University of Victoria

AUVIC: Development, Design and Implementation of the 'POLARIS' AUV

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I. Abstract

Autonomous Underwater Vehicle Interdisciplinary Club (AUVIC) is an undergraduate student team from the University of Victoria. The team designs and builds autonomous underwater vehicles (AUVs) with the goal of competing in the RoboNation RoboSub competition held at the SSC Pacific TRANSDEC facility in San Diego.

The main objective of the team is to give students the opportunity to apply the material learned in class to real world applications and experiment with projects outside of their main discipline. The club also offers students with an opportunity to learn from others as well as teach others. These experiences translate to job opportunities and allows students to stand out when looking for co-op positions and employment after graduation. For a university located on an island, learning about underwater technology and underwater systems is particularly relevant.

Figure 1: AUVIC's Logo

II. Competition Strategy

AUVIC is competing for the second year in a row with our AUV Polaris. This year our team faced a serious decrease of members, from approximately 40 down to 15. As a result of the smaller team size the team opted to keep our past AUV and perform improvements. We began by analyzing and understanding our weak points from the 2018 competition, these are shown in *List 1*.

List 1: Identified Areas for Improvement

1. Unresponsive/static control system
2. Little to no computer vision
3. Procedure-less water-testing
4. Slow motor PID controller

Without a large team, working through the night will be difficult, therefore we are focusing on the computer vision and control system development. Our strategy is to gather points from the "Enter the Undead Realm," "Slay Vampires," and "Stake Through the Heart" mission objectives by completing them with the utmost difficulty. Over a 10 month period, 60% of the time is allocated for software development, 30% for submarine development, and 10% for administration (outreach, sponsorships, etc.). We estimate reaching 8,100 + x points.

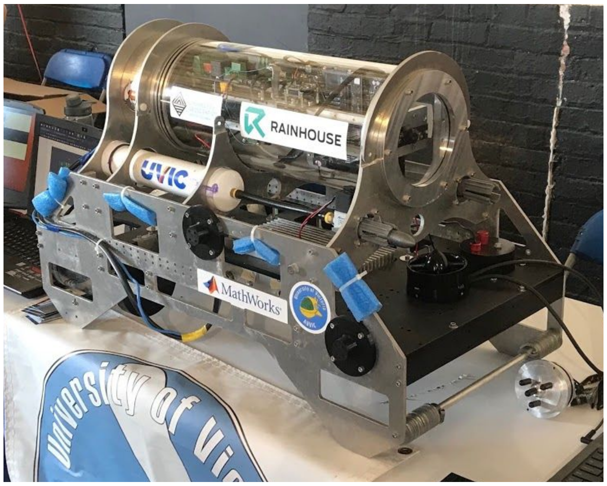

Figure 2: Polaris 2019 (without thrusters)

III. Design and Implementation

A. Software

Control Systems

The submarines control system's design bases itself off of the structure of a deterministic finite automaton (DFA). The DFA approach is well defined theoretically, thus implementing the system was a simple translation of generalized computer science terms to a specific C++ implementation. The DFA also provides defined state transitions for every possible code, which is desirable because the control system needs to know its order of operations, and its mechanisms for error recovery.

Modularity, the submarine achieves this by dynamically loading the runtime configuration for operational behaviour on startup. This allows the adjustment of task completion order, state specific parameters, and system-wide parameters. Modularity is also highly advantageous for faster testing, tuning, and route adjustments.

Robustness, the submarine must be able to recover from errors. You can see this in Figure A, where the dynamically generated states require specification of error recovery states. This however does generate possible infinite cycles in the state machine. This is remedied by the addition of error loop counting mechanisms.

One of the limiting factors from the implementation last year was our software implementation of the PID controls for our motor. This module was located within the control system node, which operated at 10Hz which meant our PID controller wasn't doing nearly as much good as it should have been. With the undergone revisions we've moved the PID controller to firmware.

Computer Vision

A large part of Polaris's software revolves around the image processing through its computer vision modules. The computer vision alone allows for the submarine to accomplish a majority of the tasks.

This is seen on the gate task which is the first obstacle, where the vision allows Polaris to understand where the Gate is in relation to the submarine and accurately pilot Polaris through the runtime specified side of the gate. Similar methods are used to follow the underwater paths however, using the downward camera instead of the front camera.

The vision system also utilizes feature matching to properly identify what the AUV is looking at. This is mainly seen on the buoy task, in which the AUV must know what side of the three sided buoy to hit. It is also used to identify patterns on later tasks in the competition. Such as the slay vampire task.

B. Electrical

For 2019, The electrical team revised two PCBs: Hydrophone Preamp and Power board. Moreover, a pinger is in development to test the new pre-amp.

Hydrophone System

The hydrophones electrical system consists of two different stages and two separate PCB's. One Preamplifier circuit in the hydrophones enclosure and a high speed simultaneous sampling ADC in the main housing. The sampling board transmits time domain data to the main computer for FFT and processing.

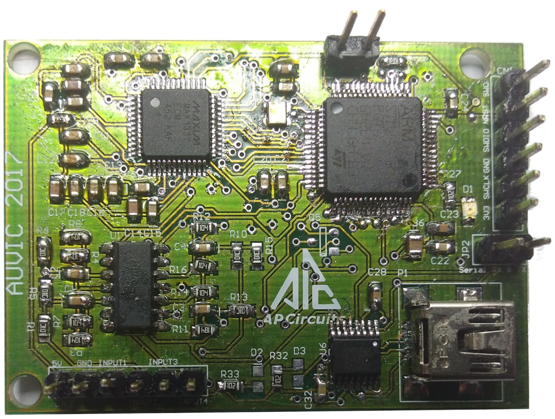

Figure 3: 2017 Hydrophone Preamp Board

For 2019, the new hydrophone preamp and filter circuit was designed to aid the submarine in locating the competition's pingers. The submarine has four hydrophones mounted to it, which can receive the pinger's signal and triangulate its location. The piezo-electric component of the hydrophones will each generate an AC voltage signal in response to the audio signal emitted by the pinger, whose phase can be compared to the other signals to determine which direction the pinger is in. For the submarine's analog-to-digital converter (ADC) to be able to convert the signals into usable data, the signal needs to be filtered and amplified so that the information gathered can be more easily deciphered by the submarine's computer.

The pre-amp circuit consists of two "stages", each of which contain a capacitor which removes any low frequency noise (known as DC offset), a voltage splitter circuit (to add a predetermined and constant amount of DC offset to the signal) and an op-amp integrated circuit to amplify the signal. As the the hydrophone circuit board has no inverted DC voltage supply, and knowing the ADC requires a positive voltage signal, the AC source signal would need to be offset so that the negative half of the signal would not be lost when traveling through the op-amp integrated circuits. The reason for separating each channel's preamp into two stages was to manage the amount of required signal offset required for the signal to pass through the amplifier without losing information, as the op-amplifiers will also amplify the amount of offset. With the AC signal amplitude compounding through each stage, and the offset being set specifically before each amplification, the signal could be tailored more easily to sit directly between 0V and 3.3V thresholds of the op-amp, ensuring the minimal amount of information is lost. Additionally, any altering of the gain in either stage of the preamp during competition by swapping out the through-hole resistors in the feedback loop of the amplifier will affect the offset less drastically as well.

The filter circuits, which are placed after our pre-amplifier in each hydrophone channel, each consist of three stages: two active Butterworth low pass filters and one passive high pass filter at the end. The filters attenuate any signal outside of the 25-40kHz range. The last filter was chosen to be passive as the design team ran into problems with the two Butterworth active high pass filter stages they had originally intended for the filter design. The active filters remove any signal offset before passing the signal through the circuit's op amps, which would effectively remove half of the signal. As the passive circuit doesn't use op-amps, the problem was avoided at the cost of making the signal attenuation slightly less effective, though still acceptable. Following this, one final voltage divider circuit was added to resupply the signal with the offset that was removed during the highpass filter stage.

Motor Controller

The motor controller board makes use of eight simple HobbyKing ESCs and eight PWM outputs to control the motors on Polaris. Rather than use expensive ESCs with built in sensors, this functionality can be provided by the motor controller board itself which provides temperature sensing and RPM readings.

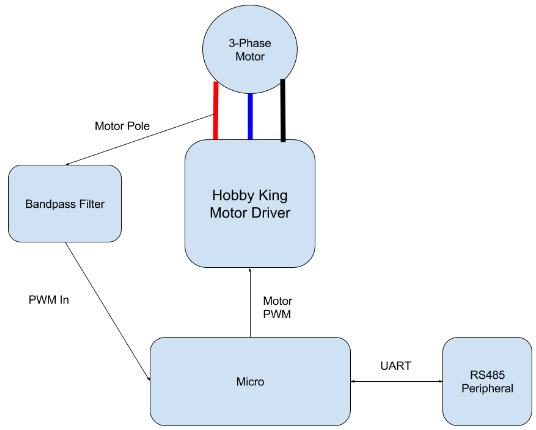

Figure 4: RPM Feedback System

Previously, the PID RPM control was done on the main computer. However, to save system resources and drastically speed up the latency of the RPM control, the RPM control has been moved to the firmware on the motor controller.

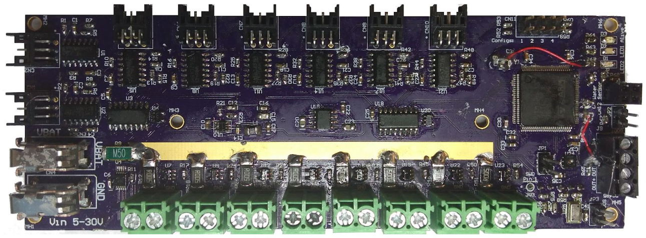

Figure 5: 2018 motor controller

Power Board

The Power Regulation Board is the central power hub for all components on the submarine. The board selects either the two 12V Li-Po batteries or a tethered power source to power the sub, and is capable of cutting power via an on-board micro-controller to various systems in the submarine. A "kill switch" is implemented by using a magnetic switch attached to the outside of polaris for the diver to cut power. The Power Regulation Board handles enough current to power the eight motors. This board also acts as a monitor for the main housing of the submarine by monitoring the housing pressure, temperature and humidity. It includes an on-board water sensor, and has the capability to measure the external water pressure. It measures the current being drawn from both the batteries and by individual subsystems, and has the ability to connect and disconnect the batteries in parallel using control logic from the STM32F0. The board is fused to protect against short-circuits in any of the subsystems.

The board has a USB connector that can be used for USART communications. The microcontroller also has the capability to be powered either through USB or by the batteries, which is useful for debugging purposes, when the batteries aren't available. The relays are used to switch between battery power and tether power, and will always choose tether power over battery power when the tether is available. This can be used to easily conserve battery life during testing.

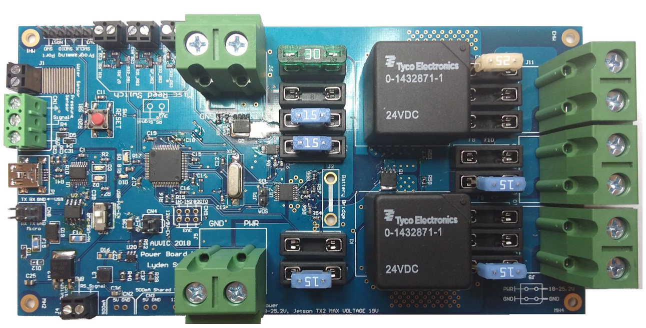

Figure 6: Power Board

C. Mechanical

The main design goals with Polaris, was to create an AUV that is relatively simple to control and provides adequate space and accessibility in its main housing.

Thrusters Positioning and Mounting

The AUV makes use of 8 thrusters total, so that two four thruster can be dedicated to up down movement, and 2 thrusters each for sideways and forward backward motions. To make the submarine easier to control, Polaris has a very strong righting moment with a very high center of buoyancy and low center of mass. This design reduces the work the thrusters will need to do to keep the AUV balanced.

The major improvement to Polaris's mechanical system were the upgrades to the thrusters as well as a new mechanical design for holding the kill switch. The new thrusters are the T100 made by Blue Robotics. While not as cost effective as the custom 3D printed thrusters they are replacing, they offer needed performance improvements at low RPM and are more durable in heat and direct sunlight. To facilitate the addition of these thrusters to the frame of Polaris a custom mount was designed that adapts the previous mounting specification to the new thrusters.

Figure 7: Blue-robotics mounting posts

Torpedos

The mounted dual-torpedo system allows us with two attempts at successfully scoring points on the slay vampire challenge. The torpedos are printed from grey PLA and are propelled using compressed air stored inside a PVC cylinder. The pressure is actuated using a solenoid-controlled one-way valve.

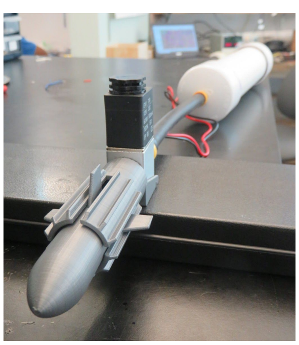

Figure 8: Torpedo system

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 AUVIC 5 of 7 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.

V. Acknowledgements

The organizations responsible for providing AUVIC with funds, providing us with the opportunity to participate are listed in *List 2* below.

List 2: Sponsors

- Rainhouse
  http://www.rainhouse.com/
- UVic Engineering Students Society
  http://ess.uvic.ca/
- Solidworks
  https://www.solidworks.com/
- Mathworks
  https://www.mathworks.com/
- IPP Nanaimo
  https://goindustrial.ca/index.php/en/
- PCB Way
  https://www.pcbway.com/
- Ocean Networks Canada
  http://www.oceannetworks.ca/
- Unlimited Fabrication Inc
  http://www.unlimitedfab.ca/

VI. References

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

Appendix A: Outreach

AUVIC has participated in several community Outreach events: the Ocean Science Symposium, the ESS Middle School Tour, and the Rainhouse engineering competition.

Ocean Science Symposium
Team members delivered a presentation on marine engineering and hosted an activity where middle school students had to design a circuit using PVC pipe and a water jug battery to make a wheel spin. Hosted by Ocean Networks Canada, students found the more parts used caused more water to be lost in transit, developing an understanding of energy-loss.

ESS Middle School Tour
AUVIC spoke to a group of middle school students touring UVic’s Engineering Lab building. We discussed how the submarine was developed and what the RoboSub competition expects us to complete. Students showed interest in pursuing electronic projects and had ideas for potato guns, sound effects, and among others.

Rainhouse Engineering Competition
The Rainhouse Engineering Competition was co-hosted by Rainhouse and UVic to bring together engineering clubs from Victoria together and display their projects to the community. The competition aspect was each group were competing to gather the most votes from the attendees.

Appendix B: Expectations

Subjective Measures			
	Maximum Points	Expected Points	Scored Points
Utility of team website	50	30	
Technical Merit (from journal paper)	150	90	
Written Style (from journal paper)	50	50	
Capability for Autonomous Behavior (static judging)	100	75	
Creativity in System Design (static judging)	100	75	
Team Uniform (static judging)	10	5	
Team Video	50	50	
Pre-Qualifying Video	100	0	
Discretionary points (static judging) \	40	20	
Total	650	395	
Performance Measures			
	Maximum Points	Expected Points	Scored Points
Weight	See Table 1 / Vehicle	10	
Marker/Torpedo over weight or size by <10%	-500 / marker	0	
Gate: Pass through	100	50	
Gate: Maintain fixed heading	150	75	
Gate: Coin Flip	300	75	
Gate: Pass through 60% section	200	0	
Gate: Pass through 40% section	400	50	
Gate: Style	+100 (8x max)	0	

Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the "Path" (2 total)	100 / segment	200	
Slay Vampires: Any, Called	300, 600	900	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	0	
Drop Garlic: Move Arm	400	400	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	2200	
Stake through Heart: Move lever	400	400	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	500	
Expose to Sunlight: Surface in Area	1000	1000	
Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	400	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	500	
Random Pinger second task	1500	1500	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	Tx100	500	
Total	13878.4	8100	

APPENDIX C: COMPONENT SPECIFICATION.

Component	Vendor	Model/Type	Specs	Cost(if new)
Buoyancy Control				
Frame				
Waterproof Housing				
Waterproof Connectors				
Thrusters	Blue Robotics	T100-R1	Online	$1,500 CAD
Motor Control				
High Level Control	NVIDIA	Jetson TX2 Dev. Kit	Online	
Actuators				
Propellers	See Thrusters			
Battery	Turnigy Power Systems	Multistar 6S 12000mAh 22.2V 266.4Wh	Online	
Converter				
Reglator				
CPU	NVIDIA	Jetson TX2	Online	-
Internal Comm Network				
External Comm Interface				
Programming Language 1	C++	C++11		
Programming Language 2	Python			
Compass				
IMU				
DVL				

Cameras				
Hydrophones				
Manipulator				
Algorithms: Vision	OpenCV	Feature Matching Cascade Classifier	Online & Online	
Algorithm: acoustics	NVIDIA	FFT	Cuda	
Algorithms: Autonomy				
Open Source Software	Open Robotics Foundation	Robot Operating System	Online	
Team size			14	
HW/SW expertise ratio			2:1	
Testing time: simulation			0h	
Testing time: in-water			8h	