OTUS TEAM's Journal Paper for 2016 RoboSub Competition

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***Abstract*— OTUS/AUVSI Team at Oregon Institute of Technology (called Oregon Tech or OIT) is proud to be participating for the 1st time at the 2016 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 document and template to be used in preparation of RoboSub journal papers by Oregon Tech (OIT). The goals of the OTUS journal paper for 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 the organizations developing and producing autonomous vehicle technologies. Moreover, it is to raise engineers and scientists who would be a future asset for developing marine technology and science while culminating not only all kinds of knowledge we have learned but also learning real-world challenge through the Competition environment. 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. Frame Design

Our OTUS frame has dimension where all the frame has size limitations and can only be 3'x3'x6'. The vehicle must also be within 5% of neutral buoyancy. With these restrictions we had to make sure the frame is a reasonable weight and size to accomplish buoyancy. Smaller and lighter would be the best option if we maintain similar performance. The frame must also be a shape that provides stability; it would be much better if the frame is symmetrical to ensure that the vehicle reacts as expected and stays stationary when all motors are off but also stays in the navigating. The material is made of thin-flat wide aluminum. The position of the many components drastically changed to accommodate buoyancy and weight distribution issues.

B. Hull Design

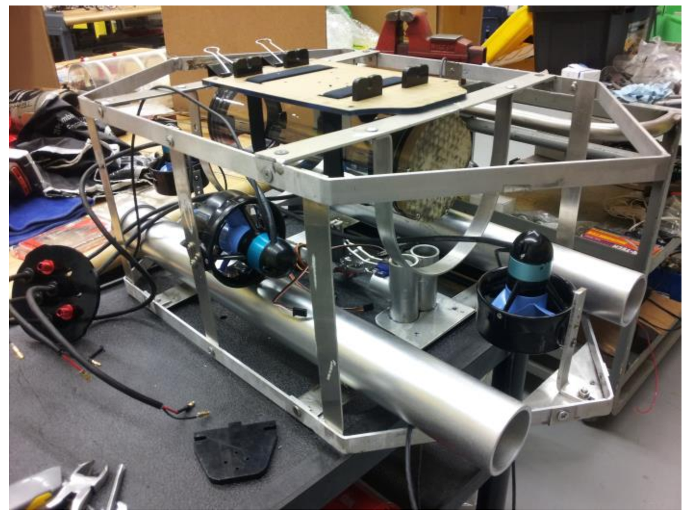

Fig 1. Frame and Hull Design

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 made a couple of modifications. At first it was designed to be an Acrylic tube with a length of 18" and a diameter of 6". To seal it we, we designed and 3D printed our own end caps with a double O-ring to maximize the sealing effect. 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. Later, we decided that two boards would be better than one, so that are circuits could be more spread out.

Fig 2. Hull Design.

C. Electrical Circuit Boards in the inner Hull

Here is the layout of the electronics with power system with wires inner hull.

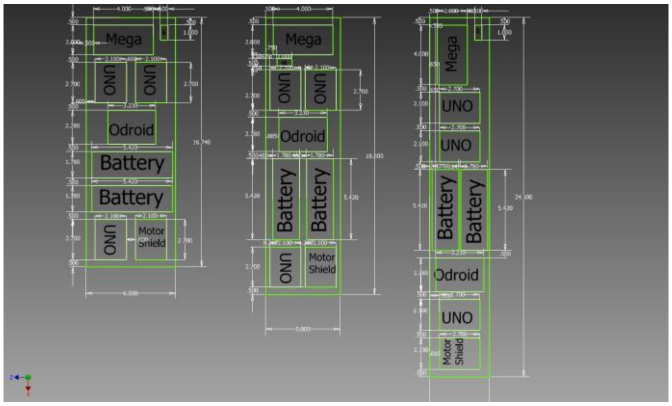

Fig 3. CAD Layout of Electronics with power in the Hull

D. CFD Analysis

To test our initial models, we performed computational fluid analysis and provided us with a good concept for hydrodynamics with respect to our mechanical design.

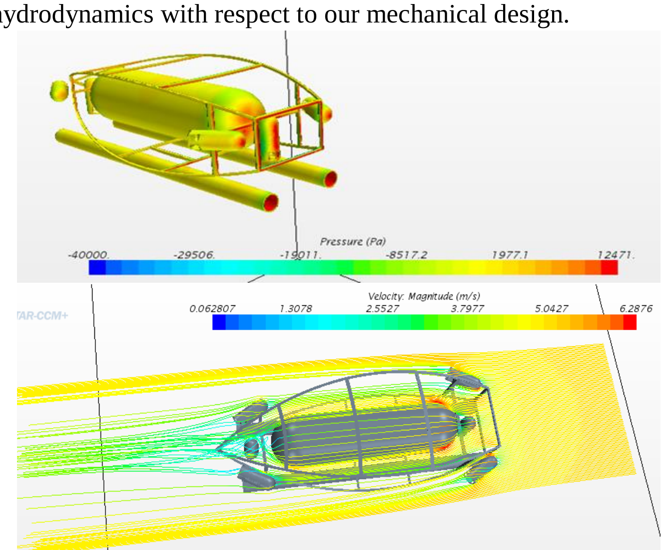

Fig 4. CFD Analysis

The following models are set up for the analysis: Steady, Liquid, Constant density, Turbulent, K-Epsilon, and segregated flow. The forward force is measured 662 Newton, Upward force 2095N.

E. Thruster Design

Our original design for the thrusters was to make four of our own custom made ones, and attach them to servos to allow them to rotate on the XY plane. This design was chosen to help mitigate cost, but due to the complexity of the rotating aspect, we decided to use the BlueRobotics thruster motors that are T200 brushless DC motor with electronic speed controller (ESC) for three-axis differential control of the underwater robot propulsion, which results in 6DOF control x-y-z axes with roll-pitch-yaw torque control due to the differential speed control algorithms. Motor power is controlled by ESC that works with Arduino Mega SCL and SDA I2C communication for forward and reverse control.

Fig 5. Blue Robotics Thrusters

F. Robot Manipulator (Grippers)

we designed our own using CAD modeling software, with the intent to 3D print it. Another gripper is chosen by an off-the-shelf gripper mounted on the bottom of the main frame working with a bottom-towards camera. The gripper improved its dexterity with a reasonable price. The robot is compatible with Arduino microcontroller and works well with waterproof servo motors.

Fig 6. Robot Manipulator (Gripper)

G. Markers

The marker system is designed to be two T-shaped PVC pipe connectors attached together along with a servo motor. Attached to the servo was a rotating arm with rigid metal wire connected to it. This wire held the marker in place by passing through holes drilled into the side of the T-shaped connectors. To drop the markers the servo would first rotate one way, removing the wire holding it place, which allowed the marker to drop. To drop the second marker it would rotate in the opposite direction causing the same series of actions to occur.

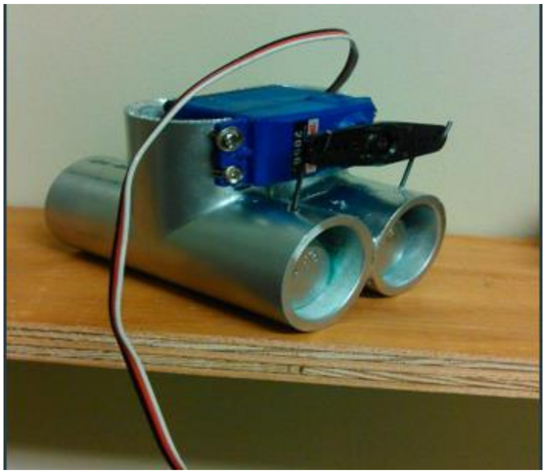

Fig 7. Marker

H. Torpedo

The torpedo is a self-propelled torpedo to shot small and big openings (holes) on the target as in the Set Course. It has an elastic firing mechanism by lighting equipped with photo-resistors that activates its self-propulsion after passing a magnet at the end of the torpedo tube. We chose to activate the torpedo by placing a light in the tube that would begin to flash when the torpedo needed to fire, activating the photo resistor; the ignition of the torpedo propulsion is obtained by sensing the change in light from a photo-resistor inside the nose of the torpedo. When the torpedo's self-propulsion was activated, it runs right away to shot small and large openings at the same time from each left and right torpedo, maintaining the vehicle body stationary and stable. We further modified the torpedo by adding a flashing light to it after it turned off to aid in the recovery of them.

Fig 8. Torpedo with Launching Device

III. ELECTRICAL, COMPUTER SYSTEM AND SOFTWARE

A. Main Target Computer

The main board is D525 embedded computer with fanless Intel Atom Dual-core CPU with a heatsink, 4GB RAM for MATLAB/Simulink both installation, SATA hard disc. It has multiple interfaces such as 4xUSB, 4xCOM ports, 2xREaltek 100/Gigabit LAN with VGA/DVI ports. Additionally, optional wifi or PCI-e module. This computer is hardware-in-the-loop target computer. As a host computer we are having a laptop computer (as well as Desktop for lab test) which has x64bit Windows 7 with free Microsoft SDK 7.1 Compiler to run MATLAB/Simulink 2016a version compatible with Real-time xPC target system.

B. Hardware-in-the-loop

We have built above customized hardware-in-the-loop computer system (host-target computer), where the main board in the target computer is based on 32-bit FAT-32 file systems, The target computer has xPC Target driver system relative to the host computer, which has latest version MATLAB/Simulink R2016a to facilitate multiple additional toolboxes such as Raspberry Pi 3 module including Arduino toolbox, sponsored from MathWorks on Windows 7 platform. The machine codes running in the robot on target computer are downloaded after compiling Simulink with Embedded MATLAB files through the host laptop computer, equipped Real-time Workshop and with 2010 VC++ compiler and later updated by Windows SDK 7.1.

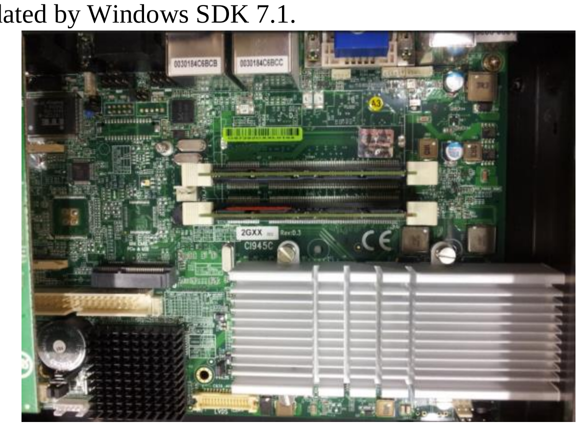

Fig 9. Target Computer

C. Cameras

The main front camera is Creative Live Cam Sync HD 720P Webcam with LED lights for front camera and the bottom camera is the Pixy camera to help the robot arm pick up () correctly.

Fig 10. Front Camera

We chose an off-the-shelf camera, Pixy camera, capable of detecting the color of the objects based on built-in image processing algorithms although its performance is limited due to being not very strong light CCD sensor. However, we decided to use it because 1) it is cheap and Arduino-compatible,

2) we don't have to program except adjusting for detecting objects for bottom-oriented camera.

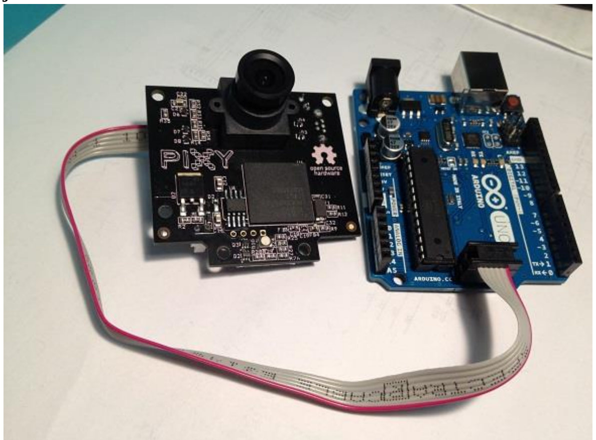

Fig 11. Camera Towards Bottom Object Detection

D. Inertial Navigation System (INS)

MicroStrain Lord 3DM-GX4-45 is an Aperture Heading Reference System (AHRS) sensor and used to measure speed and angle of the OTUS vehicle for navigation, measuring the attitude such as position and linear velocity from three-axis accelerometers and angle and angular velocity from three-axis gyros. We don't use magnetometers and GPS in underwater circumstances. But we are additionally utilizing a pressure sensor (BAR30-SEMSPR-R1) for measuring depth in 2mm resolution because of possible drift from inside the pressure altimeter sensor.

Fig 12. AHRS sensor by LORD MicroStrain for position, velocity states

E. Pressure Sensor

Incorporated into above INS sensor, BlueRobotics's BAR30-R1 absolute pressure/altitude sensor (0-30 bar barometer) is used to measure the depth with 2mm depth resolution. The compact sensor is easily converted to the depth (altitude) and really inexpensive sensor and is connected with Arduino Mega via I2C communication. This sensor will be incorporated into altimeter sensor in the INS sensor

F. Raspberry Pi / Arduino Mega Camera Processors

Having perception sensors such as vision systems with adequate lighting is the key technology for AUV Robotics Competition. In order to separate main program with video data due to heavy computation and data communication, two webcams with LED lights are used; one for front camera data processed by Raspberry Pi 3 with camera with Adafruit Flex cable. The raspberry camera uses MATLAB/Simulink Image processing toolbox and Computer vision library and communication toolbox as well. Another one for downward camera, Pixy (CMUcam5), which has color detection algorithm inside, processed by Arduino Mega. Depending on the performance in terms of color and object detection we are able to switch both camera. We used two LED lights for each camera.

G. Propulsion controller – Arduino-Mega2560

The OTUS robot has six propulsion motors for x-y-z axes with differential control, which yields 4DOF control (x-z directional position by thrust forces and pitch and yaw motion via differential control of thrust motors). One Arduino-Mega microcontroller is used; four PWM pins are used to generate pulse width module (PWM). This makes autonomous program as simple as possible and later we are supposed to add side-directional (y-axis) thrust motor and yaw motion.

H. Waterproof Servo motors

A variety of servo motors are used for robotic tool operation of the vehicle such as Hitec waterproof, HS-5086, servo motors for motion of Grippers, Traxxas hi-torque waterproof, 2056, servo motors for Marker, and Hobby King, HK 153208D, waterproof digital micro servo motors for Torpedo etc.

Fig 13. Waterproof Servos (e.g., HS-5086WP Hitec Micro Digital Servo)

I. Hydrophones

A hydrophone is a microphone used in underwater for listening, detecting, and recording to sound coming from acoustic sound sensor as a pinger. For implementing the last task, Buoy Treasure, four-TC4013 hydrophones are designed to be used for detecting a Pinger signal, which is 35kHz. The robot can detect multiple signals due to losses and reflection, the hydrophones have to find correct direction and signal. Arrangement of hydrophone is used to detect the signals and sample the acoustic sound signal and then a DSP board is used to process signal processing with band-pass filtering with noise suppression.

Fig 14. A hydronphone (Teledyne TC-4013)

J. Power System with Distribution

Two batteries, 2 x 8000mAh and 12VDC, are used to provide stable motor power and an independent battery, 4000mAh, for control power is designed to pass through 12V-to-5VDC converter with DC-to-DC converter to provide sufficient and steady power for electronics with control signal with possibly less noise signals. Emergency (EMG) switch as kill switch is designed to kill power of all moving parts of the vehicle off but electronic devices in which computer and sensors are still functioning unless pressing the button for computer power system, which yields the sensor to be power off. Main voltage and current are monitored via DMiotech dual voltage/current meter panel (DC0-100V, 20A with each LED) and feedback to the computer to display the status of the power system with warning messages.

K. Acknowledgements

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L. 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

M. OTUS Team