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

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***Abstract*—S.O.N.I.A. (Système d'Opération Nautique Intelligent et Autonome) is a student-run club from École de Technologie Supérieure in Canada, where 18 members devoted countless hours engineering an autonomous underwater vehicle (AUV). The team is divided into four departments: mechanical, electrical, software and administration. Over the past years, the team implemented many new features without considering the power consumption of the hardware integrated into the vehicles, thus resulting in premature overheating. This year, our goal is to improve the vehicle's own localization in relation to its surroundings and object detection while reducing the resources needed on the onboard computers. To achieve this goal, the team re-examined all the sensors to increase their accuracy and decrease their latency. Both submarines have been improved considerably by the hardware teams to enhance reliability and ease of work for servicing and repairing when out of the water. At the 25th annual RoboSub Competition held in Washington D.C., S.O.N.I.A.'s objective is to complete all the tasks by dividing them among our two submarines, AUV7 and AUV8. Futhermore, we firmly believe the communication between both submarines is what will set us apart from others, ensuring the completion of every challenge successfully.**

***Index Terms*—Autonomous Underwater Vehicle, Technical Design Report, RoboSub, RoboNation.**

I. Competition Strategy

Team S.O.N.I.A. has participated in the RoboSub competition for 22 years and will look forward to compete for the years to come. Our strategy has always relied on durability and repeatability. This year, the team has put a lot of effort on developing flexible submarines for the competition. The goal was to completely redesign both AUVs for them to run on the same electronic components and software. This has reduced the complexity for the team when troubleshooting and has made it possible to have a backup submarine in case of any major problems. With reduced differences on our AUVs, we focused our efforts on making our submarines less dependable of their environment. In the previous year, we used Deep Learning as our only image detection technique, but this year, we decided to add conventional vision and a sonar system to complete the image detection, improving the detection rate and speed. The strategy of merging multiple image detection techniques has been chosen to increase our repeatability during the competition.

A. Mechanical Team Strategy

Despite the penalty points added due to the weight of our second submarine, the points that will be gained from having two submarines working together outweighs the points lost. To do so, the mechanical team had to make sure both AUVs were operational by refurbishing AUV7 as well as designing replacement parts for the mounting brackets in the submarine. AUV8 required additional floaters to ensure that its buoyancy would be improved and a new power supply unit board had to be implemented in the design.

B. Electrical Team Strategy

With the newest features from our control, the power delivery has been redesigned on both submarines to add monitoring to the motor drivers and has improved the reliability of the power system. The controller is able to adapt itself depending on the amount of motor at fault. This ensure that the submarine can complete a 20 minutes run even in the case of motor failures. For AUV8, the strategy is to go at the random pinger after passing through the gate. With the new location and change in the environment, the algorithm for the acquisition card of the hydrophones has been updated to reduce the rebounds that can occur in a pool environment. With this update, we are confident that AUV8 can complete both random pingers. As previously mentionned, AUV7 has seen a complete redesign to update the platform with the newest custom printed circuit boards developped for AUV8. This change has greatly reduced the maintenance time on both submarines since they shared the same hardware. Futhermore, the electrical team will not have to create as much backups of our custom boards.

C. *Software Team Strategy*

Our strategy relies on the fact that AUV7 and AUV8 will be in the pool simultaneously during the competition allowing us to have more time to complete all the tasks and obtain the points for inter-sub communication.

Last year, the software team focused on developing the navigation equations as well as the control law of our AUV. This year, our strategy is to reduce travel time by generating a continuous trajectory over multiple waypoints, rather than stopping at each point, waiting for convergence, and then starting again. The amount of time saved by finishing the course faster can increase the points for the run. We also created a simpler interface with the control to reduce our mission's complexity. Finally, the detection system has been remade to improve the object detection. The artificial intelligence (AI) is efficient for computer vision but it's very expensive to calculate and need hours of labelling each year. Because we need to recognize specific images in the water, we added the ORB algorithm that doesn't need any training and that can find the images with less calculation in addition to the AI. Finally, we decided to implement a sonar on the AUV8 to reach a higher level of autonomy. The vision system is suitable for the alignment of the submarine with the obstacles as well as for the identification of the tasks, but it is unable to accurately determine the distance from the target.

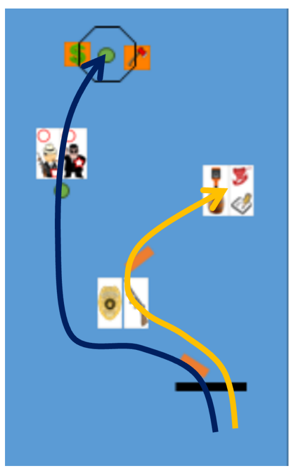


Fig. 1: Submarine paths (dark blue AUV8 & yellow AUV7)

II. Design Creativity

A. *Mechanical*

1) AUV7: The refurbishing of the inner components led to the redesign of the inside structures in AUV7 with the knowledge we acquired while designing AUV8, thus ensuring that the implementation and the maintenance of the parts is faster and easier than previously achievable with the old designs. The new racks were also made in a way that puts the electronic components and the custom printed circuit boards towards the upper part of the sub to avoid potential short in the event of a leak inside the sub.

2) AUV8: As for AUV8, four floaters were made from liquid foam casted in a 3D printed mould and to improve their sturdiness, they were covered with a few layers of epoxy resin. There were added to improve the buoyancy of the submarine since AUV8 has a smaller body volume and thus a smaller volume of displaced water than the previous models made by the team. This implies that even though AUV8 is lighter than AUV7, it will tend to sink without the added floats. Also, the new power delivery system had to be implemented in the submarine as the electrical team was able to increase the current limit for the motors. The existing rack had to be changed to house the new printed circuit board which is twice the size of the old one. The rack, using design cues from the rest of the mechanical design, makes use of a clip system that allows a quick separation of the printed circuit board from the rack to allow faster access time to the rest of the submarine's component. Active cooling was also implemented to mitigate the heat output from the electronic component. The fans make use of channels in the rack that runs along the aluminum walls which improves the efficiency of the cooling.

B. *Electrical*

1) Power Management: This year, the electrical team has added relays in series with the actual mosfet used for the power delivery of the motors. They will mechanically cut the supplies in case of an over-current or/and over-temperature. We have decided to implement the relays to add a safety measure for the emergency stop of the submarine. At the beginning of the year, we had some issues with the mosfet failing closed and keeping the motor energized while triggering the emergency stop.

We decided to go with the relays instead of going with other type of switches since they disconnect mechanically the power from the motors. The only problem is the recommended breaking current of the relay at 20 amps. If we open the relays while the thrusters are running, the current can create an electrical arc and damage the relay overtime. To negate this effect, a delay is added between the opening of the mosfet and opening the relays.

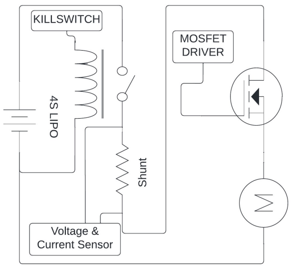
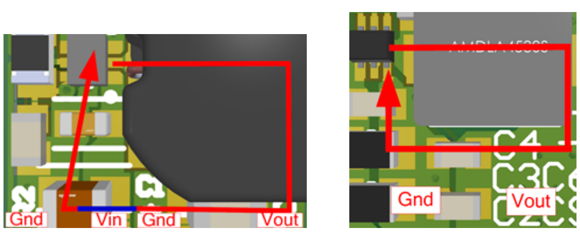


Fig. 2: Power System for a single motor

2) *DC-to-DC Converter Redesign:* It is crucial for us to have access to voltage regulator both for new project and to create spare of existing project. Last year, we decided to create a separate board for our DC-to-DC converter. We wanted to improve the current efficiency of the converter to reduce the number of time that we need to change batteries, thereby increasing testing time. To address this, we chose a regulator who's internal mosfet had a lower on-resistance reducing power waste during conduction.



(a) Old Design (b) New Design

Fig. 3: Improvements for the high frequency switching loops.(red : top layer & blue : bottom layer)

As another design consideration, we chose to reduce the voltage ripple of regulator to avoid possible instability with our microcontrollers. To achieve this, we used some of the space saved by using smaller capacitors to add filter capacitor on the output. Finally, we have minimized the switching loop area.

C. Software

1) *State Machine for Autonomous Behaviors:* The team currently uses FlexBE as the main engine to create our own states and behaviors for the missions. Having a highly modular mission system means that we put an emphasis on re-usability and avoiding reprogramming every single mission from scratch during the testing phase. This year, the members can successfully test the missions through the telemetry together with the 3D simulation built on Unity. The combination of simulation and pool testing marginally improves our ways of testing and debugging our states and behaviors.

2) *Motion Planning:* We have created our own system to interact with AUV based on pose systems used with industrial robots. Therefore, it is possible to create custom frame at run time and create a position according to it. The AUV center point can also be modified to create rotation around a specific point. The motion planning will first convert all the desired target in the inertial frame and then uses different interpolation methods that the user can choose. With a discrete contour integration, it is possible to compute the trajectory time based on max velocity and max acceleration for example.

3) *3d Mapping:* We decided to create local maps based on the tasks we want to create a complete 3D map of the pool. The proc_mapping ROS node allows the users/missions to start or stop the creation of a point cloud, to filter it and apply functions to evaluate it such as the dimensions or the position of the object. All those features can be called directly using our mission system. To correctly map the object in front of the submarine, we also developed some mapping strategies to filter and merge the point clouds.

4) *Vision Algorithms:* The name of our new algorithm to help with the image detection is ORB for Oriented FAST and Rotated BRIEF. It is a free to use alternative to the SIFT and SURF algorithms. One of the main advantage of this algorithm is that it's invariant to scale and rotation. In theory, we should be able to recognize an image in the water from short or long range or with a submarine upside down. For our AI, a few modifications have been made to improve it's reliability. Firstly, we updated our inference to Tensorflow 2.6.0 to access the newest model included with the new version. Secondly, we added the ability to apply filters before using the images for the inference. This is important to simplify the task of the AI and avoid false positives.

III. Experimental Results

A. Mechanical

To improve the control of both submarines, the team used Ansys to create a fluid dynamic analysis for each submarine. These analyses give us the mechanical constant like the center of gravity, the buoyancy and the inertia of the submarine that are important for the model control. Without them, we would have to find then with trial and error during a pool. Even if the values aren't perfect, they really improved the control of our submarines. Also, we can change parts easily since we don't have to go through the trial and error process each time.

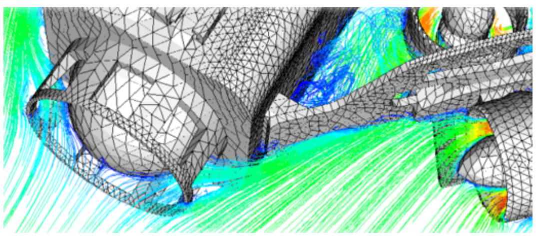


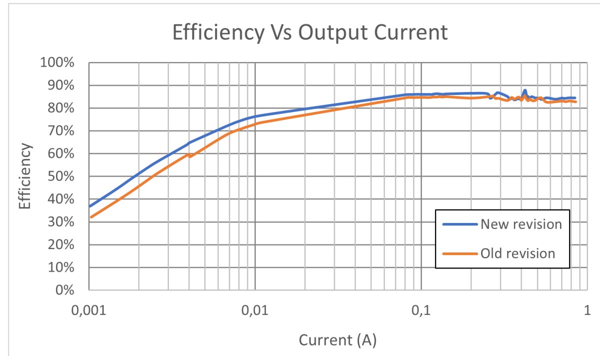
Fig. 4: AUV 7 Ansys fluid analysis

B. Electrical

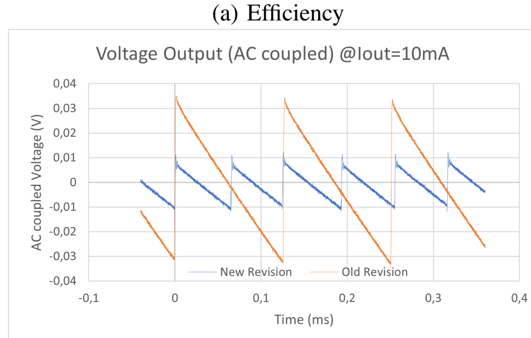
The electrical team focuses on designing and prototyping the custom circuit boards for our submarines. With each project, the basic circuits like the power activation or simple logic gates circuits are simulated with a SPICE software. With these simulations completed, we can order the parts as soon as possible since the current market is problematic to keep the same parts on all our designs. After the design is finished, the circuit boards can be ordered to test the circuit. With JLCPCB, we have around 2 weeks of lead time which gives enough time for the team to prepare the tests and parts.

1) Power Delivery Temperature Testing: To make sure we don't damage the mosfet on the power management board, multiple tests have been done to verify the maximum power allowed using different passive cooling configuration. After testing, the biggest heatsink was selected since it was fitting on the board and it gives the best current capability with a current of 4.58 amps at a temperature rise of 43°C following a constant 10 minutes test with passive cooling. With these results, we can limit the maximum power that can be used by the controller to move the submarine. Even if the results don't show the actual use of the system, this result is more a worst-case scenario.

2) DC-to-DC Converter: To confirm the new design of the DC-to-DC converter, we are verified the efficiency and the output voltage ripple of the converter.



(a) Efficiency



(b) Output Ripple Votlage

Fig. 5: Graphs of DCDC converter characteristics

As expected, the new revision is slightly more efficient. Furthermore, the new revision has a lower ripple voltage although we do observe a more pronounce ringing with the current revision.

C. Software

1) State Machine for Autonomous Behaviors: The team troubleshoots the missions created with the simulation in two ways. First, the simulation can be use as a preview of the vehicle's behaviors before a pool test. This allows the members to work on missions remotely. Second, with this year's improvements, we can now have a preview of the submarine's mission's execution in real time when it is connected to the surface. With this preview, we can abort the mission faster if it doesn't behave the way we expected it to.

2) Motion Planning: This year, we were able improve our search area by generating a smooth trajectory instead of a multitude of single line. The travel time has been reduce by a factor of 2 compared to the previous implementation. This result can be achieved since the submarine doesn't stop at each points of the trajectory.

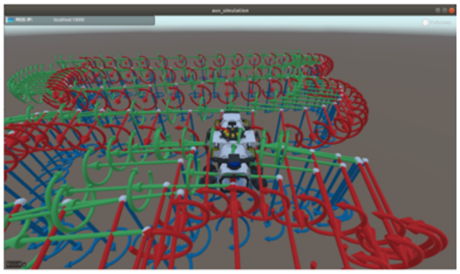


Fig. 6: Trajectory created showing in simulation

3) 3d Mapping: To create this project, we obviously needed some data, and this is why we decided to add the sonar into our simulator.

We were able to acquire sonar data using the Unity simulation to test our mapping strategies and filter algorithms. When we were satisfied with the simulation, we placed the sonar on the submarine to test it in a real environment. We were able to map objects such as posters and walls with a precision that will be useful during the competition. The precision isn't comparable as a 3D Lidar in the air, but it will be really useful to give the range to a poster or wall.

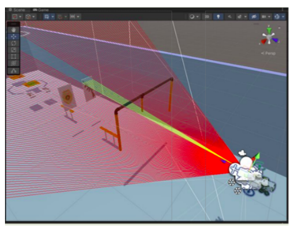


Fig. 7: Simulation of the sonar

4) Vision Algorithms: Because the process of the ORB algorithm is consistent, we can calculate the descriptors of the reference images before a run. This gives us a list of descriptors that we can be saved for each image.

This process doesn't have to be done at each test, but only when the images change. When the algorithm is deployed on the submarine, it only calculates the descriptors for the camera image, and we match the descriptors with the list previous created. If there is enough matching points in an area, the algorithm will draw a rectangle around the matching points and call the image found. For the moment, the detection of the image is working at certain extend. The size variation is affecting the detection which is unexpected. There is more work that needs to be done until the competition to finalize the detection rate.

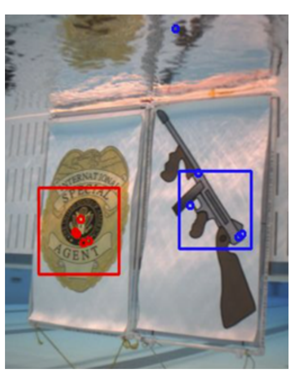


Fig. 8: Testing of the ORB algorithm

Acknowledgment

We want to highlight the involvement of Prof. Alain April from the Software Engineering department of École de Technologie Supérieure. For several years, he has helped our team members with their projects.

Also, we want to highlight the involvement of Prof. Tony Wong from the Systems Engineering department of École de Technologie Supérieure. In the past year, he has supervised and has helped our team members in their projects.

Finally, we want to highlight the involvement of Prof. Jean-Philippe Roberge from the Systems Engineering department of École de Technologie Supérieure. He is currently helping the team in improving the submarines' control and is now supervising two end-of-studies projects for S.O.N.I.A.

We wanted to thank members that dedicated a course to help our team:

For the integration of the underwater communication: A special thanks to Francis Alonzo supervised by Prof. Tony Wong.

For the uniform driver design for DVLs: A special thanks to François Côté-Raiche supervised by Prof. Tony Wong.

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Gold: Teledyne Marine, Labelbox, Caisse Desjardins, VectorNav and Drillmex

Silver: Parc Jean-Drapeau, Tritech, Impact Subsea and Digi-Key electronics

Bronze: Nvidia, Connect tech In., Blue robotics, Laser AMP, Anodisation Expert, Groupe Rivest, Simplify 3D, General Dynamics, Attaches Richard, WaterLinked and Omni Robotic

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APPENDIX A
COMPONENT SPECIFICATIONS (AUV7)

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of purchase
Buoyancy Control	-	Added mass	Brass plates	Purchased	-	2016
Frame	-	CNC aluminium system	6061-T6 CNC machined and anodized	Custom	-	2016
Waterproof Housing	-	Carbon Fiber and CNC aluminium system	6061-T6 CNC machined and anodized	Custom	-	2016
Waterproof Connectors	TE Connectivity	Seacon connector	Wet Mate	Purchased	-	2016
Thrusters	Blue Robotics	T200 (x8)	0.02 kg f	Purchased	-	2016
Motor Control	HobbyKing	AFRO ESC	30A	Purchased	-	2016
High Level Control	-	LTV MPC	-	Custom	-	2022
Actuators	-	Droppers only	Solenoid Activation	Custom	-	2022
Battery	MaxAmps	4S 16000mAh	14.8V	Purchased	-	2022
Converter	Texas Instruments	LM25116MH	Synchronous Buck Controller	Purchased	-	2020
Regulator	-	Powersupplies	12V 15A Step-down	Custom	-	2020
CPU	Nvidia	Jetson AGX Xavier	16GB RAM	Purchased	-	2019
Internal Comm Network	-	RS485	2 twisted pairs Ethernet cables	Custom	-	2022
External Comm Network	ConnectTech	XDG021	1000 Mbps Switch	Purchased	-	2016
Compass	VectorNav	VN-100 Rugged AHRS	Standard calibration +25°C	Purchased	-	2022
Inertial Measurement Unit (IMU)	VectorNav	VN-100 Rugged AHRS	Standard calibration +25°C	Purchased	-	2022
Doppler Velocity Log (DVL)	Nortek	DVL500	300m	Purchased	-	2016
Vision	Flir	Chameleon 3 USB	55FPS, 3.2MP	Purchased	-	2022
Acoustics	Brüel & Kjaer	8103	0.1 to 180kHz	Purchased	-	2016
Inter-vehicle communication	Water Linked AS	MODEM M64	64 bits, omnidirectional	Purchased	2000$	2021
Manipulator	BlueRobotics	Newton Subsea Gripper	modified to open up to 10cm	Custom	-	2021
Algorithms: Vision	OpenCV TensorFlow2	Sift MobileNet	- -	Custom Custom	- -	2022 2022
Algorithms: Localization and Mapping	Matlab Octomap	Extend Kalman Filter 3D occupancy grid	TBD -	- -	- -	2021 2022
Algorithms: Autonomy	FlexBe	Finite-state-machine	-	Custom	-	2021
Open source software	OpenCV, FlexBe, AirFlow, TensorFlow, ROS, Unity Robotics, Docker, React, WikiJS, Github					
Team Size	18					
Expertise ratio	7/11					
Testing time: simulation	250 hours					
Testing time: in-water	25 hours					
Programming Languages	C/C++, C#, Python, React JS, Matlab					

APPENDIX B
COMPONENT SPECIFICATIONS (AUV8)

Component	Vendor	Model/Type	Specs	Custom/ Purchased	Cost	Year of purchase
Buoyancy Control	-	Added Volume	Foam	Custom	150$	2022
Frame	-	CNC aluminium system	6061-T6 CNC machined, anodized and painted	Custom	-	2020
Waterproof Housing	Homemade	CNC aluminium system	6061-T6 CNC machined, anodized and painted	Custom	7000$	2020
Waterproof Connectors	MacArtney	Subconn connector	Wet Mate	Purchased	4000$	2020
Thrusters	Blue Robotics	T200 (x8)	0.02 kg f	Purchased	200$/each	2019
Motor Control	Emax	Bullet Series ESC (x8)	30A	Purchased	15$/each	2019
High Level Control	-	LTV MPC	-	Custom	-	2022
Actuators	-	Droppers & Torpedos	Solenoid Activation	Custom	-	2022
Battery	MaxAmps	4S 16000mAh	14.8V	Purchased	2000$	2020
CPU	Nvidia	Jetson AGX Xavier	32GB RAM	Purchased	1000$	2020
Internal Comm Network	-	RS485	Ethernet cables	Custom	-	2020
External Comm Network	ConnectTech	XDG016	1000 Mbps Switch	Purchased	-	2020
Compass	VectorNav	VN-100 Rugged AHRS	Standard calibration +25°C	Purchased	-	2022
Inertial Measurement Unit (IMU)	VectorNav	VN-100 Rugged AHRS	Standard calibration +25°C	Purchased	-	2022
Doppler Velocity Log (DVL)	Teledyne	Pathfinder	600kHz, 140m	Purchased	20000$	2020
Vision	Flir	Chameleon 3 USB	55FPS, 3.2MP	Purchased	1200$	2020
Acoustics	Brüel & Kjaer	8103	0.1 to 180kHz	Purchased	-	2020
Inter-vehicle communication	Water Linked AS	MODEM M64	64 bits, omnidirectional	Purchased	2000$	2021
Algorithms: Vision	OpenCV TensorFlow2	Sift MobileNet	- -	Custom Custom	- -	2022 2022
Algorithms: Acoustics	-	Time Differental of Arrival (TDOA)	FPGA Implementation	Custom	-	2022
Algorithms: Localization and Mapping	Matlab Octomap	Extend Kalman Filter 3D occupancy grid	TBD -	- -	- -	2021 2022
Algorithms: Autonomy	FlexBe	Finite-state-machine	-	Custom	-	2021
Open source software	OpenCV, FlexBe, AirFlow, TensorFlow, ROS, Unity Robotics, Docker, React, WikiJS, Github					
Team Size	18					
Expertise ratio	7/11					
Testing time: simulation	500 hours					
Testing time: in-water	150 hours					
Programming Languages	C/C++, C#, Python, React JS, Matlab					