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 20 members who dedicate countless hours to engineer an autonomous underwater vehicle (AUV). Its first design goes back to 1999. The robotic team got its name under the acronym *Système d'Opération Nautique Intelligent et Autonome*. There are four departments: administration, 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 control and deep detecting algorithms and new computer Jetson AGX Xavier, the submarine can calculate its speed and distance more efficiently and detect objects in shorter time-intervals. The team's current focus is the design of the new submarine AUV-8 while maintaining AUV-7. The main goal of the team was to be able to bring two functional submarines to this year's competition. All the electrical boards were redesigned to fit on a smaller footprint. The new hydrophones were implemented in the new submarine with improved algorithms. The team purchases a new DVL and receive a new IMU for the new submarine. Equipped with those new features and processing systems, the team wanted to accomplish all the tasks at the 2020 Robosub competition.**

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

I. Competition Strategy

Having two submarines (AUV-7 and AUV-8) for the first time, the team needed to prepare for how they wanted them to interact with the obstacles in the pool and not hitting each other.

The main objective being to score as much points as possible, each submarine needs to be able to score points on any task. With the need to build an entire new submarine, administrative members realized this year's funds were not enough budget to acquire equipment for both submarines. With this in mind, two cameras, one dropper mechanism, one torpedo-shooting mechanism and hydrophones were needed for each prototype. Then, to get the maximum amount of points, specific equipment like a sonar and an arm will be added to a single submarine.

The team decided to divide the pool in two areas, the first one with the buoys and droppers tasks, the second with the torpedoes and the octagon tasks. Each submarine would have an attempt at their own area then would exchange place with the other one.

Since the new submarine is design to have a better control and be faster, it would go first during the competition. To maximize the amount of point scored in this area, the arm needs to pick up the bottles. The new AUV will also host the sonar, has it's needed to have a better evaluation of the distance for the torpedoes and even be able to do a random pinger. Meanwhile, the older submarine would make its way to the buoys and the droppers.

Each submarine would have a timer of ten minutes for each area. At the end of the timer, the submarines would stop their attempt and proceed to go in the other zone. To make sure they would not cross path, they would be at two different depth. To go in the second zone, AUV-7 has to follow the pinger while AUV-8 might have more trouble to find its new zone. The sonar is needed to detect the buoys and then, using the bottom camera, it will be able to follow the first path to find the bins. AUV-7, on the other hand, will shoot torpedoes and make surface to make sure that the maximum points is achieved.

A. Mechanical

For Robosub 2020, since the current AUV-7 platform is still operational from a mechanical point of view but aging, the team has decided to focus their energy on the development of a new submarine AUV-8. Focusing on maximizing the submarine score during the competition, the team worked on two key points that were the most problematic during the past competitions.

A.1 Weight Strategy

The current submarine has a large volume and the interior space is unorganized. The carbon fiber was innovative, but it was lighter than expected. Therefore, the submarine's density is too low, and it becomes challenging for it to dive. To overcome this challenge, the mechanical team added 25 pounds of ballast in order to reduce the buoyancy. One of this year's goals with the new submarine design is to reduce weight penalties.

With the new submarine, the design is a lot smaller in order to increase its density. This way, no unnecessary mass was added. Even though the submarine as to be smaller, it was important that all the existing hardware could fit inside, due to budget and logistical constraints. The mechanical team aims for a total weight of 77 lbs compared to 106 lbs with the previous submarine. In Figure 1, it is possible to look at the difference between the old (grey) and the new design (blue).

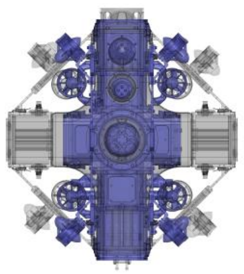

Figure 1: AUV-7 vs AUV-8

A.2 Accessibility

With two submarines to maintain, the mechanical team needs to be as responsive as possible when technical design issues happen during the competition. Therefore, it was clear that the components accessibility needed to be the main focus of the new design. The team decided to increase the number of access points in addition to increasing their size. The interior is fully hollow without internal obstruction, such as inner bolt circles. A clip system was added to save the team from having to screw components inside the submarine. During the competition, this part is vital since it allows the team to take out all critical parts quickly and without specific tools. For the competition, the 2 platforms (AUV-7 and AUV-8) are design to be equipped with a torpedo launcher and a module of droppers to attack most of the obstacles.

B. Electrical

With the new design, the electrical team had to keep functional the AUV-7 platform while designing new PCBs for the AUV-8.

To increase the control on AUV8, the team needed a better estimate of the power of the motors. The submarine's control is using the current used by the ESC to calculate the power of the motors. Furthermore, the new power supply design enables the submarine to double its maximum speed. A higher speed will be helpful to get to the hydrophone's objective without losing valuable time. If the task is not successful, the submarine will be able to change destination to change the objective and go to the octagon and the bins.

One of the team's main goal was to better achieve the manipulation tasks during the competition. Through the development of the new platform, the I/O embedded system was revisited, and additional. servo motors were added to increase control over AUV8's object manipulation apparatus during RoboSub pick up and drop tasks.

Another task that the team wanted to improve was the hydrophones task. This year the hydrophone has been rebuilt to allow the submarine to get to the objective without having to listen to more than two pings from the pinger saving precious time for each run.

One of the last main goal for the electrical team, competition strategy wise, was to minimize the teams' connectors problems. Last years, with weak connectors, the members of the electrical team were confronted with many issues during the competition. This year's goal is to design PCB that benefits from a sturdier design along with strong connectors for fewer electric problems during the runs at the competition.

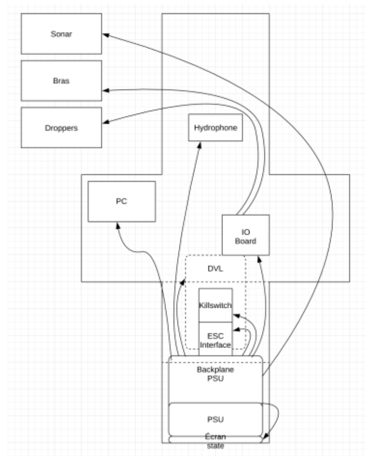

Figure 2: 12V Electrical Power Distribution

C. Software

It was a busy year for the software team. One of the biggest challenges for this year's competition was to improve the telemetry. The old simulation system was on the old team's telemetry. This year, to give the team the opportunity to better test the missions, the system was upgraded for Gazebo. This will help the team to simulate the different tasks of the competition during test days.

To follow the new technologies, the team continued to work with a GPU for the deep learning. Having an external GPU with the software team at all time is cost and time savings in the long terms since it is possible to adjust the models during the competition. It also allows to do more testing/training during the day at Transdec which is a big improvement for the software team.

Figure 3: Deep Learning: GPU system

II. Design Creativity

A. Mechanical

This year, the mechanical team decided to design and build a new submarine. The main goal was to reduce its width and weight. The team tried to get the smallest possible submarine with a more longitudinal shape. The older submarine also highlighted the importance of standardisation in shapes, fasteners and sub-component assembly. Overall, the design is made simpler, more efficient and easier to handle by the team's members.

A.1 Exterior Design

The biggest problem was the weight of the cross-shaped submarine. The buoyancy was to high and the team had to add extra weight in order to sink it. With the new design, the team decided to go with a full aluminium hull after some deliberations. First, the raw material is less expensive and easier to manufacture, compared to carbon fiber. Second, with aluminium, the heat exchange from the submarine to the water will be better than the carbon fiber shell.

Most of the parts were programmed and machined by the mechanical team. It was decided to anodise the new AUV-8 to protect it over the years. A light color was chosen as additional protection and to reduce the heating of the submarine outside of the water.

A.2 Interior design

For the interior, the mechanical team designed most of the support racks to be 3D printed. The main goal for the racks are that they do not require any fastener or tools for the assembly and disassembly. These racks can be taken apart quickly to help the electrical team members to debug an electrical malfunction during the competition. The main challenge is to fit all the big components, such as the Jetson Xavier and the DVL, will maintaining access and removability inside of the hull. Careful design and testing ensured that everything fits without any snags or over bending wires.

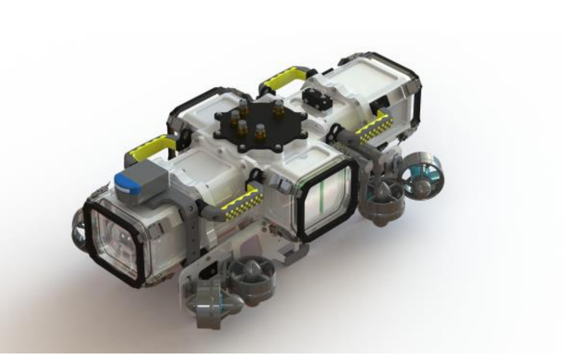

Figure 4: AUV-8 Design

B. Electrical

The electrical team had to face many design challenges this year. The main challenge was to repair the old platform while designing the new AUV-8.

With the new mechanical design, the whole electrical platform had the be reengineered. The first goal of the team members was to fix the issues from the previous platform without increasing the work of the software team. The new custom boards of AUV-8 are using the same communication protocol previously used on AUV-7.

The major change on the new prototype is its size. Since, the new submarine is considerably smaller in volume, the PCB needed to be smaller in design. The power supply board needed to fit the new extrusion design with a reduction of its size by 40% without compromising the power delivery for the ESC while using the thrusters at a better efficiency. The power supply still needs to provide two power delivery channels for the ESC and one channel that converts the 16V of the batteries to 12V.

Another team's goal was to change the current and voltage sensor. On AUV-7, the team was not able to use these sensors. The members changed the analog sensors for a digital sensor that communicates with I2C protocol. INA226 sensors is used to monitor the current and voltage of the ESC and for the 12V converter. The main objective of this project is to be able to have a better feedback of the electrical state and consumption of the submarine to improve its control.

During last year's competition, the electrical team had some issue with the 12 V channels of the power supply of the submarine. For the new design, they wanted to lower the ripple for the DC-DC converter that was used. The target was for it to be lower than 100mV at 12 amps. The team chose the DC-DC converter LM25116 after multiple researches t be able to get an average ripple voltage around 75mV.

Regarding the submarines' cables, last year, S.O.N.I.A. used prefab RS485. This year, the team uses ethernet cable instead of flat cable for RS485 communication. One of the main reasons for this change is that Ethernet cable have internal twisted pair and have a more resistant connector. These cables have a low price and can be bought in multiple sizes. These cables' changes force the electrical team to design their own RS485 board since no prefab RS485 have an Ethernet connector. They decided to use a LTC2855 chip for the RS485 communication and they added a switch to be able to choose the value of the RE pin, TE pin and DE pin of the chip.

Another new addition regarding the connectors was the use of a USB C connector for the USB communication instead of a USB B. The USB C was chosen because of its right angle which is mandatory because of the mechanical restriction with the new design and its cheaper cost.

With the new design, the electrical team chose to fit within AUV-8 standard STM32 solution and integrate additional SMD components to be able to achieve a smaller footprint. Replacing the THT components helped the PCB benefit from a sturdier design with the addition of new stronger connectors. This new design reduced the electric problems, especially during the pool tests and the competition.

Another project was the ESC interface. The problem with the old design of the ESC interface is that it used a lot of space, which was not a problem with the AUV7, because it had a lot of space inside. Since AUV8 design is significantly smaller than its predecessor, new interface was designed to have all the ESC interface on one PCB. The microcontroller of the board is generating 8 PWM signal, one for each ESC. This design will use less space in the submarine and will reduce the amount of loose wires.

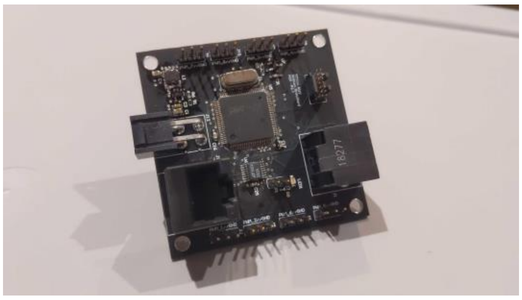

Figure 5:   AUV-8 ESC Interface Design

The last project of the electrical team was the hydrophones. The hydrophones system has been upgraded with more accurate band pass filter that allow the phase of the overall system to change the same way. This year, the team received four new hydrophones with shorter cable which has resulted in a better signal to noise ratio and better ping detection. To improve the decision of a ping and reduce the detection of false positive ping, the preamplifier was changed, from an instrumentation amplifier to a charge amplifier. The modification of the preamplification circuit as well as the addition of better shielding allowed the team to reduce the amount of noise previously encountered around 35k Hz. In the previous design the noise at 35k Hz was problematic because it was covering the ping signal at 35k Hz, making the submarine unable to locate the pinger at 35k Hz. The power tree and all the supply has been redesigned to allow the board to work properly even if the USB connector was disconnected and reconnected. Regarding the power, the new design integrated more filtering at the input power port reducing the EMI sensibility when all the thrusters are running. The new design integrated a new SPI flash memory, allowing the FPGA to not need a configuration each time the submarine is shutdown. Since the project is cost sensitive, the board support the size of FPGA which are pin to pin compatible allowing the team to upgrade the FPGA if a bigger algorithm is used in the future.

C. Software

With two platforms, the software team faced many challenges this year.

C.1 Development and Documentation Process Review

Senior members of the software team had identified a lack of defined process in many of the development process and in our previous documentation.

The previous documentation process required many manual steps to deploy the new information on our previous documentation site. During the 2020 winter semester, Martin Gauthier and Kevin Charbonneau, members of SONIA software team, reviewed the documentation process. Documenting process and development was a hard task since it required many steps before deploying code and notes to our previous documentation solution. Many meetings with the team occurred to ask all members their view on the ideal solution. Many ideas came out of those meetings, members wanted the solution to be easy to use, they wanted to be a WSIWG editor solution. The idea of having a solution where the members could include diagrams either for the software team, the electrical team or the mechanical team was also needed. Since the previous documentation tool was open source and S.O.N.I.A. supports open source software, a new documentation solution Wikijs is now being used. The new documentation is hosted at https://wiki.sonia.etsmtl.ca/. Documentation and process review are key elements to be agile in software development and members wanted to apply these to all of our technical teams (software, mechanical, hardware). This documentation will ease up the arrival of our new members and the knowledge sharing across the team.

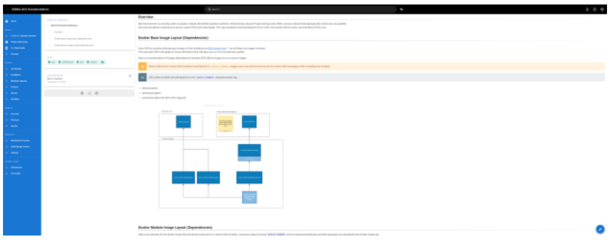

Figure 6: Wikijs Interface

Finally, during the summer semester, three members did their final project on the development process. The main objective was to containerize packages and to add CI/CD on the development process. To do so, they migrated custom ROS messages and services in a single package. Using it as base, they add over twenty Docker images containing one package that control one aspect of the submarine (control, thruster, sonar, etc.). With the addition of the Docker, development environment is uniform for everyone in the team. Debugging and testing the different components of the software is easier. Containers can also be debug directly on the submarine, using Visual Studio Code Remote Container extension. The team made the choice to use GitHub Actions as CI/CD for building Docker images when commits are pushed on GitHub. These images are pulled on the submarine and are ready to be run (there's no more C++ or Python deployed directly on the sub, only container containing each modules).

Finally, the three members worked hard on a new CLI for the software, allowing a better diagnostic of the platform, execute specific commands, deploy and run packages on both platforms and install the dependencies such as docker, git, etc. (with the new Docker images, there's no need to install ROS on the development platform).

C.2 Deep Learning and Training

This year S.O.N.I.A. acquired an NVIDIA RTX TITAN and an eGPU case. With these new acquisitions, the team will be able to do more prototyping and training throughout the year. Since it is very portable, it will be possible to be brought during off-site testing and during next year competition. Another change was also regarding the DAGs developed under the Apache-Airflow platform and those will ease up model deployment on our subs.

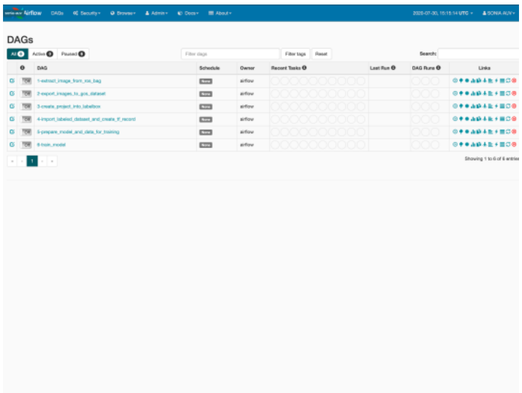

Figure 7: ETL jobs using Apache Airflow

C.3 New Dockbox

Last year, the software team developed a new dockbox. This new dockbox is driven by an NVIDIA Jetson TX1. A router and a network switch are installed inside the dockbox to allow the team to connect to the AUV. The team also use the dockbox as a file storage server. To access the internet, Eduroam is used. Eduroam (education roaming) is an international roaming service for users in research, higher education and further education. It provides researchers, teachers, and students easy and secure network access when visiting an institution other than their own. Authentication of users is performed by their home institution, using the same credentials as when they access the network locally, while authorization to access the Internet and possibly other resources is handled by the visited institution. The Jetson TX1 is used to bridge the Eduroam network inside the dockbox to provide internet to the software team and the AUV if needed.

This device also run a Samba share to store and access many files during our pool tests.

C.4 Flexbe

In the process to change the telemetry, the team decided to change the old homemade mission controller for Flexbe. This decision was made after experimenting some inconsistent bugs and diverse time-consuming issues. Flexbe will be more consistent for the team in the future and will be easier to use and adapt by the team members. Since Flexbe and the old mission controller both use SMACH, the software team was able to easily adapt the existent state. The team took the opportunity to improve some of the states as well.

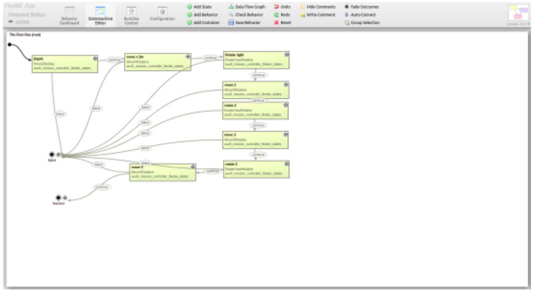

Figure 7: FlexBe Mission System

C.5 Gazebo

Since the old simulation system was on the old telemetry, the software team decided to improve this system by using Gazebo. The old system was imprecise and could only simulate displacement on a 2D map and a depth indicator. With Gazebo, it will be possible to have full 3D simulation with the real physical model of our submarine.

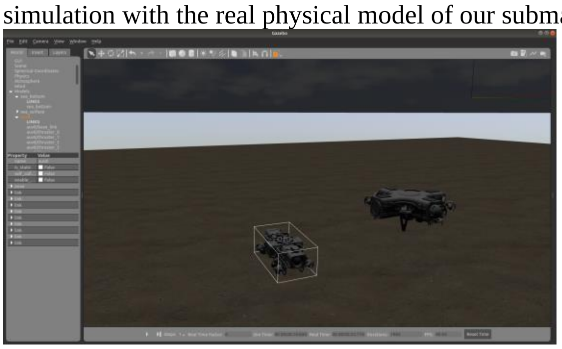

Figure 8: Gazebo Simulation

III. EXPERIMENTAL RESULTS

At ÉTS, students have three regular semesters a year. Therefore, when participating in a scientific club like S.O.N.I.A., the need to go to school persists even during summer right before the competition. Many students are taking full course load, and some are working, while others are involved in extracurricular activities.

2020 has been a difficult and challenging year. With a new design, the team had a big year ahead. Unfortunately, COVID-19 decided otherwise. Since March, the university closed, only available online and the team cannot access the workshop and the prototype.

That did not stop the team to work on the project. The software team had all the necessary material at home and was able to juggle between online classes and online meetings. In order to have a well-organized planning remotely, Trello was used to keep track of the different team’s goal and weekly tasks. The mechanical team was lucky. They work really hard during the fall semester; therefore, the new mechanical design of the submarine was almost completed when the university closed.

Even with the recent events, more than 20 members are still contributing their time for the accomplishment of S.O.N.I.A. It would not have come this far without the dedication of passionate and hardworking students.

ACKNOWLEDGMENT

S.O.N.I.A. AUV would like to thank David Morgan, Claire Babin, Pascale Cloutier, Noël Giguère, Alain April and Francis Bordeleau for their continuous support throughout this journey.

COMPONENT	VENDOR	MODEL/TYPE	SPECS	COST (If New)
Waterproof Connectors	TE Connectivity (AUV7) MacArtney (AUV8)	Seacon connector Subconn connector	Wet mate Wet mate	3200 USD
Thrusters	Blue Robotic	T200	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster/ (8 thrusters)	1770,57 CAD
Battery	Multistar (AUV7) MaxAmps (AUV8)	4S 16000mAh 4S 16000mAh	14.8V 14.8V	2500 CAD
CPU	Nvidia (AUV7) Nvidia (AUV8)	Jetson AGX Xavier Jetson AGX Xavier	16GB RAM 32GB RAM https://developer.nvidia.com/embedded/jetson-agx-xavier-developer-kit	1149,08 CAD
Internal Comm Network	None	RS485	2 twisted pairs Ethernet cables	150 CAD for whole change
Programming Language 1	C++			
Programming Language 2	Python			
Programming Language 3	Typescript/Javascript			
IMU	MicorStrain (AUV7) VectorNav (AUV8)	3DM-GX3-25 VN-100 Rugged IMU/AHRS	Standard calibration +25	Sponsorship
DVL	Nortek (AUV7) Teledyne (AUV8)	1 MHz Pathfinder	Sample 8Hz http://www.teledynemarine.com/Lists/Downloads/pathfinder_600_datasheet_lr.pdf	20 009,04 CAD
Camera(s)	Flir	Chameleon 3 USB3	https://www.flir.com/products/chameleon3-usb3 (4 cameras)	2 sponsored + 1538,36 CAD
Hydrophones	Bruel & Kjaer	Type 8103	**Frequency range re. 250 Hz** 0,1 Hz à 20 kHz (+ 1 / −1,5 dB) / 0,1 Hz à 180 kHz (+ 3,5 / −12,5 dB) **Voltage sensitivity with cable at 20°** 30 uV/Pa ± 8 uV **Max operating static pressure** 252 dB = 4 × 10^6 Pa	Sponsorship

Open Source Software	ROS, OCLIF, TensorFlow, Visual Studio Code			
Team Size	20			
HW/SW expertise ratio	11/9			
Testing time: simulation	20 hours			
Testing time: in-water	30 hours			

Appendix B: Outreach Activities

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. Since 2018, S.O.N.I.A gives back to the community by presenting its project in elementary schools. The team firmly believes that the presenting a project as ours can inspire children to pursue their studies in a scientific field. Last year, the project reached 2500 students. This year, the team did more than 10 presentations in different elementary schools in Quebec.

Another project linked to these presentations is SIVUMUARNIK Project. With the help of *Ingénieurs Sans Frontières Québec*, 2 members of SONIA will go in Nunavik to present robotics to the first nations living there. In Nunavik, they do not have all the resources that we have back in the southern regions. Seasons are harsh and they are often left alone. The goal of this project is to explain to the students the different engineering fields. The submarine will come with us to show them an example of project that can be achieved. Also, we want to show them the opportunities that the engineering field can bring and how they can give back to their communities after their studies.

The team was supposed to be in Nunavik in September. Unfortunately, due to the health crisis, they project is on hold and a new date will be set. We wish to go in 2020, in October or November. It is important to be careful with COVID-19 since these communities do not have access to proper healthcare facilities.