Montana State University Autonomous Underwater Vehicle: Development and Testing of the AUV "Blue November"

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Abstract

The Montana State University AUVSI RoboSub team consists of mechanical, electrical, and computer science students who were tasked with creating an AUV that is capable of performing in the annual AUVSI and ONR International Robosub Competition. The team worked to modify and improve the preexisting submarine by creating a more robust and user friendly design. The mechanical team focused on creating a more reliable waterproof capsule, a more sturdy electronics board, water-tight battery cases, and a semi-transparent camera housing. The electrical team emphasized wiring and replacing electronics as well as improving ease of access by installing new wet-connectors. The computer science team replaced and enhanced the software by implementing the OpenCV robot controller libraries and producing a more intuitive mission-programming environment.

Introduction

The Montana State University AUVSI RoboSub team is multidisciplinary capstone group comprised of undergraduate students in mechanical, electrical, and computer science disciplines. These students were given two semesters to redesign and improve the existing Robosub built by the previous capstone team to compete in the AUVSI and ONR International RoboSub Competition hosted at the TRANSDEC facility in San Diego in July. The team focused on creating a solid foundation for future capstone groups and strove to enhance continuity within the project between years. The project provided invaluable hands on experience, the opportunity to work with students of different disciplines than their own, and challenged the team to think critically and decisively within the ten month span of the design and creation of "Blue November."

Design Overview

The mechanical construction of the submarine consists of a clear 8" outer diameter polycarbonate tube sealed with two end caps. Both end caps include two fins that are bolted onto an aluminum t-slot frame. The frame simultaneously holds a camera housing, two battery housings, six motors, and weights to adjust the buoyancy of the sub. The electronics attach to a ribbed plastic board that can slide easily in and out of the tube via the rear endcap. The electronics and wiring are significantly simplified from the old design for a cleaner look and provide an easier method of troubleshooting any potential issues. The archaic preexisting software has been completely replaced with the aid of the OpenCV robot controller libraries.

Mechanical Systems

The external mechanical body is shown in Figure 1.

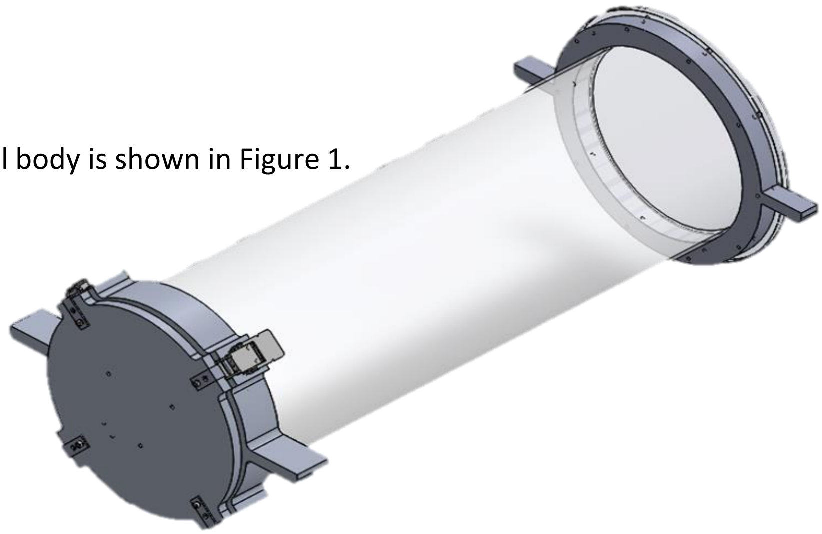

Figure 1 – Solidworks model of the external mechanical body

Frame

The frame of the submarine is built from 1”x1” extruded T-slot aluminum bars (see Figure 2). This geometry of bar permits various components to be attached with a simple screw rather than needing to cut and re-weld mounts. The frame does not enclose a sealed area and therefore cannot fill with water, something that may have been a problem if the frame was built from traditional box tubing. The frame also mechanically connects all components of the submarine, so that an applied force from one of the motors can move the entire sub.

Figure 2 – Cross section of the frame 1 x 1 in extruded T-slot aluminum bar

Rear End Cap

One of the most influential changes to the submarine’s design was progressing from a rear end cap that was sealed with a series of bolts and an O-ring to a rear end cap that is sealed with four latches and a rubber gasket (see Figure 3). The spring assisted stainless steel (McMaster PN 1794A43) latches provide a more reliable seal by applying an even pressure across the rubber gasket as well as easier access to the internal electronics. The latches are bolted into the circumference of the aluminum surrounding the chassis tube and the concurrent hooks are bolted through the front of the aluminum. The aluminum rear end plate and collar were crafted in house via CNC. Several holes were then hand drilled into the end plate for the wet-connectors and pressure sensor (not shown in figure). The collar was fitted onto the tube with a slight interference fit and sealed with a marine epoxy.

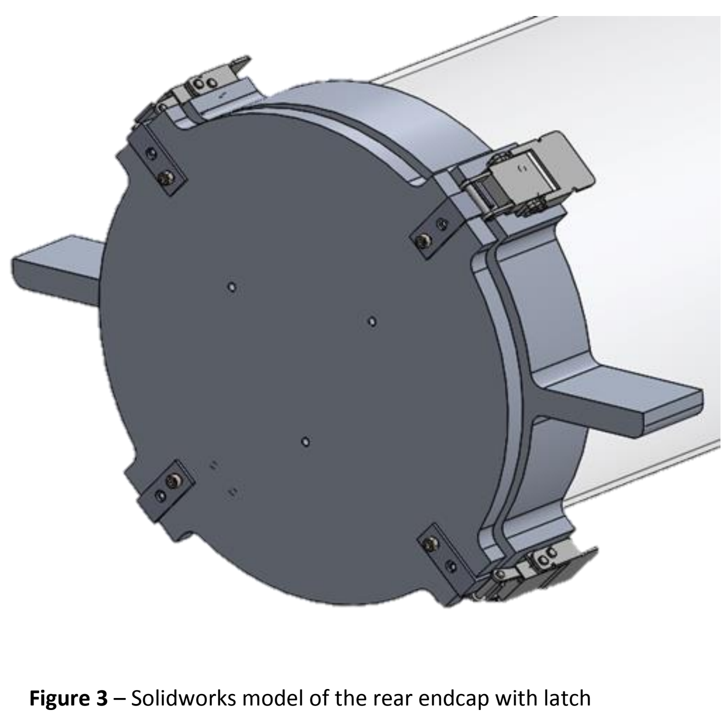

Figure 3 – Solidworks model of the rear endcap with latch mechanisms

Front End Cap

The front end plate is made of polycarbonate (like the chassis tube) and is bolted into an aluminum collar that surrounds the tube (see Figure 4). The seal between the collar and end plate is created by an O-ring that is positioned in a groove so that the O-ring cannot warp or move. The O-ring groove has been properly sized so that a Dash 371 O-ring will provide the appropriate seal.

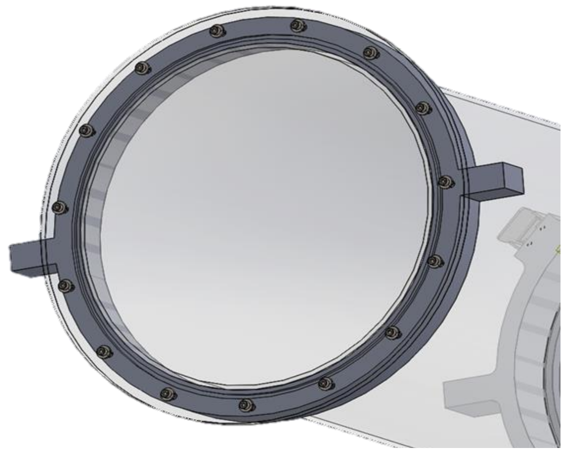

Figure 4 – Solidworks model of the clear front end cap

Camera Placement

Further heat transfer analysis indicated that the finned heat sink that previously inhabited the submarine was unnecessary. Therefore, the aluminum end plate was replaced with a clear end plate so that the camera could be internally mounted. This allows for the camera to be hard wired into the motherboard rather than having to be connected through Wi-Fi which can be temperamental underwater. A bottom facing camera is externally mounted to the frame in an aluminum waterproof housing with a clear endplate sealed with a ring of bolts and an O-ring (similar to the front plate design).

Electronics Rack

The electronics rack is comprised of a rib like structure that slides into the chassis tube (see Figure 5). The rack fits all the electronics and hardware necessary within the tube including the IMU. Since the IMU is very sensitive to its position relative to the tube, a key way was created to lock the rack's position within the tube. This new design fixed several problems with the preexisting aluminum electronic mounting board. This solution is lighter weight, more accessible, and does not have the issue of smashing some of the electronics when taken in and out of the tube as was frequently witnessed with the previous design.

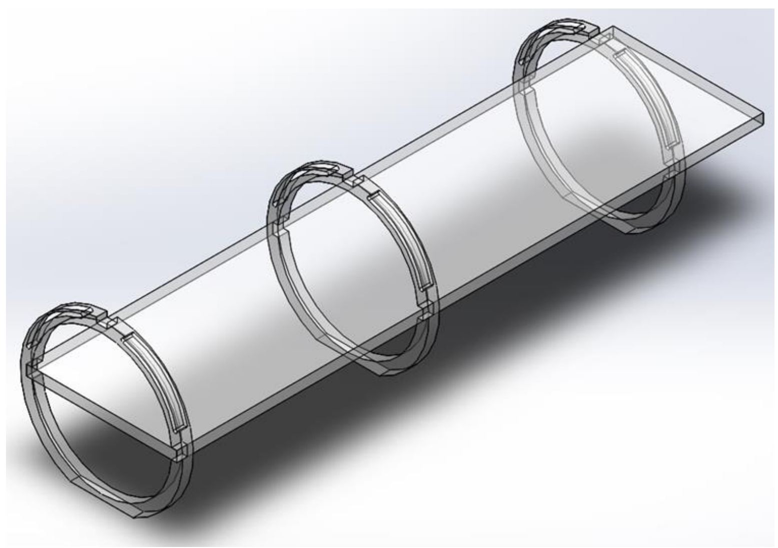

Figure 5 – Solidworks model of electronics rack. Rectangular key ways are shown at top.

Battery Placement

The batteries are mounted external to the tube so that they may be moved along the length of the frame to assist in balancing the sub as well as increase accessibility for recharging. The batteries are contained in two waterproof housings on either side of the main tube.

Electrical Systems

The electrical architecture consists of several different interfaces. Due to the complexity of the system, much of the explanation will be given by diagrams and descriptions of individual components with interfacing in the subsequent sections.

The main feature of the electrical system is the motherboard with an Intel i5 processor. Controllers and sensors are essentially all interfaced to the computer. Windows 7 is the current operating system with several additional software programs. With programming (mostly C#) and software setup, all the devices of the Robosub can be controlled.

An overview of the control scheme is as follows:

- A voltage controller delivers power from the batteries to the motherboard and some other components.
- Six motor controllers are connected via USB to the motherboard. The motor controllers control six underwater thrusters: two for forward and backward, two for submerging, and two for turning and strafing.
- An Arduino is connected via USB to the motherboard. Sensors (mainly the pressure sensor as of now) are connected to the Arduino, which converts signals into usable data for the motherboard. The Arduino is also the motherboard's interface to turn on relays that control pneumatic triggers for the torpedoes and droppers (not implemented in this year's design).
- Cameras are connected via USB to the motherboard. Cameras provide the means to handle most of the missions.

The block diagram in Figure 6 lays out the connections between all the electrical components and is an overview of the general parts necessary to make the submarine function.

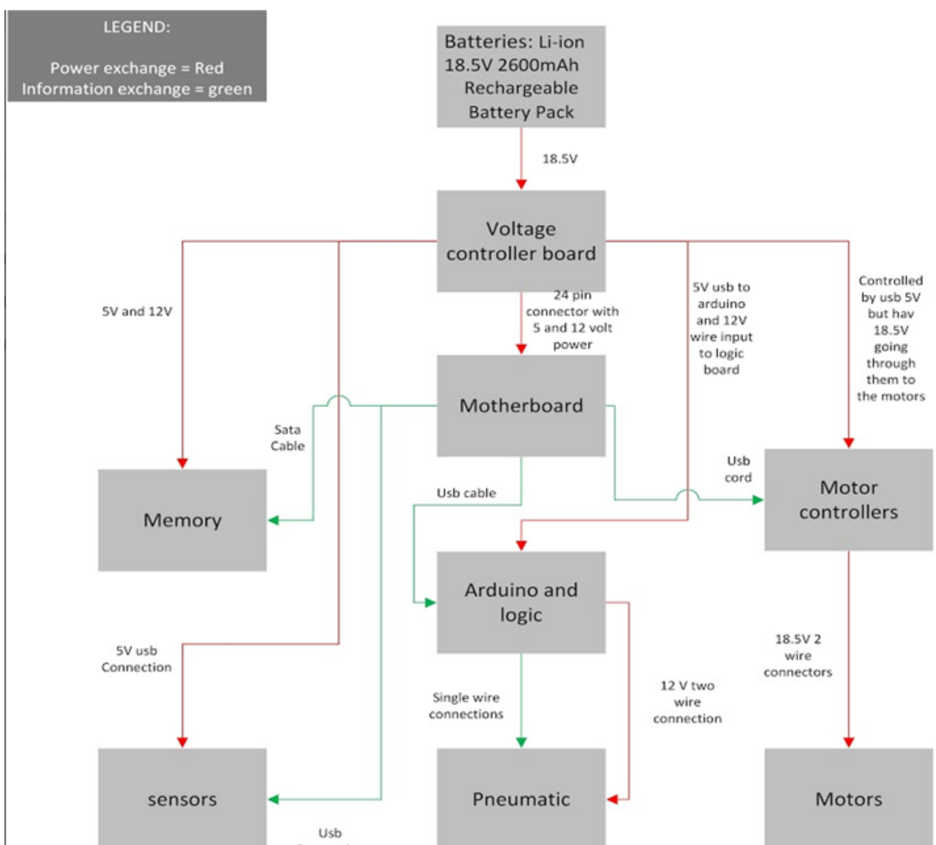

Figure 6 – Electrical System Block Diagram

Pressure Sensor

The pressure sensor is a p51 media sensor pressure sensor (see Figure 7). It allows the sub to determine its depth. It interfaces with the Arduino microcontroller which transforms the raw data into a useful depth reading. It is mounted into the rear end cap so that it is in direct contact with the surrounding water. In the current design, without the pressure sensor the sub would not be able to control or maintain a depth.

Figure 7 –Pressure sensor and cable

Motor Controller

The Pololu Jrk12V-12 motor controllers as shown in Figure 8 are the interface between the motherboard and the motor thrusters that move the sub. There are six motor controllers, one for each engine, that are connected to the motherboard through a USB hub. The motor controllers are also connected directly to the 12 volt power strip. The CPU and the motherboard then interface with the motor controllers which turn the motor thrusters on or off, forward or reverse, with variable power output to control the submarine's movement.

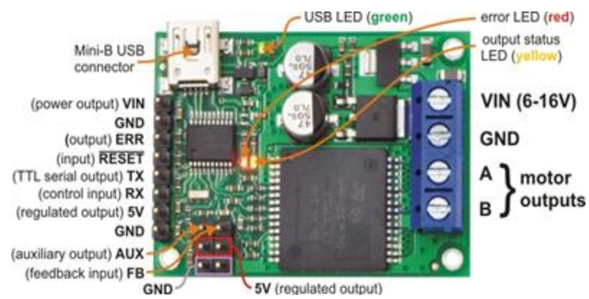

Figure 8 – Top view of the motor controller with pin information

Motor Thrusters

The Robosub is controlled by six SeaBotix BTD-150 motor thrusters (see Figure 9). These motor thrusters allow the submarine to control itself and move in three dimensions while submerged. Two of the thrusters are pointed horizontally side-to-side, two are pointed vertically and two are oriented from front to back. These thrusters are essential to the function of the sub and are connected to the motor controllers that manage their speed.

Figure 9 –Motor thruster and connected cable

Cameras

The cameras are both generic brand 150 degree fisheye-lens board-level USB 720/1080 HD cameras. These cameras were selected for their wide field of vision and lack of auto-color and auto-focus features.

Batteries

Due extensive testing time in the pool, the batteries were selected to provide a 50% increase in battery capacity to the thrusters and a 100% increase in battery capacity to the computer from the previous design. There are four Venom 18.5V 5000mAh Li-Po batteries that are necessary to power the submarine.

Wet-connectors

The wet-connectors are the mechanism that joins external components to the internal components in a way that is completely waterproof. The motors, camera, sensors, pneumatic actuators, and the batteries are all connected to the internal components with bulkhead wet-connectors. Shown in Figure 10 is an example of the type of wet-connectors that are implemented in the new design.

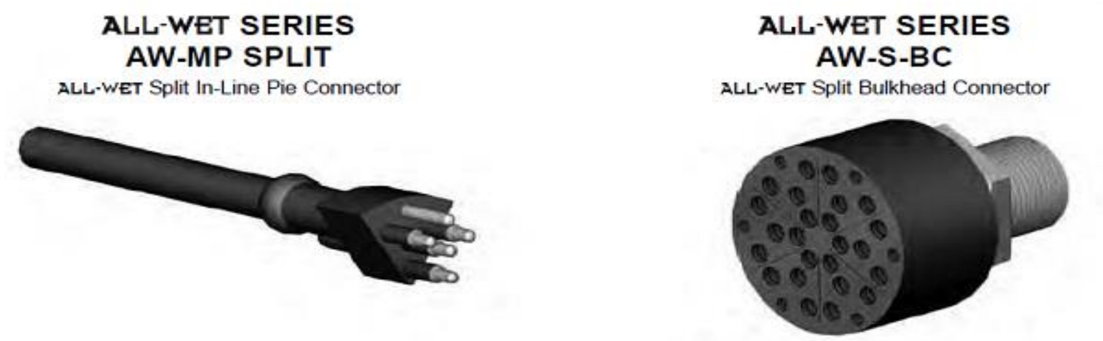

Figure 10 – Wet connectors implemented in Blue November (manufactured by Seacon)

<u>Software Design</u>

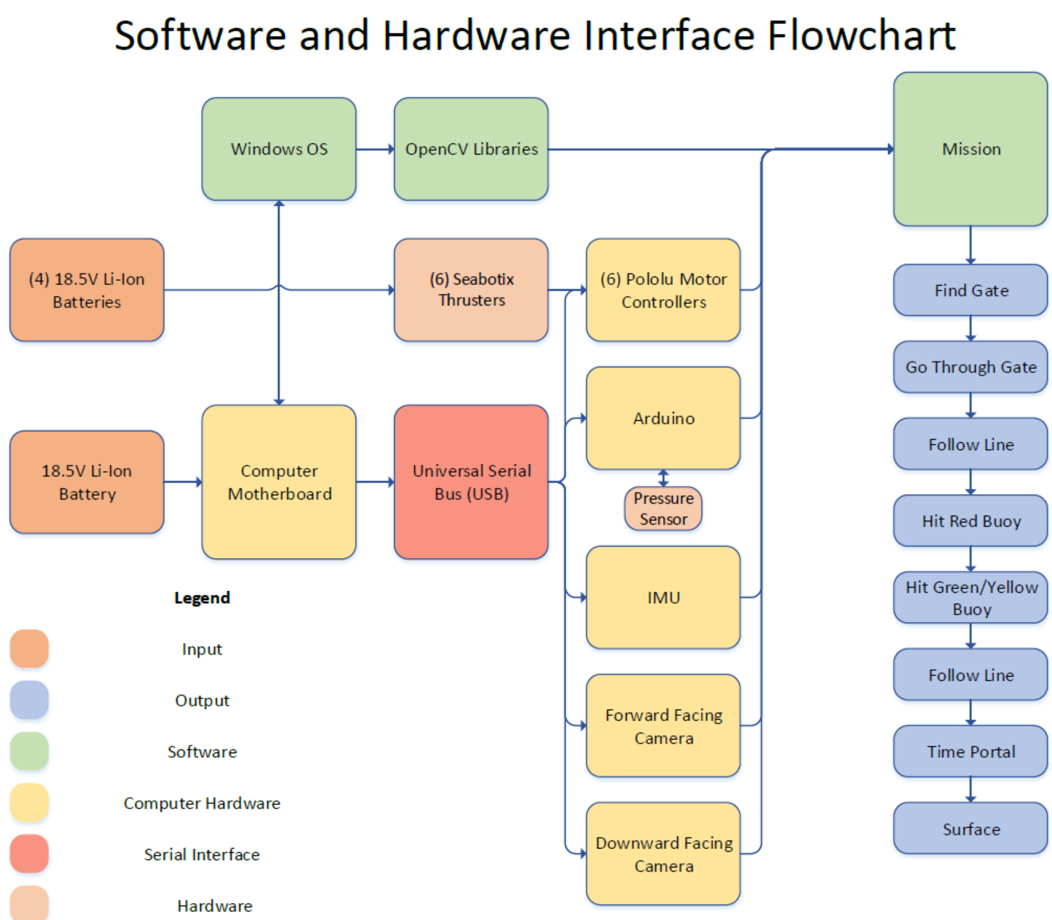

Figure 11 – Software Block Diagram

The software block diagram is shown in Figure 11. The main input to the system is power from lithium-ion batteries, and the output is the sub completing tasks in successive order. The team decided to switch over from Microsoft Robot Developer Studio to OpenCV. Using OpenCV has increased the robustness of the software interface by permitting better control and customization of the autonomous movement of the submarine. An example of the program running while tracking a buoy is shown in Figure 12.

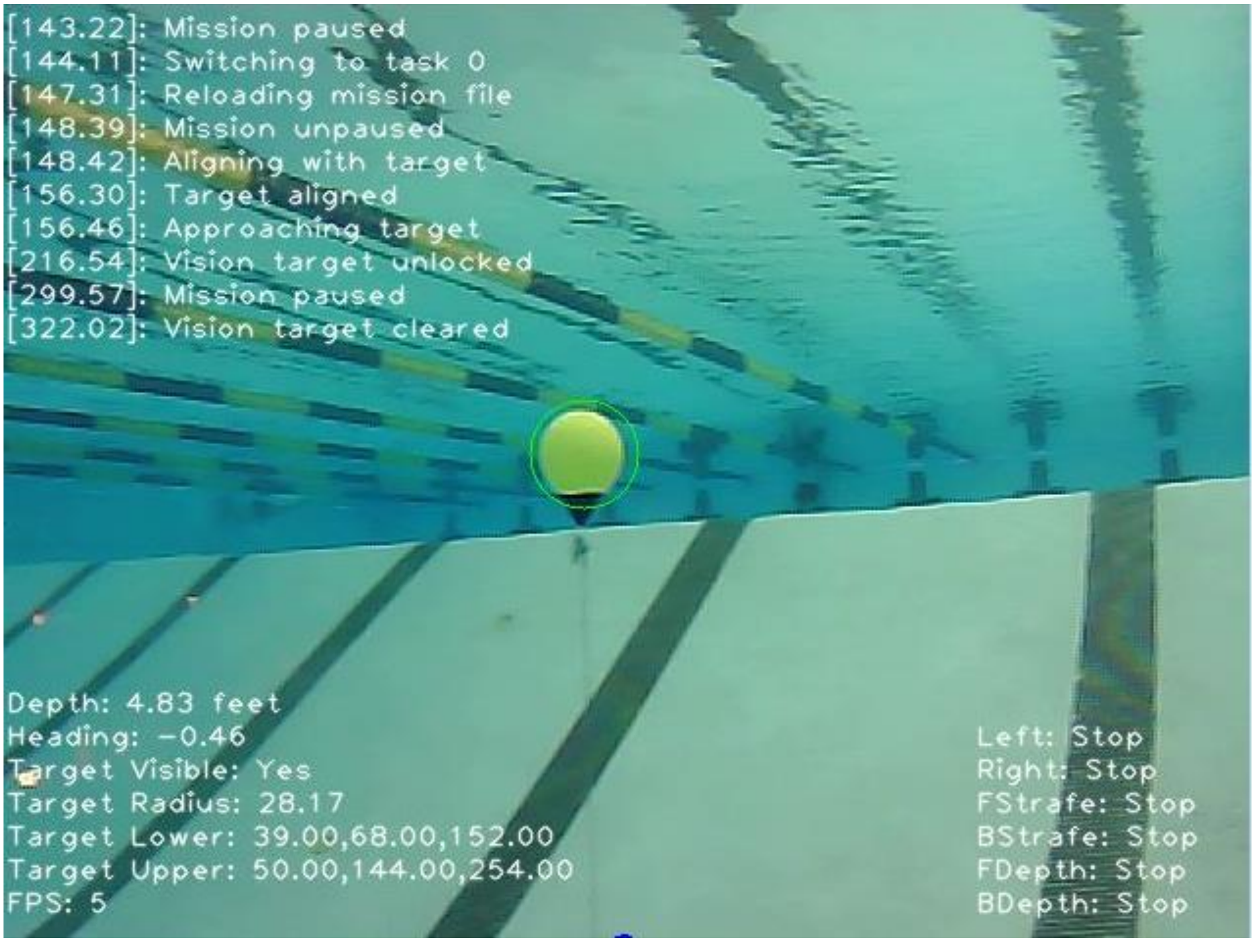

Figure 12 – Program running with view from front camera while tracking a buoy

<u>Testing</u>

Blue November has been tested weekly or biweekly since the beginning of the project period to assist the team in troubleshooting the current design and searching for methods of improving the infrastructure, balance, usability, or general operation of the submarine. Testing consists of transporting the sub to the pool, submerging the sub, testing for leaks, and then running all programs/missions that have been changed since the preceding pool test. (See Figure 13).

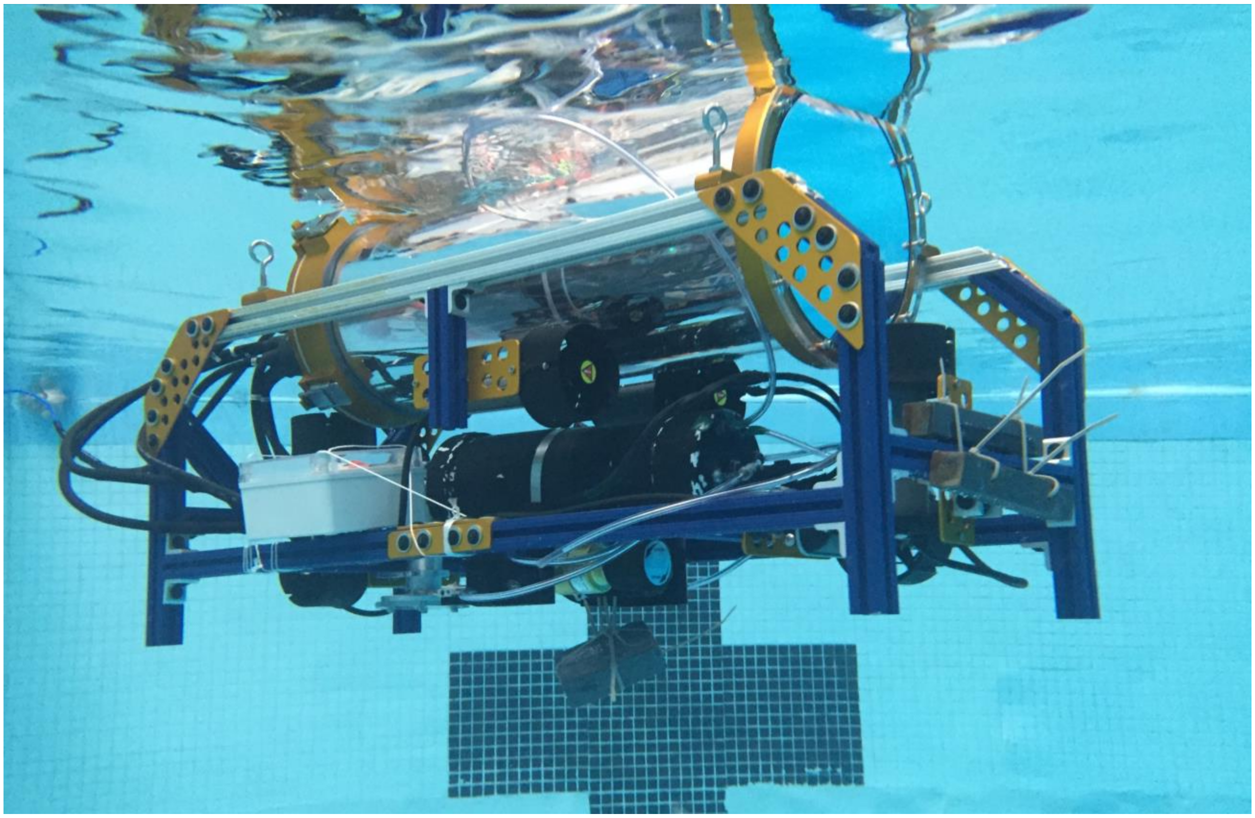

Figure 13 – Blue November during a pool test (surfaced)

Acknowledgements

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