper motor. The motor will be activated when the AUV is above the object dropping task. This system is attached to the bottom of the bottom panel and was 3D printed using ABS filament.

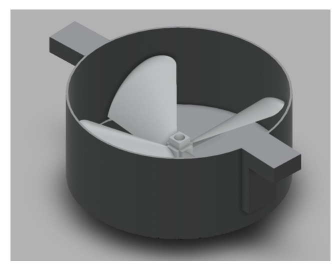

Figure 11: Dropper

IV. EXPERIMENTAL RESULTS

Due to unforeseen circumstances, this year's vehicle has not entered the testing phase yet.

V. ACKNOWLEDGMENT

The WE AUV team would like to thank the following supporters: The Texas A&M University Women in Engineering program, the Fischer Engineering Design Center, BP, Accenture, Blue Origin, and Caterpillar. 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	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	-
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 2Jetson 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
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	-	-	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
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
Team Size	-	-	31 Members	-
HW/SW ratio	3:1	-		-
Testing Time	-	-	Due to unforeseen circumstances the AUV was unable to be tested	-

Appendix B

Project Team's Workshops
Supported 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. In continuation of last year's efforts to extend member's skill sets the team has continued to offer open workshops to all underrepresented students in the college of engineering. This has given other students who are not on the team a chance to learn skills they wouldn't have learned in the classroom. Our team has continued offering these workshops virtually and hosts Q&A sessions for members to interact with other underrepresented students, answer any questions about the workshop and address any issues as necessary. Not only has this helped engage our members but it has also helped advertise the team to other students who may be interested in joining the team.
These workshops include:

- Mechanical
  - SolidWorks
  - Fusion 360
  - Manual Mill
  - Woodworking
  - Basic Hand Tools
- Electrical
  - Intro to PCB Design
  - Electrical Connections & Soldering
  - Breadboard and Soldering PCBs
- Programming
  - Micocontrollers
  - Python OpenCV
  - Intro to C++
  - ROS tutorials

The team has also continued participating in events such as the Virtual Project Showcase and the Virtual Student Research Week at Texas A&M University This allows our team to demonstrate and promote the applications and extensive research work achieved by the team over the past 5 years.