OTUS Team's Journal Paper for 2018 RoboSub Competition

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***Abstract*— OTUS/AUVSI Team at Oregon Institute of Technology (Oregon Tech) is proud to be participating for the 3rd time in the 2018 RoboSub underwater robotics Competition, sponsored by AUVSI and ONR which will be held at SSC TRANSDEC San Diego. The purpose of this project is to design and manufacture a functional autonomous robot capable of completing several tasks underwater.**

This paper is both an instruction and technical document in preparation of RoboSub journal papers by Oregon Tech. The goals of the OTUS journal paper for the RoboSub Competition are to assist teams in becoming more familiar with the preparation of scientific publications, to articulate the linkage between vehicle design tradeoffs and overall competition strategy, and to document successful approaches and lessons learned for future team members.

I. INTRODUCTION

The purpose of the OTUS RoboSub competition is to provide opportunities for students to experience the challenges of system engineering, to develop skill in accomplishing realistic missions with autonomous vehicles, and to foster relationships between young engineers and organizations developing autonomous vehicle technologies. Moreover, it is to spur interest for future engineers and scientists to develop marine technology. The process of developing a robotic submarine, in conjunction with a competitive environment, creates more competent students in engineering design and development. Furthermore, we try to contribute to the domain of autonomous unmanned underwater vehicles (AUVs).

II. MECHANICAL SYSTEM

The journal paper consists of the following mandatory sections and two optional sections (Acknowledgements and Appendix). Additional sections may be included; however, the overall limit of 10 pages applies to all sections—the only exceptions are the References and Appendix.

III. A. Design Strategy

The design strategy of the robotic submarine is derived from the competition. The main objective of the submarine is to submerse and pass through the ten feet wide validation gate. Once through the gate, all subsequent tasks will provide bonus points. The 2018 Oregon Tech submarine failed to complete this preliminary task. Consequently, completing this task is the main objective of Oregon Tech's 2018 Submarine.

The 2018 Oregon Tech submarine was incomplete at the beginning of the competition. This lead to the computer power supply being wired backwards, causing the on board computer to short circuit. This unfortunate experience proved the importance of a completed and tested sub, and as such, a completed, tested sub is a main consideration in Oregon Tech's 2018 submarine.

Oregon Tech's main goal of passing through the gate will be met by creating a sub with more robust systems, with particular attention to wire connections that may be exposed to water as this was one of the largest setbacks with the 2018 sub. Additional components, such as the torpedoes and robotic arm, are integrated into the design as well; although, they are not of paramount importance.

B. Frame Design

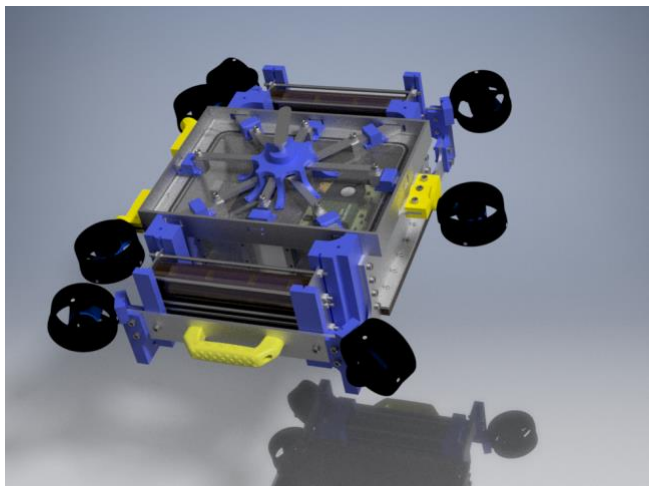

Fig 1. Final Frame Design with Thruster Placement.

The frame for our robot was built around the idea of mastering movement first and speed second. With this in mind, the decision was made to include 7 thrusters for the sub, with 3 motors moving in the vertical direction and 4 in the horizontal direction. The horizontal motors are mounted at a 30° angle for more efficient horizontal movement. The current frame for OTUS has dimensions of 22" wide, 29" long, and 9" tall. The aluminum hull allows for placement of all 7 motors. The main hull is built from 3/16 5051 aluminium sheet; the connecting parts, add-on mounts and fastening brackets are 3D printed from ABS plastic. The hull is designed to allow easy access to electronics, and offers large polycarbonate windows to view the onboard computer monitor and allow team members to easily spot any water ingress. The hull is also the main structure of the sub. Due to the size of the hull, the robot must weigh close to 50 lbs to be neutrally buoyant. The large hull allows for precise placement of weight to balance the sub.

C. Hull Design

The hull is one of the crucial components needed for the success of the submarine. It is what holds all of our electrical components and keeps them from getting wet. The hull in this years design is vastly different than 2017. The hull used in 2017 was a 6 inch diameter tube 55 inches long. This presented problems such as poor electronics accessibility and the tangling of wires. Our new hull is a box design that uses a single handle hatch, similar to a bank vault door. This allows team members easy access and there is no need to move or adjust wires when opening or closing the sub. All wires into the hull enter through the sides, making the lid free of wires. The new hull also boasts a large polycarbonate window that allows an onboard computer monitor to be viewed.

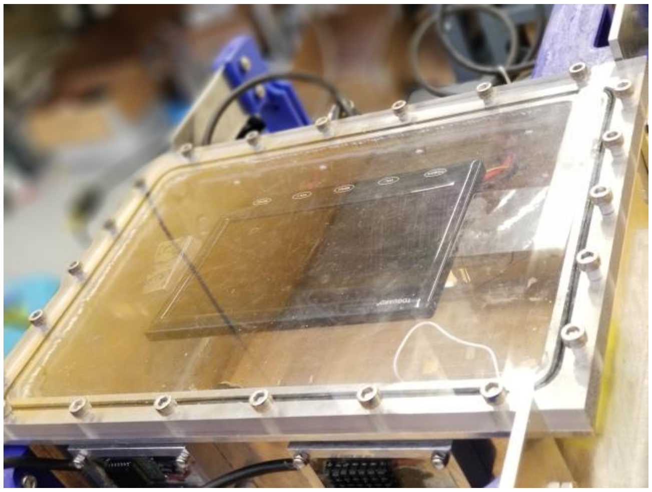

Fig 2. Hull Window

D. CFD Analysis

To test our initial models, we performed computational fluid analysis in order to understand the effects of drag on our vehicle. We also ran a CFD analysis of the electrical components to determine if finding a method of cooling said components was necessary. We found that drag will play minimal role when compared to the potential thrust our motors are able to output. The internal electronics do not require additional cooling.
The following models are set up for the analysis: Steady, Liquid, Constant density, Turbulent, K-Epsilon, and segregated flow.

E. Thruster Design

We decided to use the BlueRobotics T100 brushless thrusters paired with BlueRobotics Blue ESC's for propulsion. Motor power is controlled by ESC that works with Arduino Mega SCL and SDA I2C communication for forward and reverse control. The ESCs are potted in aluminium housings that are bolted to the external walls of the sub. This allows direct water cooling of the ESC's thus reducing the internal hull temperature.

Fig 3. Thruster and ESC

F. Manipulator (Payload Retrieval/Deposit System)

To complete the arm retrieval and payload delivery challenge, the team needed to first devise a way in which the box top would be removed. First and foremost, the device needed to be extremely simple. We went with the simplest option of a single degree of freedom, two arm vise that is designed to close around the arm handle. This allows some freedom and precision in the submarines ability to directly center over the handle and clamp down. The device will be actuated by a single waterproof servo that rotates a two-way threaded rod. The threaded rod will be threaded half with left handed threads and half with right handed threads. That way, when the rod is rotated, it will allow the allow the nuts to move in opposite directions, thus enabling the arms to close together.

G. Torpedo

The torpedoes on our submarine are vessel armed, vessel aimed, and self-propelled. The operation of the torpedoes comprises the following; activation, aiming, firing and recovery. The activation of the torpedoes will be comprised of identifying a vertical reference point of the target, stabilizing the vessel and sending a signal to the torpedo tube. At the tube a flashing LED on the tube will signal a photo resistor located on the torpedo. The photoresistor will activate small electric motors located at the bow and stern. The torpedo is self-propelled and will travel until resistance or loss of power. The fire and forget nature of these necessitates the addition of a flashing beacon to aid in recovery. This beacon will be activated at the time of arming.

The target will be identified by the forward camera. After identification, a vertical level will be attained, along with a distance from target which will be determined from testing. Once this position is attained the system will be armed the light pulse to the tube will be sent and the torpedo will be fired.

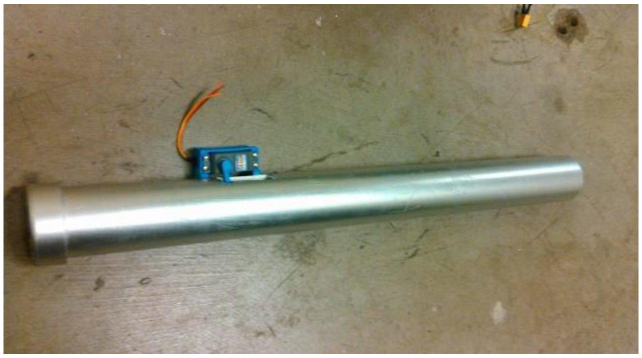

Fig 4. Torpedo Tube

III. Electrical, Computer System and Software

A. Main Target Computer

The main board is an Intel NUC Board. It has an i3 Dual-core CPU with a heatsink and fan, 4GB RAM, and a SATA hard disc. It has multiple interfaces such as 4xUSB, 2xmDP, and 1x eDP Graphics Output. It has integrated LAN, Wifi, and Bluetooth. The main board is running a Windows 10 operating system, Visual Studio 2017, Arduino IDE, and LibrePilot are installed on the main computer.

Fig 5. Intel NUC

B. Mission Planning Control System

Our sub is controlled using a combination of Google's Tensorflow and the OpenCV C++ libraries respectively. The main control system is divided into subsystems. There is a subsystem for each of the competition tasks. Additional sub-systems included in the Mission Planning Control System are referenced from the Mission Planning Algorithm for multiple tasks. Startup/ Initialization Procedures, Image Recognition, Depth Controller, Motor Controller, and Navigation are the main non-task specific subsystems that Robosub uses.

C. Cameras

There are two cameras mounted on the submarine; one on the front and one on the belly of the submarine. The main front camera is a dual-array Logitech C510. The camera was physically modified and a custom housing was built for it in order to waterproof the camera. The camera is capable of determining how far away objects within its field of view are from the camera which is used for object recognition and orientation due to its stereo vision capabilities.

Fig 6. Dual-Camera Array Logitech C310

The second camera, mounted on the belly of the submarine, is a Logitech C510 Webcam housed in a waterproof enclosure. The belly-mounted camera is used to detect objects on the bottom of the pool.

Fig7. Logitech C510 Camera

D. Flight Controller

A pololu IMU was used to stabilize the submarine horizontally. The flight controller has a built in MPU-6000 3-axis gyroscope and accelerometer and is usually used to stabilize quadcopters. A single "throttle" signal is sent to the IMU. The IMU uses the throttle input signal along with the built in MPU-6000 to adjust power to the four elevator motors. The power to all four elevator motors is constantly being adjusted in order to keep the submarine level.

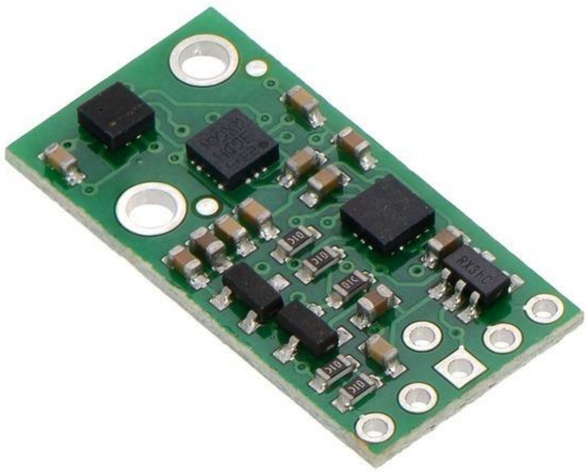

Fig 8. AltIMU-10 v4 Gyro, Accelerometer, Compass, and Altimeter (L3GD20H, LSM303D, and LPS25H Carrier)

E. Pressure Sensor

A Bar30 Pressure Sensor from Blue Robotics was used to determine the depth of the submarine. Robosub uses data from the pressure sensor to adjust the throttle signal that is sent to the Flight Controller. The pressure sensor, flight controller, and the four elevation thrusters work together to maintain a desired depth under the water's surface.

Fig 9. Bar30 Pressure Sensor

F. Arduino Mega 2560

An Arduino Mega 2560 is used to enable the main computer to communicate with sensors, motor speed controllers, servos, cameras, and other devices. Data is sent from the sensors to the Arduino Mega using I$_2$C Communication. The data is converted into a simple variable which is forwarded to the main computer. The main computer then uses the variable to make decisions and determine what actions the submarine needs to take next. This communication also works in reverse which allows the main computer to send commands to the servos, flight controller, and motor speed controllers.

Fig 14. Arduino Mega 2560

IV. IV. EXPERIMENTAL RESULTS

Testing for this years Oregon Tech Robosub began April 2018. This was the point where the submarine was water worthy. The preliminary tests included a bucket and small pool testing for motors and full sub. The early sub had a PVC hull with an acrylic window and screw caps on each end. This was a stand in hull (Figure 1.) while our final polycarbonate hull was being completed. While testing with this hull we began to write scripts for the Arduino via a USB cable. The large pool testing occurred at Ella Redkey pool in Klamath Falls, OR.

Fig 11. Sub with top-down view of bank vault style lid

Once the final hull was completed the testing started to ramp up for time in water. We acquired a small 300-gallon tub to use on campus for small scale testing. This allows the team to test any day of the week for as long as we needed. It also allows us to present the sub in situations on campus, which is more convenient for professors and students.

The majority of the testing occurred in our 300-gallon pool on campus (Figure 16), however major tests were conducted in a full size pool. The most extensive limitation pertaining to testing was the lack of a resident pool facility on the OIT campus; a community pool off-campus was rented for full scale mobility testing.

Fig 16. Final Hull with all thrusters

One of the major tests that occurred was on June 7, 2018 when the sub was able to be controlled through Matlab and a gaming controller. This achievement allowed for the Matlab code to finally run with the camera control instead of being tethered to a computer with a USB.

Since most of the testing occurred in the spring term for the whole Robosub the time in water is relatively low, approximately 25 hours so far. These hours were actually high productivity hours, where we ran different scripts and actually got live feedback from the sub for adjustments. We also learned about the thrust output of our motors and the rigidity of our frame. Since the frame is 3/16ths'' 5051 aluminium, it could potentially crack and fail from bolt torquing, but so far the frames rigidity has held. This is primarily due to the tungsten tig welded joints increasing the rigidity of the aluminium along the frame.

Oregon Tech's Robosub team has created and tested a working submarine that will perform in competition. The testing involved allowed our team to gain knowledge and improve the project as more testing occurred. As the competition gets closer more tests will be conducted and we will keep improving the functionality of the sub.

V. Acknowledgements

Special thanks to OTUS AUVSI Club members and Senior project teammates (not included in the members shown in the author section) who have worked for this project.

- Student Participants at Oregon Tech (OIT)

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  Jason Farrell
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  Julian Mindlin-Davidson
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Fig 1.

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Fig 2.

V. VI. References

1. Preliminary Mission and Scoring: Casino TRANSDEC, www.robosub.org AUVSI Foundation, '18(cited 2/25/18)
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Fig 3.