OTUS Team's Journal Paper for 2017 RoboSub Competition

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***Abstract*— OTUS/AUVSI Team at Oregon Institute of Technology (Oregon Tech) is proud to be participating for the 2nd time in the 2017 RoboSub students' 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.

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 2016 Oregon Tech submarine failed to complete this preliminary task. Consequently, completing this task is the main objective of Oregon Tech's 2017 Submarine.

The 2016 Oregon Tech submarine also wasn't fully waterproof. This lead to the sub to sink and lose all the electronic components. This unfortunate experience proved the importance of a watertight sub, and as such, this is a main consideration in Oregon Tech's 2017 submarine.

Oregon Tech's main goal of passing through the gate without experiencing any water breaches requires the sub design to place emphasis on maneuverability and sealing capabilities of the hull. 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

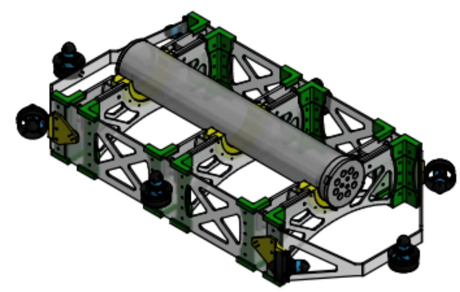

Fig 1. Final Frame Design with Hull Placement.

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 8 thrusters for the sub, with 4 motors moving in the vertical direction and 4 in the horizontal direction. The horizontal motors are mounted at a 45° angle for more efficient horizontal movement. The current frame for OTUS has dimensions of 31.7" wide, 62.4" long, and 13.0" tall. The large frame allows for a symmetrical placement of all 8 motors. The main frame is built from acrylic plates and the connecting parts, add-on mounts and fastening brackets are 3D printed from ABS plastic. Placement of the hull adds to the symmetrical design and creates an even level of buoyancy. Because of the size of the hull, the robot must weigh close to 70 lbs to be evenly buoyant. With the symmetrical design system, the weight that needs to added to the sub can be easily added or removed as needed.

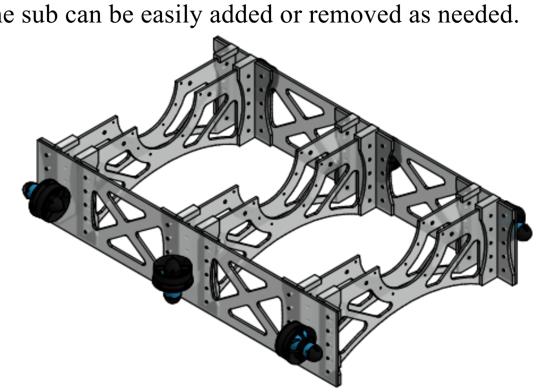

Fig 2. Original Frame Design

The frame shown in Fig. 2 was the original frame our team had built at the start of the year. This frame had 6 motors in total, with 4 motors moving in the horizontal direction and 2 in the vertical direction. A number of theoretical designs were made on how to improve performance on the robot and each design added an additional 2 motors in the vertical.

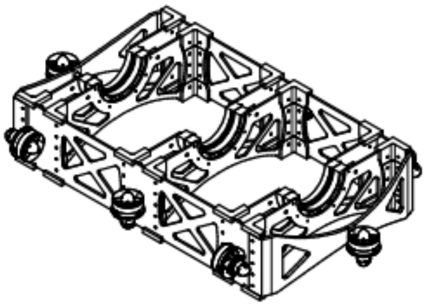

Fig 3. Experimental Design 1

The first experimental design added 2 additional motors in the vertical direction. The frame is symmetrical in the placement in all 8 motors, however, the added frame pieces are too close to the edge of the hull restricting placement for the hull.

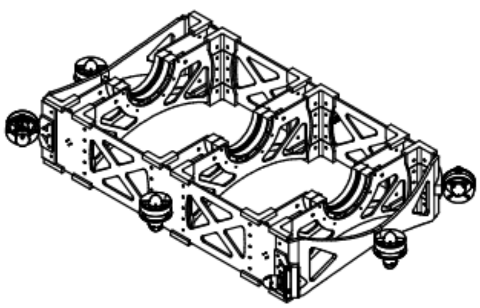

Fig 4. Experimental Design 2

The second experimental design is very similar to the first. The only difference is parts to mount the horizontal motors at the corners of the sub frame. This allowed for better horizontal movements.

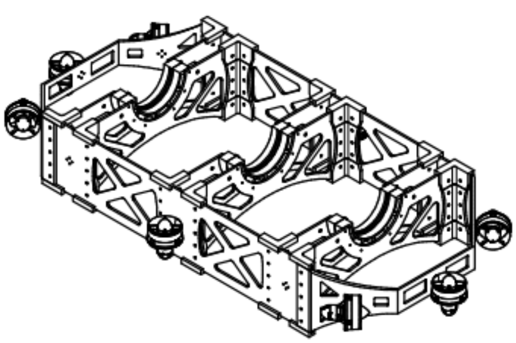

Fig 5. Experimental Design 3

The third experimental design is designed around the concept of using the added acrylic frame parts to be a mount for the added motors. The concept was making an end bracket that was at a 45° angle with holes in the acrylic to mount the motors. This design is what would be the basis for the final design as it combined the 45° angle end bracket with the corner-mounted parts from the second experimental design.

C. Hull Design

The hull in the frame 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. During the design process our hull underwent several modifications. At first it was designed to be an Acrylic tube with a length of 55” and a diameter of 6”. We originally designed and 3D printed our own end caps with a double O-ring to maximize the sealing effect. The 3D printer endcaps were not sufficient for waterproofing. Therefor we decided machine endcaps out of 6061 aluminum. This was done by our group members using a mill and lathe. To mount our circuits, we laser cut an acrylic board to, run down the center of the tube. As the design got further, we made some 3D printed rings to go inside the tube with notches in them designed to hold the board.

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. It will be necessary to install a fan inside the hull to circulate airflow, this combined with the aluminum endcaps working as a heatsink will be sufficient to keep our electrical components within working parameters.

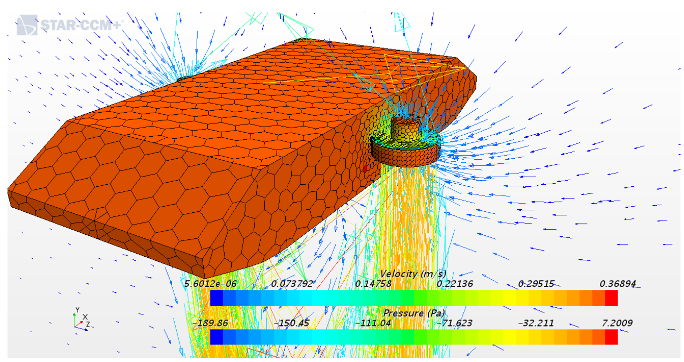

Fig 6. CFD Drag Analysis

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 T200 brushless DC motor with electronic speed controller (ESC) for control of the underwater robot propulsion, which results in 8DOF. Motor power is controlled by ESC that works with Arduino Mega SCL and SDA I2C communication for forward and reverse control.

Fig 7. Thruster

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 photo resistor 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.

The tubes are mounted on the submarine with two connections, the rear will be fixed, yet allow for rotation from a traversing mechanism where the front connection is located. The path of the torpedoes is unknown, and having an adjustable mechanism will allow for corrections without the need to fundamentally change construction. The traversing for the tubes will be limited to 15 deg from the forward axis.

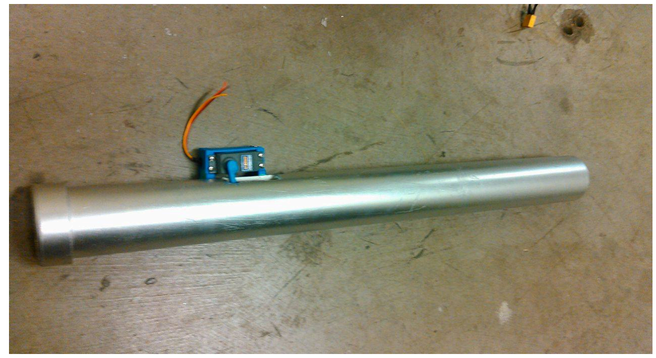

Fig 8. Torpedo Tube

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 for MATLAB/Simulink, 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. MATLAB/Simulink, Visual Studios 2015, Arduino IDE, and LibrePilot are installed on the main computer.

Fig 9. Intel NUC

B. Mission Planning Control System

Our sub is controlled using a Simulink Real-Time control system. The main control system is divided into sub-systems. 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 sub-systems 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 an Xbox Kinect camera. 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.

Fig 10. Xbox Kinect Camera

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.

Fig 11. Logitech C510 Camera

D. Flight Controller

A CC3D Flight Controller 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 flight controller. The flight controller 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.

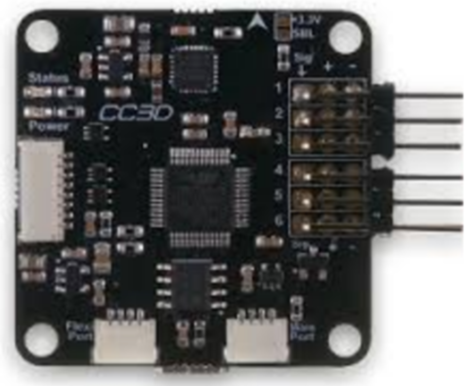

Fig 12. CC3D Flight Controller

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 thrustors work together to maintain a desired depth under the water's surface.

Fig 13. 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^2C 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. Experimental Results

Testing for this years Oregon Tech Robosub began April 2017. 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 (Firgue 1.) while our final polycarbonate hull was being completed. While testing with this hull we began to write scripts though the Arduino via a USB cable. The large pool testing occurred at Ella Redkey pool in Klamath Falls, OR.

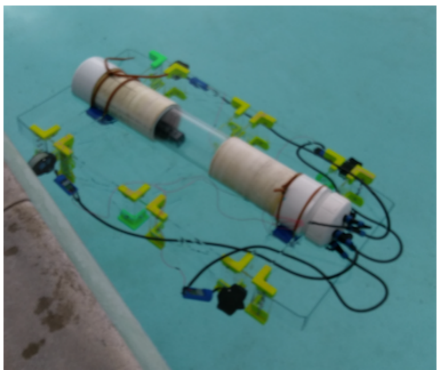

Fig 15. Sub with Stand-in Hull

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.

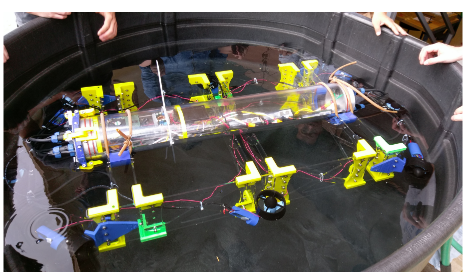

Fig 16. Final Hull in 300 Gallon Tank

One of the major tests that occurred was on June 7, 2017 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 learning about the true output of our motors and the rigidity of our frame. Since the frame is .25'' acrylic it could potentially crack and fail, but so far the frames rigidity has held. This is primarily due to the 3D printed joints increasing the rigidity of the acrylic along the frame.

Oregon Tech's Robosub team has created and tested a working submarine that will preform 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 players shown in the author section) who have worked for this project.

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VI. References

1. Preliminary Mission and Scoring: A Pirate's Life for Thee, www.robosub.org AUVSI Foundation, '15(cited 12/25/15)
2. AUVSI Foundation and ONR: Engineering Primer Document for RoboSub Competition, Maritime RobotX Challenge, AUVSI and ONR, 2006