S.O.N.I.A. AUV Technical Design Report

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***Abstract*— S.O.N.I.A. is a Canadian student club from *École de Technologie Supérieure* that involves 21 members who dedicate countless hours to engineer an autonomous underwater vehicle (AUV). The club is divided into four departments: business, electrical, mechanical and software, each of which contribute to the achievement of the project. It is essential for an AUV to be able to interact autonomously with its marine environment using its incorporated resources. With its improved algorithms and devices, the submarine can calculate its speed and distance more efficiently and detect objects in shorter time-interval. The team's current focus is the integration of a new image recognition system. The NVIDIA Jetson TX2 is the innovative artificial intelligence (AI) computing device that is added to this year's prototype for the drive of introducing deep learning. Additionally, the members optimized the I/O control board to handle higher power needs, like solenoids. The competing submarine is equipped with a newer enhanced torpedo, powered by an electric solenoid actuator, and capable of accurately aiming small targets. With its new features and processing systems, the AUV will, without a doubt, deliver a great performance at Robosub 2018.**

Keywords—autonomous, underwater, submarine, vehicle, robot, Deep Learning

I. Introduction

S.O.N.I.A. is an autonomous underwater vehicle scientific club that was established in 1999 at the *École de Technologie Supérieure* in the heart of Montreal. The robotic team has its name given under the acronym *Système d'Opération Nautique Intelligent et Autonome*. Thus far, the team has dedicated their efforts to engineer eight prototypes. Their objective is to improve their design and strategies for every year's competition. July 2018 marks S.O.N.I.A.'s 19th participation to the ROBOSUB competition held in San Diego, California.

Although each member focuses on different aspect of the project, such as mechanical, electrical and software, all contribute to the continuous improvement of the submarine. The team believes that sharing knowledge is essential for the advancement of robotics, so by valuing a harmonious, educational environment, everyone can benefit from each other's area of expertise, thus maximizing team work and chances of success.

A new prototype of S.O.N.I.A. is generally built biyearly. The current submarine (shown in Figure 1) is a continuation of the previous year's prototype. The contribution of many students is crucial to the development and improvement of the AUV. One of the main objectives involves the integration of a new processing system using deep learning. The software team has developed new algorithms for the learning of the submarine. By introducing an AI computing device, the electrical team made several adjustments to the components, such as improving the I/O control board, in order to increase the compatibility of the new technology. The mechanical team focused on optimizing the design to better adapt the AUV to the different tasks of this year's competition.

Figure 1: 2017-18 S.O.N.I.A.'s AUV

II. Competition Strategy

A. Mechanical

The new challenges brought up by Robosub 2018 required additional capabilities and new modules. The team worked on a new version of torpedo launcher that can now accurately hit small targets, allowing the AUV to achieve the "Hit the jackpot" challenge. The members also designed a new golf ball dropping and collecting system (shown in figure 2) dedicated for accomplishing the "Play roulette" task. For the team to be able to test and practice these new concepts, the mechanical team strategically focused on incorporating fused filament fabrication (FFF) as it can rapidly prototype iterations of the designs.

Figure 2: Droppers

B. *Electrical*

The electrical team this year focused their attention on improving the add-ons of the platform, specifically the torpedoes and droppers. With the new technology, the Jetson TX2 AI computing device, the team added a connecting cable attaching the component to the power supply. See figure 3 for the electrical power distribution plan.

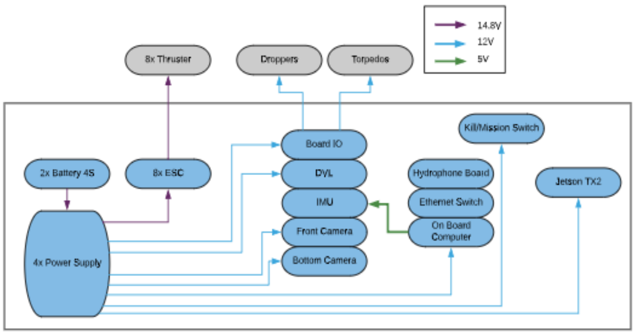


Figure 3: Electrical Power Distribution

C. *Software*

The complexity levels of this year's Robosub meant that the software team had to make a few adjustments. Object detection is necessary for the submarine to autonomously overcome the competition's tasks. The team focused on two different techniques for image recognition. First task involves recognizing dices emerged underwater. In this challenge, the submarine processes the information using deep learning (see figure 4). For the second part of the challenge, the roulette mission, the team chose Vision Filtration module for completing the task.

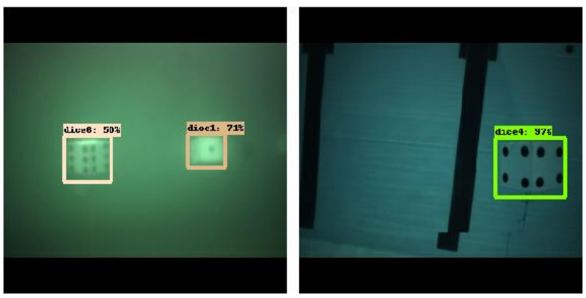


Figure 4: Deep Learning Object Detection

III. Design Creativity

A. *Mechanical*

This year's main emphasis was devoted to the optimization of the platform built last year. We keep relying on our cross-shaped design since we found out that the fundamental characteristics of the assembly worked to perfection, and the symmetry in the X and Y planes allow an easier control. With the design of the four arms, modules are easily added, or modified without major problems. Furthermore, the electronic boards and the wires are manageable. For this prototype, the team has decided to remove the sonar component since it did not produce the expected results and it is not necessary for this year's strategy.

As mentioned previously, the vehicle is the same as last year. This means that we only had to perform minor repairs and modifications to enhance its reliability. Since the last competition, some changes include upgrading the front rack, which allowed the installation of the Jetson TX2, a more reliable front facing camera placement, and better wire management and access. Using the free room inside the submarine, the weight ballast placement was improved to enhance the static balance of the AUV.

Another design created by the mechanical team is the torpedo launcher as shown in figure 5. It shoots markers using a spring-based system. That way, its power can efficiently expand, and trajectories are repeatable and non-violent. The launcher is triggered by an electric solenoid actuator. We realized that it was easier to use this design compared to the previous one for two reasons: (1) no extra batteries were necessary since the solenoid actuator is connected to the main battery of the submarine, (2) pneumatic systems are not required and reloading time is very minimal. Inherently, there is less risk attached to this new setup as it does not involve high pressure handling and less maintenance is required compared to electrical or pneumatic system procedures.

Figure 5: Torpedo Launcher

Similar to the marker launcher, the golf ball dropping system works with the same electric solenoid actuator. Both are low profile and are located under the submarine.

B. *Electrical*

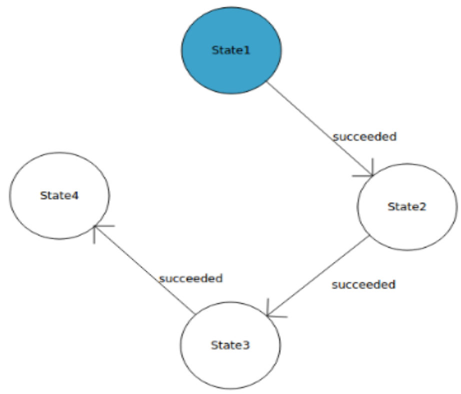
In terms of power supply, the same battery model (4S lithium-ion battery of 16.0V) is used for this year's competition as they are shown to be most suitable for the brushless motors. The team chose to keep these batteries for their ability to avoid lowering of the tension in the motors. In other words, they can bypass the voltage regulator, so that only control and monitoring process are necessary for the functioning of the motors. Two of these batteries are necessary; thus, the submarine was designed so that two compartments are in opposite sides in order to optimize the connections between the components. Since there are eight motors in total, eight ESC are used, and disposed inside the submarine's core. They are used to control the level of power usage of the motors according to their efficiency rates. Since there are eight motors in total, eight ESC are used. Each battery is connected to a power supply cards with three channels. Two of the channels have the same nominal voltage as the battery (16.0V), allowing a direct connection to the four ESC. To supply the other components, the third channel has a switch-mode power supply (buck converter) that reduces the initial 16.0V to 12.0V. The voltage conversion is a mandatory process as the channel supply power to important submarine components. One conversion channel connects to the two cameras and the PC, whereas the second channel connects to the Jetson TX2, I/O control board for input and output control, the cooling fans and the DVL.

In overall, the electrical team's major focus this year was the optimization of the I/O control board to allow the integration of the solenoid for the add-ons (torpedoes and droppers), and the improvement of the electric cables. Grounding and shielding was added to the hydrophones' cable assembly in order to minimize electric noise coming from large power expenditures, like the thrusters.

C. *Software*

Last year, the software team worked on integrating the ROS platform to the submarine. The low-level module was previously written in python. Last year, due to lack of time, the software team chose Python for the development of their AUV drivers (Doppler Velocity Log, DVL RS-485). By this year's competition, to have a more effective and robust code, it decided to refactor the code by changing most of it from Python to C++. The language modification will lead to an increased performance in the driver's functionality.

The team also worked on a mapping algorithm for the hydrophones. Since the results generated were initially interesting, they've worked on it more profoundly. The objective was to have a better detection system for localizing the pinger by solving linear equations system. However, with repeated testing, they've concluded that the results were not recurrent, thus unstable. Currently, the team is working on developing another algorithm based on *visual servoing*[1][1]. Instead of using feedback information from the DVL, it will use feedback from the camera to control the movement of the robot. This allows the extraction of information about the speed of the submarine relative to the image of the targeted object.



Every year, many ways are explored to improve the functionality of the submarine. This year, the team worked on underwater vision tool. After discussing on different methodology for object detection, the team chose to focus on deep learning. Since normal vision is less efficient when filters are included in certain conditions, they've worked on new models that would allow the submarine to better detect objects based on deep learning. It implies creating a dataset to train the model. It is key to building a model that will permit the submarine to ''learn'' based on a large dataset. Image segmentation can enhance and generate information to train the neural network. Furthermore, deep learning for object detection can help the AUV to identify and locate objects such as the dice from this year's challenge.

In addition to these changes, the team created a new algorithm based on a dynamic model for the control system. A coordination of the desired position enters the algorithm as an input variable. The information is then translated into speed. In other words, the submarine perceives the distance between the initial and final destination, which is deducted by the submarine as the speed it requires to arrive at the desired location. The output of this dynamic model is the force required and generated by the submarine to move to the destination.

Refactoring of the mission system is also an aspect the team worked on this year to adapt to the new challenges offered by Robosub 2018. In the previous year, the mission system operated by state machine. It allows the submarine to accomplish complex tasks based on many simple tasks. We would send many simple tasks for the submarine to accomplish. Simple would turn into more complex tasks. The more difficult tasks are a combination of many simple tasks.

To test our mission system, the software team developed a simulation system that allows us to evaluate the functionality of the submarine without having to indulge (test) it physically in water. Being able to simulate a test environment for the submarine is largely convenient as it saves time and required less people to be implicated during the simulation.

[1] visual servoing refers to "the use of vision in the feedback loop of the lowest level of a (usually robotic) system control with fast image processing to provide reactive behavior" (Janabi-Sharifi, 2003, p. 15-1)

IV. Experimental Results

It is important for students to maintain balance between personal, school and work life. S.O.N.I.A. values as much psychological health as respect among members. Many students are taking full course load and some are working, while others are involved in extracurricular activities. In order to have a well-organized planification, a weekly schedule was planned out for four consecutive months preceding the competition. The calendar includes pre-determined compulsory meetings and tests. Dates were settled weekly for the first month. The number of tests and meetings increased to two to three times a week as the competing date approached. It goes without saying that these tests are vital for the success of this project. These tests not only evaluate the performance of the submarine, but also the team's performance.

The amount of test depended on several factors that may not have been the team's control. For example, the availability of the pool was a deciding factor. On the other hand, if technical issues occurred, priority was given to repairs over testing. As mentioned earlier, although each member has an assigned task, such as focusing on the conceptualization of the droppers, everyone devote time to help others when needed. Overall, it was important for the team to dedicate many hours at the pool to test the submarine in every angle as possible. Tests were done in different locations, such as other College or University's swimming pool, and diving facilities. It allowed the submarine to be evaluated in distinct underwater environments. Specifically, it allowed us to simulate and recreate an ecosystem similar to the competition, such as adding obstacles and being surrounded by natural elements (i.e. algae). Participating in a test meant preparation, transportation, reservation and settling of equipment. Some tests were done with limited number of members due to lack of transportation mean. However, the challenges allowed the team to work together and find solutions to cooperate and progress in the project.

It is with great privilege to have the 21 members contributing their time and effort for the accomplishment of the project. S.O.N.I.A. would not have come thus far without the dedication of passionate and hardworking students.

Acknowledgment

S.O.N.I.A. AUV would like to thank every member who dedicated their time and effort, as well as the *École de Technologie Supérieure* for making this project possible. A special thank you to David Morgan, Claire Babin and Pascale Cloutier for their continuous support throughout this journey. We would also like to thank our sponsors for their products and funding, and the following services for allowing us conduct tests in their facilities:

Diamond partners:

- Bruel & Kjaer, Cégep du vieux Montréal, ÉTS and Altium.

Platinum partners:

- AEETS, FDÉTS, Lenovo and Nortek.

Gold partners:

- Teledyne Dalsa, KINOVA, Labelbox and Drillmex

Silver partners:

- Digi-Key, Parc Jean-Drapeau, Travis CI, samtec and CAE.

Bronze partners:

- BlueRobotics, Premier Tech, Laser Amp, Quincaillerie Notre-Dame, Connect Tech Inc and nvidia.

Facilities:

- Cegep du Vieux-Montréal
- Carrière Morrisson
- Mcgill University

References

[1] Janabi-Sharifi, F., 2003. "Visual Servoing: Theory and Applications," *CRC Press LLC*, p. 15-1.

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APPENDIX A: COMPONENT SPECIFICATIONS [2]

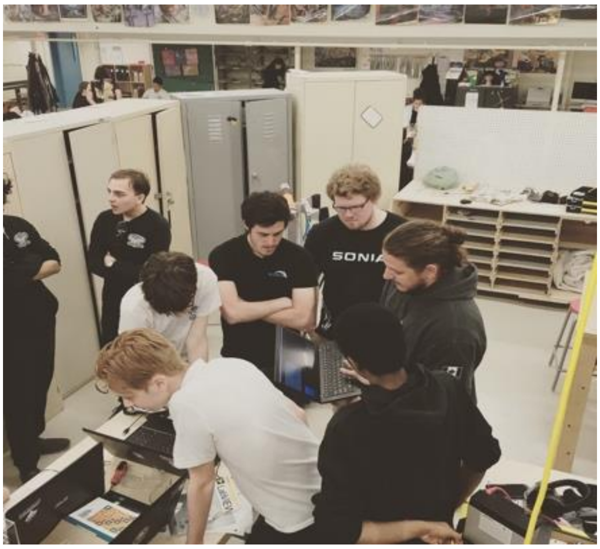
Component	Vendor	Model/Type	Specs	Cost (if new)
Buoyancy Control	-	-	-	-
Frame	-	CNC aluminum system	6061-T6 CNC machined and anodized	-
Waterproof Housing	-	Carbon fibre hull	Twill weave prepreg carbon fibre	-
Waterproof Connectors	Seacon	IL4MP/IL8MPX/IL8FSX	4 pins/5 pins/8 pins	-
Thrusters	Blue Robotics	T200	Max Thrust Forward 16V: 5.1Kgf	-
Motor Control	Afro	Race Spec Mini with ESC	30A	-
High Level Control	-	Cartesian PID controler	4 DOF	-
Actuators	-	-	-	-
Propellers	-	-	-	-
Battery	Hobbyking (Multistar)	Multistar High Capacity 16000mAh 4S 10C	16000mAh 4S 10C multirotor lipo pack XT90	-
Converter	-	TP820CD	20A max charge/ 10.5-28 DC input	-
Regulator	-	-	-	-
CPU	ADLINK	COM Express Basic Size Type 6 Module with 6th Gen Intel Xeon E3-1505M	12V DC input, 6th Gen Intel Core, Xeon and Celeron Processor with Intel QM170/HM170/CM236 Chipset, U to 32 GB dual channel ECC or non-ECC DDR4 at 2133 MHz, 4X PCIe x1 Link, 2X USB 2.0 link 2X SATA Link	-
Internal Comm Network	-	TCP/IP, RS485, RS232, USB	-	-
External Comm Interface	-	TCP/IP	-	-
Programming Language 1	-	C++	-	-
Programming Language 2	-	Python	-	-
Compass	-	-	-	-
Inertial Measurement Unit (IMU)	MicroStrain	3DM-GX3-25	-	-
Doppler Velocity Log (DVL)	Nortek	1 MHz	Sample 8 Hz	-
Camera(s)	Teledyne Dalsa	Genie Nanos Series	52 fps	-
Hydrophones	Brüel & Kjaer	Type 8103	4 kHz to 200 kHz	-
Manipulator	-	-	-	-
Algorithms: vision	Deep Learning	Tensorflow Object detection API	-	-
Algorithms: acoustics	-	Triangulation	-	-
Algorithms: localization and mapping	-	-	-	-
Algorithms: autonomy	SMACH	State Machine	-	-
Open source software	ROS	Kinetic Kame	-	-
Team size (number of people)	9 competing (All members: 21)	-	-	-
HW/SW expertise ratio	3/4	-	-	-
Testing time: simulation	20h	-	-	-
Testing time: in-water	200h	-	-	-

Appendix B: Outreach Activities

Introducing S.O.N.I.A. to Roberval Academy

Many innovators contribute countless hours for the advancement of science and often, their passion begins from experiencing exciting activities at school. This year, S.O.N.I.A. chose to present the submarine to students passionately working on robotics at Roberval Academy. Two members have graduated from that school and were still able to contact the science teacher, M. Germain Leroux. To encourage adolescents to learn more and pursue education in the engineering field, S.O.N.I.A. decided to approach the school community to help the students broaden their understanding on autonomous underwater vehicle.

Students ranged from 16 to 17 years old. Their project consisted of building a robot that could be operated by a video-game controller and compete at the annual Robotic First Quebec. As we introduced S.O.N.I.A., it was evident that the students had interest in marine robotics. Numerous questions were raised regarding the mechanical, software, electrical and even business aspect. S.O.N.I.A. team was impressed by their high level of motivation and willingness to learn about the topic, even outside of school hours, at such an early age. This event was fulfilling and allowed us to teach others and to learn about ourselves. Members present that day were rewarded with a feeling of accomplishment for educating and guiding the youths.



Inventive and Genius Challenge

Défi génie inventif is an annual competition that groups students from all levels of high school. S.O.N.I.A. along with DronoLab, a drone team from ÉTS, cooperated and had a chance to showcase their projects. Students would use their knowledge acquired from school and apply them in real life situation. Schools across the province competed against each other. During break sessions, they had the chance to learn more about the importance of technology and engineering. It was a good opportunity to encourage young geniuses and introduce them to the field of AUV. Parents as much as the kids were interested in S.O.N.I.A. and paid great attention to the details englobing the submarine.

Woman in Engineering

Women in engineering are on the rise, however, a lot more can be done to promote their presence. SONIA is proud to have three female members with one being the team leader of the electrical department. Emilie Demers-Morin took part in an activity that was designed to advocate women's role in an engineering project such as ours. At S.O.N.I.A., we firmly believe in equity and equality for all genders, and this activity was a form to outline our stance. We believe to have influenced a few girls and hope for their involvement in the engineering field in the near future.