University of Victoria AUVIC: Development, Design and Implementation of the 'NAUTILUS' AUV

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Abstract— **AUVIC (Autonomous Underwater Vehicle Interdisciplinary Club) is an undergraduate student team from the University of Victoria. The team is designing and building an AUV (Autonomous Underwater Vehicle) with the goal of competing in the 2017 AUVSI RoboSub competition held at the SSC Pacific TRANSDEC facility in San Diego. The main purpose of the team is to give students the chance to practice real world applications of the material learned in classes. It also allows students to gain experience with projects outside of their main discipline. This experience is beneficial to students in several ways: It helps with the understanding of class material and allows students to see the applications of this material applied to real world problems. Students gain valuable hands on experience designing, building, and testing electrical, mechanical, and software systems. This experience translates well to real jobs and allows students to stand out when it comes to looking for co-op positions and employment after graduation. For a university located on an island, learning about underwater technology and underwater instrumentation and systems is particularly relevant.**

I. Introduction

AUVIC is competing for the second year in a row at RoboSub, this year the team opted for the design of a simple vehicle that can complete several tasks. The team is made up of undergraduate students in electrical, mechanical, and software engineering as well as undergraduate students in computer science, physics, and business. While the focus of AUVIC is to give students hands on, real-world experience of the material learned in classes. AUVIC is also determined to build a well working AUV that can at minimum complete the navigate channel and scuttle ship tasks. While AUVIC has team leads for the separate sub-disciplines, team members are encouraged to work on all aspects of a project to gain skills outside of their specific field of study. Rather than divide into subgroups, specific projects are designated as mechanical, electrical, software or business and anyone can take on these projects. The team leads provide guidance and co-ordination of all projects.

II. Design and implementation

A. Design Strategy

For 2017, AUVIC's strategy is focus on improving reliability of the electrical and mechanical components, as well as extend amount of time available for pool testing. To allow ample time for testing, new components were added sparingly to the submarine and only where there would be a high return of points. The urge to improve upon an existing design was suppressed unless that system failed during competition or change was necessary to accommodate other fixes. When deciding what to focus on, each task was looked at, and a number of points were attached to that task based on what team expected to obtain. These points were then added up and grouped by system. Navigation and vision were a large bulk of these points and essential systems for the submarine. With navigation and vision we can complete three of the tasks on the course, the validation gate, channel, and the buoy task. By adding a bottom facing camera, more points could be obtained for "following the path" and the weight dropper could be attempted. The weight dropper circuit was largely designed in 2016 and could be easily added to the new sub. Dispite the difficulty of designing a hydrophone array, this system was also added to improve navigation redundancy. Even if the vision or navigation system was malfunctioning there is a chance that the submarine would be able to navigate to the octagon and surface.

The vision system relies on processing the images from a forward-facing camera by combining edge and color detection to have a reasonable estimate of basic object recognition. The objects are then further processed and identified using the LBT classifier. The navigation system uses 6 thrusters to get surge, heave, and sway as well as yaw and some pitch motion. The thrusters are controlled by in house designed motor drivers that will give us position data for each motor on startup. Data from an inertial measurement unit (IMU) and a depth sensor is used to calculate the commands to the thrusters to be able to travel in a straight line as well as to travel towards a task. To communicate with different devices different communication protocols are used depending on the type of protocol associated with each peripheral.

B. Vehicle Design

1) Mechanical Design

AUVIC's most recent vehicle, Nautilus, is a modularly designed AUV with a similar appearance to AUVIC's RoboSub 2016 vehicle, Red Herring. Like Red Herring, Nautilus' main structure consists of two side plates, a top plate for structure, and several cross bars to connect the side plates and to mount the top plate. This post-and-plate design style was chosen due to the ease of manufacturing of parts, relatively low cost of materials, and for the geometric simplicity which will easily allow retrofitting if required or desired.

Figure 1: Red Herring, AUVIC's Former AUV

Nautilus is significantly longer than AUVIC's former vehicle, to accommodate newly incorporated and expanded systems including a new bottom facing camera for the vision system, a hydrophone, and new batteries necessary to run these systems. The hydrophone is located underneath the main body of the vehicle, near the front, so that the signal is not affect by anything located in front of it. Nautilus consists of a main housing where most electronic systems are stored, two battery housings, two motor controller housings, and a separate housing for the bottom facing camera. Nautilus also uses 6 thrusters – two vertical and four to enable lateral movement.

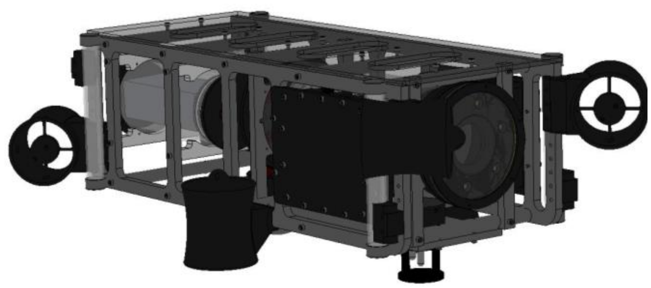

Figure 2: Nautilus, AUVIC's Current AUV

2) Power System

The batteries are stored in two cylindrical acrylic battery housings. On one end of the battery housing, the acrylic tube is sealed to an anodized aluminum end cap using a cold cure epoxy adhesive. On the other side, an aluminum end cap is inserted into the acrylic battery housings and sealed with a radial o-ring seal. Epoxy was used, rather than using o-ring seals on both sides, for AUVIC to gain experience using epoxy as a sealant and to gauge the performance of the epoxy seal. On the end cap, there is a cable penetrator used to transmit the power and an enclosure vent and plug to test the seal and facilitate closing and opening of the endcaps when not submerged. Due to

the significant size of the batteries two battery housings were used to decrease the required housing volume.
The submarine battery system was improved by switching from eight $103cm^3$ batteries with 1.5 Ah capacity each to two $803cm^3$ batteries with 12 Ah capacity each. This increased the power capacity of the submarine while decreasing the amount of batteries needed. This also allowed simplification of the battery charging process. The one drawback to this solution is our housing are cylinders so we have more unused space when we have one big battery compared to a lot of small ones.

The power monitor circuit, was redesigned to provide temperature, humidity, voltage, and current feedback to the main computer via RS485 this is in addition to it's base functionality which uses a reed switch to get an external signal to turn on the submarine. A variable turn on time, was also added so that inrush currents would not damage the batteries. After implementing the variable turn on time it was determined that the added complexity of the design seemed to add very little in terms of preserving the batteries. The team next year is going to redesign the power monitoring board and get rid of the variable on time. Instead opting for a simpler solution that acts more like an ideal switch. The inrush current will just be tolerated by the batteries with minimal damage to battery life.

3) Main Housing

The main housing is a large cylindrical housing made of acrylic. On one end, a large shouldered aluminum ring is epoxyed to the inside of the acrylic tube. The aluminum ring has a shoulder for locating and an outer lip with an o-ring grove which is used to create a face seal with a fastened end cap. The end cap is made of a polycarbonite disk with an aluminum washer ring. The polycarbonite disk allows the front facing camera to see and the aluminum ring distributes the force around the disk to prevent cracking. On the other side, the same accommodation for the light ring and the camera were not necessary so an aluminum ring was epoxyed to the outside of the acrylic tube. Face seals were also used in this location. An aluminum end cap was used as it allowed for the use of cable penetrators and subsea connectors.

This main housing holds most of the electrical team circuits, all the circuits that have high current are connected using RS485 and rest are connected using USB. The large main housing makes it easy to run wires connecting all the systems. The previous year's design had most of the components in separate housings. This was difficult from an electrical perspective as more considerations had to be taken into the wiring. Also, it was very difficult to change something after it was done.

4) Cameras

The first camera is located in the main housing, faces forward, and is used primarily for navigation. A second camera is located below the submarine, in a domed housing, sealed using a radial o-ring seal. The domed design was chosen as it enables greater vantage and the location was chosen to be central to facilitate alignment in the weight dropper task. The cameras are used in the vision systems, which is also housed in the main housing and consists of a light ring, a computer, and an IMU.

Both cameras are connected using USB and draw power off the main computer. The main computer's power is regulated by a high current buck which is capable of giving the necessary power for the cameras.

5) Thruster System

The thrusters consist of three main components: the shroud, the motors, and the propellers. Brushless DC motors are used in conjunction with modified carbon fiber quadcopter propellers. These propellers were chosen due to their moderate pitch angle, ideal mounting features, and thickness near the base which is desirable for producing thrust. The thruster shrouds are 3D printed using ABS and a contain a conical feature to direct fluid flow. The thruster mounts are also 3D printed from ABS, separately from the shrouds to avoid warping, and connected using ABS solvent cement. Two types of mounts were printed. All four lateral thrusters used 45° angle mounts to increase vehicle maneuverability. The vertical thrusters, in contrast, were mounted using 90° mounts to provide as much thrust as possible in the vertical direction to facilitate submersion. The thrusters have many possible mounting positions on the submarine due to an array of holes located on the frame. This was done to enable adjustability, as the ideal thruster location will change as more components are added onto the submarine.

The submarine uses Hobby King three-phase motor drivers to drive the motors. A custom motor controller circuit talks to main computer and controls the motor drivers. This is done because of the cost of this setup relative to buying thrusters. Our thrusters cost $110 CAD each compared to the next cheapest thrusters, Blue Robotics, at $200 CAD each. Another disadvantage of using Blue Robotics was that our previous submarine ran on 6S LiPo batteries. Blue Robotics thrusters are designed to run off 5S, our new batteries were picked for the old system. This would have added another considerable cost to the team. If given the opportunity to redesign the entire submarine it would be designed around using the Blue Robotics thrusters, but considerable knowledge was gained in the design of our own thrusters and feedback system.

This feedback is obtained through the motor controller. It does this by filtering one of the motor poles. The filtered signal goes into the microcontroller as a square wave where the frequency can be converted to RPM. The Hobby King motor drivers have feedback in them so the pole switching signal matches the motor speed. In the future, PID will be added to the motor controller so that the RPM can be set from the main computer. Currently all the hardware is on the board but a lack time has left it undeveloped. We want to do this because the thrust we achieve is proportional to the RPM of our motors.

6) Buoyancy and Trim Adjustment

The goal this year was to design a vehicle with only slight positive buoyancy, so that in the event of system failure, the AUV will float but with a buoyancy close enough to neutral that the force required to keep the vehicle submerged will be mimizied. To determine the buoyancy properties of the vehicle, two CAD vehicles models were created in SolidWorks. One vehicle model contained all the parts with their correct volume, material, and mass and was used to determine the center of mass. The second vehicle model consisted of only solid parts, hollow parts were filled in, and the density of each part was changed to that of water. This second model was used to find the center of buoyancy. The vehicle buoyancy was found to be 5% positively buoyant. Additionally, the center of gravity and center of buoyancy were found to 2 cm apart in the length of the vehicle and within 1 mm in the other two axes. Four acrylic cylindrical housings are currently being developed that will be mounted to each corner of the submarine and weighed down using lead shot to adjust the vehicle's overall buoyancy and the vehicle's center of mass to prevent undesirable moments from being generated.

7) Communication System

This year the complexity of the communication system is significantly reduced from the previous year. Last year we wanted to design a custom board for the communication system, but ran out of time and used USB splitters for what limited functionality was needed. Due to the success of the USB splitter it was implement for this submarine and the main communication system. This is a much more module system that makes additions and changes to the system simpler. If a new communication channel in the submarine is needed a USB converter can be attached to the USB splitter. Other custom circuits in our submarine have external connectors for different voltages if needed by new hardware.

8) Peripheral and Sensors

a) Weight Dropper

This is the first year the AUVIC will be using a weight dropper at the competition. AUVIC's weight dropper uses a permanent magnet to hold up a ball bearing through a solenoid. When the sub wants to drop the ball bearing the solenoid is turned on. It is important to pulse the solenoid so that it does not overpower the permanent magnet. If the magnet is overpowered than the ball bearing will polarize the other way and the ball bearing will be attracted to the solenoid not allowing it to drop.

The hardware on the weight dropper can measure both current and voltage. By doing trial and error it was calculated that 400mA going through the solenoid is needed to just cancel out the permanent magnet's field. The weight dropper is directly hooked to battery which have a changing voltage throughout the submarine run. To get the right current through the solenoid, the solenoid is pulsed at 50 kHz and the duty cycle is changed. In the future, feedback will be used to determine the duty cycle but currently a lookup table is used.

b) Hydrophones

The hydrophones system consists of an analog circuit elements such as the filter, amplifier, and piezoelectric transducer. An ADC is used to convert the analog signal into a digital signal to be processed by the main computer. The hydrophones themselves consist of four piezoelectric transducers that are spaced even distances apart from each other. Each transducer will receive a signal, transmitted from an ultrasonic pinger, at slightly different period of time, which allows for locating the direction of the pinger.

Because of the of the small signal strength received by the transducer, the signal needs to be significantly boosted and filtered before being captured by an analog to digital converter. The amplifier on the hydrophones system will receive a signal in the range hundreds of microvolts and boost it to over a volt. This will be sufficiently high enough for the ADC to reconstruct the signal with acceptable resolution.

9) Software Design

The software system of the AUV utilizes the Robotic Operating System (ROS) open-source framework running on 2 single-board computers (ODROID) connected via ethernet. To make the most of the limited system resources the ODROIDs are running Lubuntu, a scaled down and lighter version of the popular Ubuntu Linux distribution.

ROS was chosen because it allows developers to develop specialized programs in isolation (nodes) which have the capability of integrating into a much larger and complex systems. ROS nodes provide mechanisms for communicate with other nodes and processes across computers. The ROS framework allows developers to build their application in both C++ and Python which gives us free reign in integrating many other popular open-source frameworks in developing a customized, yet powerful system.

A major component to the software system is the vision processing. Vision processing is done with help the OpenCV library. The vision sub-system is broken down into 3 steps. Objects are first detected using a combination of edge detection and color recognition, which are both lightweight and not computationally expensive operations. Once an object is recognized, it is passed onto a machine-learning algorithm which will perform more complex tasks to accurately detect and identify the object in question. The machine-learning algorithm is a general-purpose algorithm which can detect patterns and similarities in datasets, based off previous data. By feeding it a series of images which distinguish an object, it is able to accurately detect instances of the objects in new situations, provided the training data was not too broad which will provide false positives, or too specific which will not allow the algorithm to analyze new situations. Objects are then pin-pointed in the image and passed onto the artificial intelligence which will make decisions on its overall path.

A Graphical User Interface, developed by previous members of the team, was redesigned in-order to make use of the newer features of the software system. Using the Qt framework, has allowed us to integrate the GUI into the ROS system, this gives direct access to the data as it is being sent from node to node. This aids in development of each node, ensuring that communications are being handled appropriately. This also allows the individual testing of each node by showing the output generated for different inputs.

C. *Experimental Results*

AUVIC has tested the pressure housings in the pool overnight at a depth of 12ft. Most housing seals survived the testing just fine, however one box had to be abandoned and redesigned since it leaked at depth. AUVIC has also taken underwater test footage of replicas of the competition targets. This footage is used to train the vision system to recognize the targets. The vision system's object recognition is able to locate and identify the targets even with the underwater distortion. The thrusters have been tested in a test tank to determine the best propellers to use in terms of the best propeller shape and materials. The software is currently being tested by simulation of the competition pool in gazebo. This simulation includes the pool with all targets and a simulation of the AUV so that it can be driven through the pool, either by joystick or with its own artificial intelligence. Extensive testing of the vision system has shown that LBT Classifiers are preferable to Haar classifiers since they are a lot less computationally intensive with only a small loss in accuracy.

D. *Acknowledgements (optional)*

AUVIC would like to thank our sponsors for their support.

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E. *Appendix—Outreach Activities*

AUVIC has participated in several community Outreach events. Team members have delivered presentations on marine engineering and the use of AUV's and ROV's at workshops for Ocean Networks Canada's annual Ocean Science Symposium. The Ocean Science Symposium is an annual event that is designed to showcase marine biology, oceanography and marine engineering to high school students who have demonstrated an interest in the oceans.

Figure 10 AUVIC Presenting at the 4th annual Ocean Science Symposium

Team members have also presented workshops for the Science Olympics, an event that sends high school students to different stations throughout the university to learn about sciences and engineering.

AUVIC participates in UVic IEEE's SkillDev workshop series by hosting a very popular soldering workshop when the series runs.

Figure 2 AUVIC 2015 Soldering SkillDEV

Additionally, team members have worked with Ocean Networks Canada Staff and local high school science teachers to assemble an OpenROV kit to test the feasibility of a high school class taking on that project.

APPENDIX

This Appendix is taken from the IEEE Transactions template on the IEEE website, and should be followed for citing references (http://www.ieee.org/web/publications/authors/transjnl/index.html).

Basic format for books:

[1] J. K. Author, "Title of chapter in the book," in *Title of His Published Book, x*th ed. City of Publisher, Country if not

[2] USA: Abbrev. of Publisher, year, ch.*x*, sec. *x*, pp. *xxx–xxx.*

Examples:

[3] G.O.Young,"Syntheticstructureofindustrial plastics,"in *Plastics,* 2nded., vol. 3, J. Peters, Ed. New York: McGraw-Hill,1964,pp.15–64.

[4] W.-K.Chen,*LinearNetworksandSystems*.Belmont, CA:Wadsworth, 1993, pp. 123–135.

Basic format for periodicals:

[5] J. K. Author, "Name of paper," *Abbrev. Title of Periodical*, vol. *x,* no. *x,* pp. *xxx-xxx,* Abbrev. Month, year.

Examples:

[6] J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," IEEE *Trans. Electron Devices*, vol. ED-11, no. 1, pp. 34–39, Jan. 1959.

[7] E. P. Wigner, "Theory of traveling-wave optical laser,"*Phys. Rev.*, vol. 134, pp. A635–A646, Dec. 1965.

[8] E. H. Miller, "A note on reflector arrays," *IEEE Trans.Antennas Propagat*., to be published.

Basic format for reports:

[9] J. K. Author, "Title of report," Abbrev. Name of Co., City of Co., Abbrev. State, Rep. *xxx*, year.

Examples:

[10] E. E. Reber, R. L. Michell, and C. J. Carter, "Oxygen absorption in the earth's atmosphere," Aerospace Corp., LosAngeles, CA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.

[11] J. H. Davis and J. R. Cogdell, "Calibration program for the 16-foot antenna," Elect. Eng. Res. Lab., Univ. Texas, Austin, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.

Basic format for handbooks:

[12] Name of Manual/Handbook, *x* ed., Abbrev. Name of Co., City of Co., Abbrev. State, year, pp. *xxx-xxx.*

Examples:

[13] *Transmission Systems for Communications*, 3rd ed., Western Electric Co., Winston-Salem, NC, 1985, pp. 44–60.

[14] *Motorola Semiconductor Data Manual*, Motorola Semiconductor Products Inc., Phoenix, AZ, 1989.

Basic format for books (when available online):

[15] Author.(year,monthday).*Title.*(edition)[Typeofmedium].*volume (issue).*Available: site/path/file

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