Design and Execution of Trident

University of Victoria (AUVIC)
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I. Abstract

The 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.

Figure 1: AUVIC's logo

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 an opportunity to learn from others as well as teach. 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.

II. Competition Strategy

For Robosub 2023, we are aiming to complete three of the five tasks: “Oh for crying out loud” (Initial), “Starting Dial” (Buoys), and “Goa’uld Attack” (Torpedos)

For the initial task of passing the gate, we will flip a coin for the bonus points, and perform complicated maneuvers.

Due to the COVID-19 hiatus the club has taken, and all previous experienced members of the club having either graduated or left, the team’s goal over the past two years has been to build a brand new AUV. This way, current members can learn about the engineering design experience themselves and document it to pass on to the next generation and build off from there. Over the last two years, AUVIC has allocated 60% of their time to the design and manufacturing of the new AUV, and 40% to building off existing electrical and software architecture.

III. Vehicle Design

A) Mechanical

As previously mentioned, AUVIC started with a brand new team with little to no design experience, so the goal was to keep the design and manufacturing process as simple as possible, while still giving the team the opportunity to express their technical creativity. Because the previous

AUV was left behind, many concepts that allowed Polaris to work were transferred over to the new AUV, Trident.
Trident was designed all around one main cylindrical electronics enclosure on a 3ft x 5ft HDPE platform with two smaller cylindrical battery compartments underneath the electronics enclosure. This was done to ensure that the vehicle's center of gravity was positioned directly below the main tube's center of buoyancy, generating a statically stable vehicle.

Manufacturing

The most difficult manufacturing challenge was fabricating the main electronics enclosure due to its massive size. The first iterations of the design had two Delrin endcaps made watertight through radial seals on each end into a cast 8" OD cast acrylic tube. Because the tube was cast, the ID of the tube could not be guaranteed to possess circularity to a tolerance precise enough for the o-rings to do their job. To fix this, the plan was to initially secure the tube on a lathe and turn down the ID to a precision that was acceptable, but this proved to be near impossible with the current manufacturing facilities UVIC had at its disposal, so a redesign was required. With the redesign, radial seals were disregarded and the team moved on to using only face seals. This was achieved by chemically welding two acrylic flanges onto the edges of our cast acrylic tube. Other components were then CNC'd or laser cut through UVIC's machine shop.

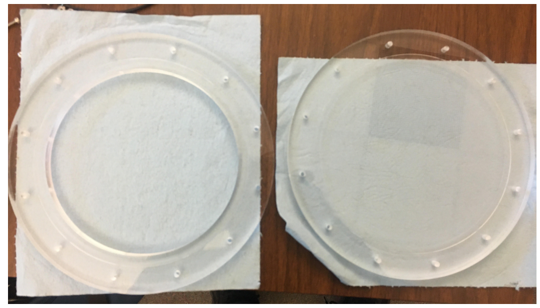

Figure 2: Manufactured acrylic flange

Main Electronics Enclosure

The main electronics enclosure was designed to be more accessible than the previous iterations. Previously, the AUV's internal electronics were accessed by opening a series of crescent cradles securing the acrylic tube to the baseplate, and then pulling the tube from a double radial o-ring seal, which proved to require at least two people to help remove the tube from the end caps due to the high friction seals. To combat this, a face seal replaced the radial seal while preserving the acrylic tube-style main enclosure. To access Trident's electronics, 12 fasteners in a radial bolt hole pattern are removed from a flange, connecting the tube and endcap together. The electronics rack is secured to the aluminum endcap, allowing the whole unit to be pulled out of the tube.

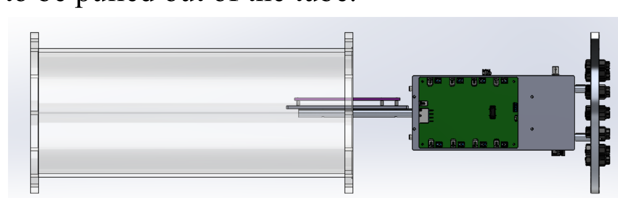

Figure 3: Main electronics enclosure CAD

Kill Switch

The kill switch was designed using a reed switch to detect an electromagnetic field generated by neodymium magnets. Several design considerations were influenced by specific constraints, such as the need for non-intrusiveness, sensitivity to the electromagnetic field, and ease of access for maintenance and troubleshooting.

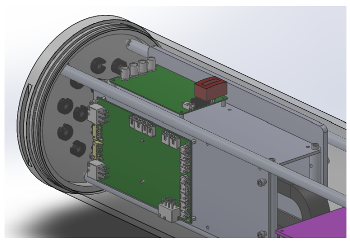

Figure 4: Kill Switch

To meet the requirement of non-intrusiveness, the kill switch was designed to operate without requiring access to the internal components of the AUV's enclosure. This was crucial to prevent potential water damage that could occur if the enclosure were opened. To compensate for the attenuation of the electromagnetic field caused by the acrylic enclosure, a reed switch with a low activation threshold range was selected. This choice ensured increased sensitivity to the magnetic fields generated by the neodymium magnets, enabling the reliable operation of the kill switch.

The enclosure housing the reed switch was designed to allow for easy removal with an engine or displacing a switch. This design consideration facilitated quick and efficient access to the main enclosure board for maintenance and troubleshooting purposes. Ample wire length was incorporated into the design to prevent strain on the Reed switch and its connection during that.

Claw Mechanism

The most recent mechanical claw design went through multiple iterations to reach its final point. Using a small-bore pneumatic cylinder, the claw transfers linear motion into mechanical leverage over two fingers designed to fit snugly around a 1" PVC pipe. The initial design used a servo motor and screw style linear actuation to close the fingers, however this was later replaced with pneumatics due to design and electronic simplicity. The screw mechanism also had friction problems caused by the rough 3d printed surfaces. Many of the parts from this previous design were incorporated into the current model, however the overall diameter, length, and body shape were changed to accommodate the pneumatic cylinder.

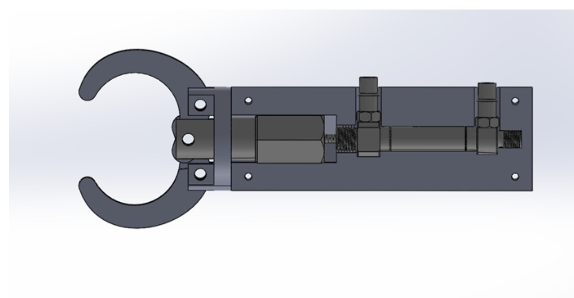

Figure 5: FDM printed claw cross-section

Most of the parts are 3d printed allowing for ease of testing and adjustment while remaining lightweight and simple to manufacture.

B) Electrical

Trident features several custom printed circuit boards and peripherals:

- ➢ DC Power Regulator
- ➢ Nvidia Jetson TX2 Computer
- ➢ DC Motor Controller
- ➢ Blue Robotics Bar30 pressure sensor

- FLIR Underwater Camera
- Blue Robotics electronic speed controllers
- Hydrophone Controllers
- External Reed Switches
- Industrial Inertial Measurement Unit

The DC Power Regulator is a four-layer PCB designed to regulate two balanced 24V LIPO batteries into several lower voltages (5V, 12V, 16V, and raw) to provide power to other components and peripherals. A four-layer approach was adopted to increase the copper thickness, improving thermal distribution. Automotive fuses were adopted to cut power in-case of a short. Moreover, several connectors were positioned around the edge of the board for easy access.

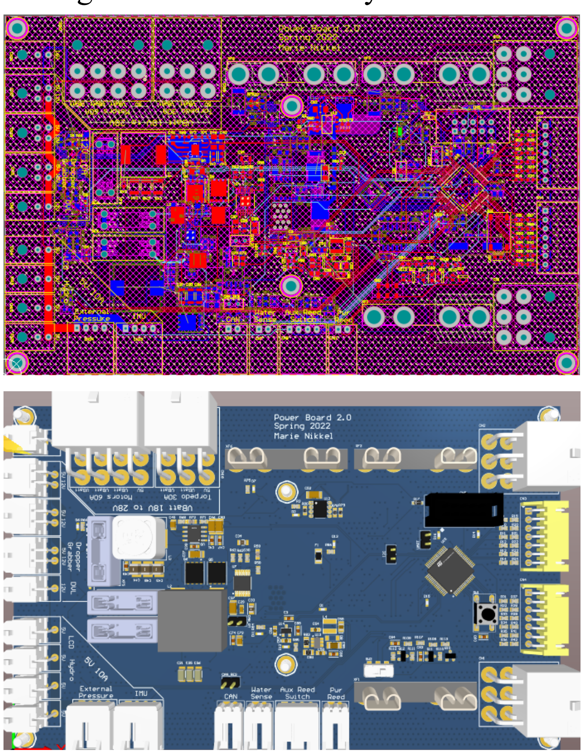

Figure 6: Power Board layout

For Power and signal connections on all boards, TI Amphenol connectors were used. Standard connectors allow ease of debugging and better wiring practices.

Figure 7: MOLEX Power connector

For control, STM32F4 microcontrollers were used. It boasts a built-in floating point unit, decreasing computation time for floating point arithmetic, useful for PID algorithms for depth control. The two 12-Bit ADC controllers provide 4096 discrete steps, equating to ~0.8mV of precision. Among many other benefits, the STM32F4 is readily available and arrives in many different packages.

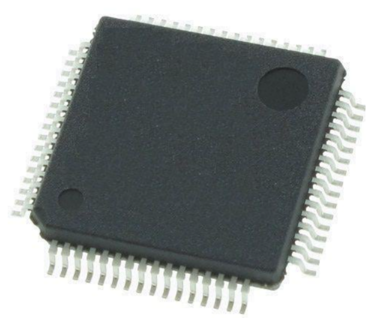

Figure 8: ARM Microcontroller [1]

The DC Motor Controller is designed to augment the blue robotics electronic speed controllers. It contains interfaces for I2C, UART, USB, among other communication networks. After receiving power from the DC Power Regulator, it further regulates it to user-settable 12/16/20V increments to ensure expected motor performance. The thrusters that drive the ESCs are Blue Robotics T100s, which have a parabolic response at set voltages. It is good to keep the thrusters operating in a predictable state to improve the dynamic performance.

The hydrophone controller contains a 2-stage op-amp preamplifier sourcing a signal from three Teledyne Benthos Hydrophones, before being fed into a microcontroller for pin-point detecting of the pinger using cross-triangulation. By detecting the phase differences of the acoustic waves measured by three hydrophones caused by the doppler effect and interference, the position of the pinger can be detected.

The Power Board was designed specifically for the new AUV, Trident by a team of fourth year electrical engineering students.

The power board PCB is a four layer board with the top and bottom designated for the various power rails and any high current lines, including those feeding to the thrusters. The two internal layers were designated primarily for small microcontroller signals and a signal ground plane. The connectors were placed along the edge of the top of the PCB and organized based on the type and power requirements. This includes sections for 5V, 12V and battery/power supply connectors. Additional connectors for the various power rails were added to accommodate future systems and loads. Power planes that were present on multiple levels were stitched together.

C) Software

1. Control System

The software stack used for Trident consists of ROS Melodic [2] running on our Nvidia Jetson TX2 with Ubuntu 18.04 (Jetpack [3]) as the operating system. Using ROS as a basis for the software stack allows the software team to write most of the source code in Python 3—a language that most of the software team is familiar with—for most of the control system, while keeping the option to write performance-critical parts in C++. This is an improvement over the previous generation, Polaris, that makes the software team more accessible to new members.

In addition, it simplifies the process of integrating disparate software subsystems into a cohesive whole via inter-node communication. Each major component is represented by a ROS node, and the nodes responsible for sensor input communicate with a central node that decides what Trident should do based on a decision model that emulates a Finite State Machine. Each task is modeled as a node, and transitions between nodes are triggered based on completion of the tasks. There is also a supervisory process running that can determine if the AUV is in an error state and attempt to recover.

2. Computer Vision

Computer Vision was implemented using Python 3. The code allows for two cameras to be used in parallel allowing for stereoscopic vision and depth sensing. One of the two cameras is a Flir Firefly FFY-U3-16S2C, which we communicate with via the Spinnaker SDK API. The other camera used is a generic 1080p usb webcam. OpenCV, as well as specialized spinnaker

SDK libraries are used to allow Python to interact with both cameras.

The main Firefly camera is used for object detection with a CNN model trained using Tensorflow [4] in conjunction with a sliding window algorithm. Training images taken by our teams during previous competitions were used, along with images posted by other teams [5], and videos captured in preparation for the competition.

Additionally the images are passed into a depth analysis function (from OpenCV) to produce a depth map. However the images have to be optimized before being passed into the depth analysis function. The images have to be translated from RGB to grayscale and checked to make sure they are the same size. Also since they are different cameras the exposure/gain/color temperature values have to be optimized to ensure the photos are as similar as possible. The results of the depth map and object detection are then sent to the control system.

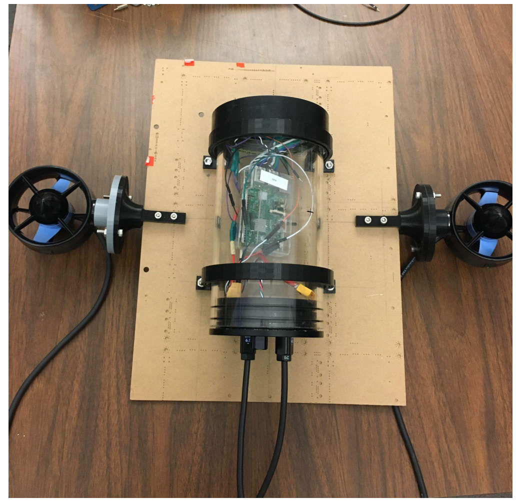

Figure 9: Mini test AUV

IV. Testing

The PID system was tested using a miniature version of the AUV, using one of the battery enclosures as a main electronics enclosure and 3D printing two thruster adapters to allow for the mini AUV to move. An M10 hole was drilled into the enclosure to secure a Blue Robotics Bar30 pressure sensor to the system, from which the depth of the mini AUV could be deduced. This setup was used to engineer TRIDENT's PID system.

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References

[1] Mouser Electronics, "All results for 'STM32F413' (32)," stm32f413 – Mouser Canada, https://www.mouser.ca/c/?q=stm32f413 (accessed Jun. 13, 2023).

[2] "ROS Wiki," ros.org, http://wiki.ros.org/melodic (accessed Jun. 15, 2023).

[3] "Jetpack SDK," NVIDIA Developer, https://developer.nvidia.com/embedded/jetpack (accessed Jun. 12, 2023).

[4] "Tensorflow," TensorFlow, https://www.tensorflow.org/ (accessed Jun. 16, 2023).

[5] B. AUV, "Dataset of labeled images for the RoboSub competition 2023," GitHub, https://github.com/beaverauv/robosub_transdec_dataset (accessed Jun. 16, 2023).

Appendix A: Component List

Component	Vendor	Model/Type	Specifications	Custom/Purchased	Cost (if new)
ASV Hull/Platform				Custom	Sponsored
Waterproof Connectors	Blue Robotics	WLP	Depth rating: 950m	Purchased	$150 CAD
Propulsion	Blue Robotics	T100		Purchased	
Power System					
Motor Controls	Blue Robotics	Basic ESC		Purchased	
CPU	Nvidia	Jetson TX2		Purchased	
Teleoperation					
Compass					
Inertial Measurement Unit (IMU)	XSENS	MTI-680		Purchased	$2421 CAD
Doppler Velocity Logger (DVL)					
Camera(s)	FLIR	Firefly DL		Purchased	
Hydrophones					
Algorithms					
Vision					
Localization and Mapping					
Autonomy					
Open-Source Software					