University of Victoria
AUVIC: Technical Design Report

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I. 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 2018 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 in real life 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. Since UVic is located on an island, learning about underwater technology, instrumentation, and systems is particularly relevant.

II. Competition Strategy

For 2018, AUVIC's strategy is focused on improving vehicle's passive stability and number of thrusters to make control easier. During RoboSub 2017 it was found that relying on active stabilization and a balanced AUV can result in small disturbances having large impacts in the vehicle direction. Every year the decision between modifying the current AUV and redesigning the AUV is a tough one. There are always improvements we would like to make to the vehicle that cannot be made without massive modifications, but putting off these improvements would result in more time for water testing which is critical for the electrical and software teams. Redesigning the AUV was ultimately decided as the best course of action for the following reasons: a completely new frame would allow us to build in a bigger self-righting moment, the Nautilus frame (seen in Figure 1) did not have room for many more components to be added and much of the course was changing from the 2017 to the 2018 competition tasks, and finally many senior members are graduating after RoboSub 2018 and a good AUV design with room to add components would set up the team well for 2019.

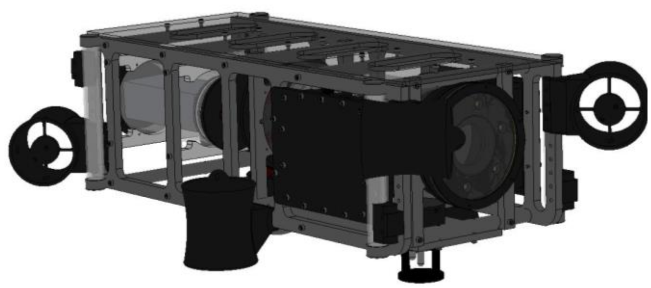

Figure 1: Nautilus, AUVIC's Former AUV

AUVIC has chosen to design their latest AUV to be built as a MVP (Minimum Viable Product). Therefore, non-critical elements can be added as they are finished and ready for testing. This same methodology carries through from Mechanical to Electrical to Software teams. Navigation and vision were considered essential systems for the AUV. 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 ball dropper could be attempted. Despite 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.

III. Design Creativity

1) Frame Design

Polaris, as seen in Figure 2, is an open-framed AUV, designed with a low vehicle aspect ratio to facilitate station-keeping. Polaris is equipped with 8 thrusters for 6 DOF control and has a large self-righting moment, achieved through the positioning of a 960 cubic inch, watertight electronics housing at the top of the AUV. Adding extra thrusters from 6 to 8 increases the complexity of the vehicle, but adds redundancy to the control strategy. With four vertical thrusters, any pitch or roll due to hydrostatics or hydrodynamics can easily be counteracted by the stabilizing control algorithm. This allows for more freedom to rush the design cycle without spending a long time analyzing hydrostatics and hydrodynamics. It also means that components can be added as they are completed or removed if they break without having to re-trim the vehicle before conducting more water testing. Polaris' subsystems are mounted to a plastic plate, produced using 2-axis manufacturing techniques. The ease of manufacturing of this plate makes Polaris a modular framework, as subsystems can be added and removed without significant modifications to the vehicle.

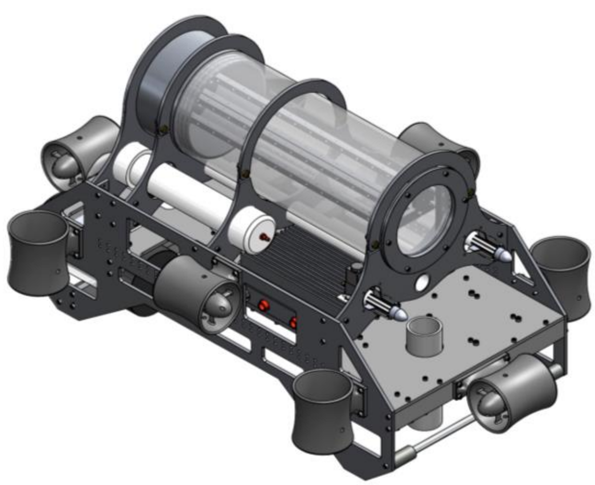

Figure 2: Polaris, AUVIC's Current AUV

2) Power System

The Power Regulation Board, seen in Figure 3, is a new PCB redesigned using the knowledge gained from designing the previous power board and RoboSub 2017. This PCB is the central power hub for all components on the AUV and must be able to handle enough current to power the eight motors. It measures the current being drawn from the batteries and by individual subsystems, the board also is fused to protect against short-circuits in any of the subsystems. Using control logic from an onboard microcontroller, the board will automatically switch from battery power to tether power when the tether is connected. This is used to easily conserve battery life during testing. The microcontroller also has the capabilities to be powered either through USB or by the batteries, which is useful for debugging purposes, when batteries aren't available. On top of the main functions of the Power Regulation Board, this board also acts as a monitor for the main housing of the AUV by monitoring the housing's pressure, temperature and humidity. It comes with an onboard water sensor, and it has the capabilities to measure the external water pressure.

Figure 3: Power Regulation Board (Top Layer)

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. 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.

3) *Main Housing*

The main housing was redesigned switching from a six inch to eight inch diameter acrylic tube. The housing is also roughly twice as long as the Nautilus main housing, stretching almost the full length of Polaris. This was done to accommodate more electronics and a bigger CPU, switching from an ODROID to a Jetson TX2, with the added benefit of adding buoyancy near the top of the vehicle to increase the righting moment. Increasing access to the electronics was a high priority during the design process. During testing of Nautilus, the main housing needed to be opened often. This was time consuming and didn't provide good access to the electronics for troubleshooting. On Polaris to gain access to the main computer two supporting clamps can be pivoted up and the acrylic tube and accompanying front cap can be slid off, revealing the internal electronics supported on an internal structure.

4) *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 PLA and contain a conical feature to direct fluid flow.

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.

5) *Peripheral and Sensors*

a) *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.

b) *Ball Dropper*

To drop golf balls on a target, Polaris is equipped with a golf ball dropper. Golf balls are loaded and stored in a compartment on the AUV. To release these golf balls, a stepper motor rotates inside a watertight housing. This stepper is magnetically coupled with the golf ball dropping mechanism, allowing the golf ball to fall and hit the target.

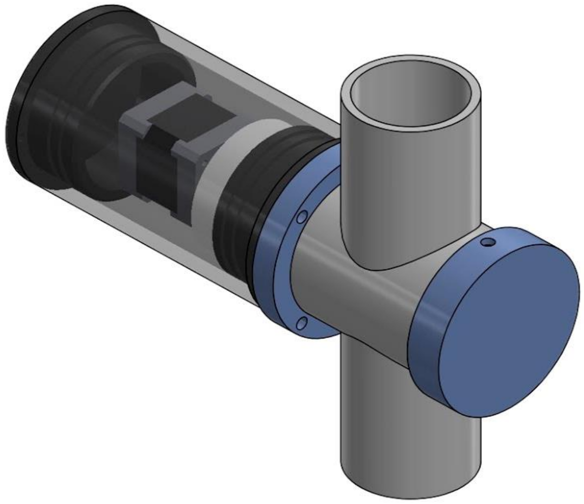

Figure 4: Ball Dropper

c) Torpeedos

Polaris is equipped with two 3D printed torpedoes. These torpedoes are propelled using compressed air stored inside a PVC cylinder and are actuated using a solenoid-controlled one-way valve.

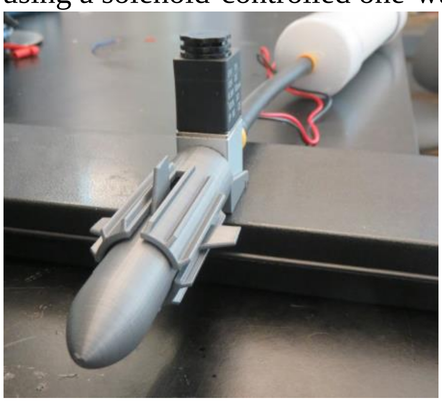

Figure 5: Torpeedos

6) Software Design

The software system of the AUV utilizes the Robotic Operating System (ROS) open-source framework running on a Jetson TX2.

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 the help of 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, when combined with data from the IMU will make decisions on its overall path.

IV. Experimental Results

AUVIC has tested most of the pressure housings through a combination of vacuum testing and water submersion before the electronics are added. The advantage of vacuum testing is that is it quick and can be done at any time, with or without the electronics inside the housing. The downside to vacuum testing is that large housings take a long time to get to 15 inHg [1] of negative pressure when using a hand pump, making it a very time and labor intensive test. Another problem regularly encountered was that air would travel through the cables from one housing to another, increasing the time it takes to before the pressure would stop decreasing. Therefore, when testing the main housing, which is a very large housing with many cables coming out of it, it was determined that water testing with the electronics inside was the best option. During this test care was taken to regularly check the main housing for leaks. This was very easy to due to the location of the main housing and the clear acrylic body. 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.

V. ACKNOWLEDGEMENTS

AUVIC would like to thank our sponsors for their support.

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VI. REFERENCES

[1] Blue Robotics, "Using the Vacuum Plug," [Online]. Available: http://docs.bluerobotics.com/tutorials/vacuum-test-plug/#testing-the-enclosure.

A. *Appendix A: Component Specifications*

Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control				
Frame				
Waterproof Housing				
Waterproof Connectors				
Thrusters				
Motor Control				
High Level Control				
Actuators				
Propellers				
Battery				
Converter				
Regulator				
CPU	NVIDIA	Jetson TX2		
Internal Comm Network				
External Comm Interface				
Programming Language 1	C++			
Programming Language 2	Python			
Compass				
Inertial Measurement Unit (IMU)				
Doppler Velocity Log (DVL)				
Cameras				
Hydrophones				
Manipulator				
Algorithms: vision		OpenCV, Tensor Flow		
Algorithms: acoustics	NVIDA	FFT	Cuda	
Algorithms: localization and mapping				
Algorithms: autonomy				
Open source software		ROS, OpenCV, Tensor Flow, Linux		
Team size (number of people)				
HW/SW expertise ratio	:5			
Testing time: simulation				
Testing time: in-water				

B. *Appendix B: 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 6 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.

Fig 1.