S.O.N.I.A. Autonomous Underwater Vehicule Concept and Design of the 2017 Prototype

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***Abstract*—After the last competition, six of the eight members of SO.N.I.A. AUV team left. With only two members remaining and a completely new robot to build, the recruitment campaign was crucial for the continuation of the club. Luckily, they succeeded to gather a big crew and the fabrication of the cross-shape submarine began. The center piece of the hull is made of carbon fiber since its shape is to complex to be made of aluminum. The extremity of the arms is made of aluminum for heat management. The new design holds eight motors, against six on the previous submarine, which gives it a better control an stability. Also, this year's AUV is equipped with a four-axis robotic arm, developed as a final project for three students, which is a lot more precise and stable than the old linear, pneumatic arm. As last year's AUV was coded both in Java and C++, the new one is fully converted to C++ with Robot Operating System (ROS) as a communication protocol, making it more user friendly for new team members. Lastly, the new telemetry developed to be compatible with ROS allows multiple people to connect on submarine simultaneously. With this fully new design and platform, S.O.N.I.A. if confidently facing 2017's ROBOSUB competition.**

I. Introduction

S.O.N.I.A is a Montreal-based team founded in 1999. The year 2017 marks the team's 18th participation to the ROBOSUB competition and the arrival of an entirely new submarine. This is the first new design since 2011, and was developed and built over the past two years in order to keep a functional autonomous underwater vehicle (AUV) at all times.

Following last year's competition, six of the eight members of the team left either to join another project or simply because they had completed their degree. Nevertheless, the remaining students decided to build the new submarine. To be able to do so, recruitment was crucial and was based on the fact that this new concept required the fabrication of mechanical and electrical components which would allow the new members to appropriate themselves the design and insure keeping of the newcomers within the team.

II. Design Strategy

The main objective is to reach a fully functional concept as it is a challenge in itself. Alongside this, part of this year's plan is to achieve a faultless functioning of the hydrophones to succeed at this obstacle as it is a key obstacle both because of its value in points and the navigational aid it represents. Also, since the team as a lot of experience with the buoys, it decided to make this obstacle another one of their priorities.

A. Mechanical

Concerning the mechanical aspect of the AUV, the members decided to shape it as a cross, as it is show in Fig. 1, to allow a better control over it as well as to make mathematical assumptions over its design as it is truly symmetrical on both the x and the y axis. Another advantage of the cross-shaped body it that it allows a better repartition of the components on the four arms as well as easier change in the configuration of the instruments.

The main part of the hull is compact, hollow, and is made of carbon fiber. This leaves more internal space in the center of the sub to place electronical components as well as ballast for the static balancing of the submarine. The design of the hull was determined to optimize the space for the components, allow an easier access to them, and to have a better control over the position the ballast plates used to manage the center of gravity. The arms were designed to allow easy insertion and removal of the electronics they contain and, just as importantly, an efficient heat management of those.

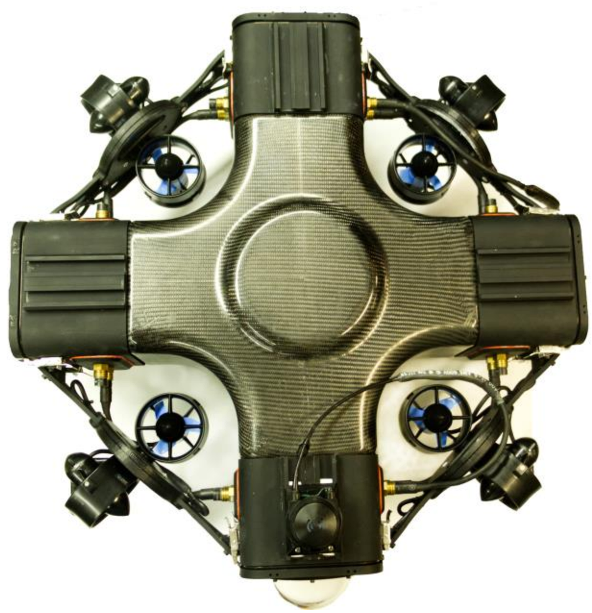

Fig. 1. S.O.N.I.A.

B. Electrical

Concerning the electrical aspect of the submarine, the objective with the new design and the new members was to once again have a profound knowledge of the technology used by the AUV. With the last submarine dating from 2011 and with the coming and going of the team members, the understanding of the old system's technicalities and subtleties was lost. Additionally, the mechanical constraints of the new concept made the old electronics unfit while the addition of two motors, for a total of eight, cranked up the load higher than the power supply cards could support. Therefore, in order to deal with these issues, no other option was left but to renew the whole electrical system of the AUV to fit the new concept.

C. Software

Beginning last year, the software team started integrating the ROS platform to the submarine. But up to 2016's competition, some modules were still operating on the old java platform. This year's main objective is to fully integrate the ROS platform so it is functional for 2017's competition. To do so, the software team worked very hard to develop a new mission system on ROS.

III. Vehicle Design

A. Mechanical

As mentioned earlier, the new shape permits a better placement of the instruments on each of its four arms. Simply said, this design has four fronts. The instruments can therefore be disposed on each of the fronts and the submarine only has to execute a 90 degrees rotation around its z axis in order to place which ever it needs to use in front. For example, the torpedoes rely strongly on the front camera and have to be placed in its field of view (FOV), but the sonar also has to be front facing when it is used. Therefore, instead of overstuffing one of the arms, the instruments can be disposed on all four of them to avoid clouding any of their FOV while keeping their full potential by simply rotating around the z axis.

The choice of the carbon fiber to build the main part of the hull was made to reduce the waste of the materials used in the fabrication process. In fact, making the hollow hull in aluminum would have required to chew off the major part of the raw material as well as a two-pieced assembly. Using a composite material allowed a much more efficient use of the material and a bigger internal size because of the strong structural properties of the carbon fiber which permitted a thinner build of the hull compared to an aluminum build with the same external size. This enhanced internal space makes for better cable and ballast management. However, the team succeeded in the making of this piece by going through a few trials. Indeed, the first time, the hull was made using four layers of carbon fiber which proved to be too flimsy to keep a rigid main structure and to resist the pressure exercised by the water. The following tryout was made using two halves made of six layers and, after these halves were glued together at their meeting flange, seemed to provide enough structural rigidity for the submarine. But it did not. The round-shaped center, hosting the Doppler Velocity Log (DVL) and a camera, would collapse as a pressure was applied on it. To address this problem, the mechanical team reinforced the center of the hull by designing and 3D printing two plastic plates that receive four threaded rods that push outward on the hull using nuts as shown on Fig. 2. Though the reinforcement chews up some space in the hull, the rods ended up being also the support on which the ballast is fixated, turning the problem into a solution.

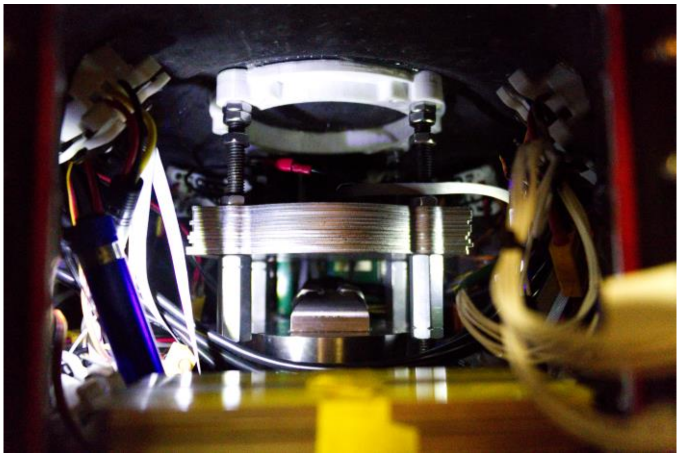

Fig. 2. Hull reinforcement and ballast plates.

The four arms of the cross are made of four aluminum blocks that were machined by one of the team members, using a computer numerical control (CNC) machine, and anodized for additional protection. These are essential for the heat management of the AUV since the computer and the power supply output a lot of heat. Each of the arms' extremity ends with a cap that grants an easy access to the components the arm contains.

Additionally, the team opted for *T-slots* to support the various instruments fixated outside of the hull because they are compatible with many standard hardware. They therefore allow different configurations as well as the use of standard tooling to add or remove the instruments. As for the torpedoes, they are auto propelled by an electrical motor which instantly solves the problems caused by the bulky pneumatic system used on the previous design as it is not need anymore.

B. Electrical

As mentioned above, the new design is propelled by eight motors instead of six as the old one was. Therefore, the submarine has now four *deep* motors, all on the xy plane, which gives more stability and control over its movements. Also, the motors are brushless which makes them similar to the motors used on quadcopters.

The two batteries in the latest AUV are 4S batteries, that have a 14.8V nominal voltage, which, despite having a lesser capacity than the old 7S batteries (25.9V), are more adequate for the brushless motors. In fact, with the 4S batteries, there is no need to lower the tension for the motors. Only control and monitoring are necessary.

Each power supply cards feeding the motors has two channels of the same nominal voltage as the battery. Each of these channels control one motor and can be activated or deactivated using a type N Mosfet transistor. A third power channel has been developed with a switched-mode power supply, more specifically a buck converter, to provide 12V to the computer and the DVL. Shortly said, on each power supply card, the system controls the opening of the channels as well as monitors the temperature, the current in the channels, and the tension of the batteries and the channels.

At the center of all the electronical components, the electrical team opted for an onboard computer from Form Factor COM Express. The team combined it with a carrier board allowing PC/104e which made it possible to stack the boards over the computer itself, as shown in Fig. 3, and therefore reducing the quantity of power dedicated cables. It also allowed the development, amongst the team members, of a new expertise concerning the implementation of PCIe material and of its software. In fact, nine printed circuit boards (PCB) on the AUV were custom made the electrical team.

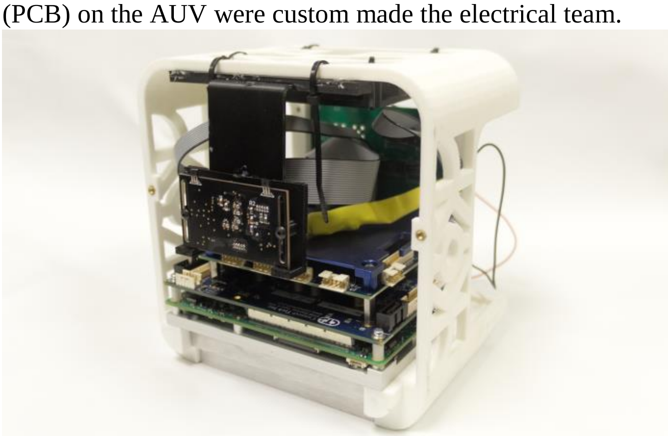

Fig. 3. Onboard computer.

The communication protocol used to rely on a CAN network. Instead, the new AUV uses a RS-485 full duplex network between the 14 devices. This protocol was developed by one of the members of the team and is specifically designed for our application in order to optimize bandwidth usage and help with flexibility.

On the new design, the backplanes are designed to facilitate the interchangeability of the components to be able to modify them and test them easily. Also, since the new design has less backplanes than the old one, there are a lot more wires which makes cable management more difficult especially since the small size of the hull restrains the accessibility.

Concerning the grabber, the old linear, pneumatic actuated arm is replaced by a four-axis robotic arm that uses the ROS middleware with a development tool called Movit. This technology is developed as a final year project for three members of the team. The main advantage of the new grabber it that the fine adjustments can be made by the arm itself instead of having to move the whole submarine as it was the case with the old one. This grants the grabber with an enhanced precision and stability. One of the challenges concerning the robotic arm is that the servomotors chosen have an IP67 rating of waterproofness while IP69 is required to ensure no damage will occur during the competition. As of today, the team is still working on an envelope to increase the waterproofness rating of the motors.

C. Software

As mentioned earlier, the objective is to fully convert the AUV into ROS. As of last year's competition, the following modules were all coded in Java with JAUS as a communication protocol: the submarine's control, the mission system, and the management of the power supplies, of the motors, of the actuators and of all devices. This year, all of these modules have been redesigned in C++/Python with ROS for a communication protocol.

In order to achieve a complete the migration from the old system architecture (AUV6) to the new one (AUV7), it was necessary to develop a new system to control the mission. The new controller mission was developed to be as user friendly as possible. Indeed, the new controller is based on ROS's SMACH library which is a Python library used to manage state machines from the graphic interface. This graphic interface allows the modification of the nature of the mission without typing a single line of code and therefore minimizes the amount of lines that the software team has to type during the competition. Basically, the software team uses state machines to decompose complicated tasks in a series of simple tasks and then uses the graphic interface to put the simple tasks into sequence to their liking. This provides a noticeable advantage during the competition since the software team members need only to arrange the states in the order they want. Therefore, the states are coded prior to the competition according to the tests ran by the team and all the state sequences are managed by SMACH. The Fig. 4 shows a glimpse of the new mission system.

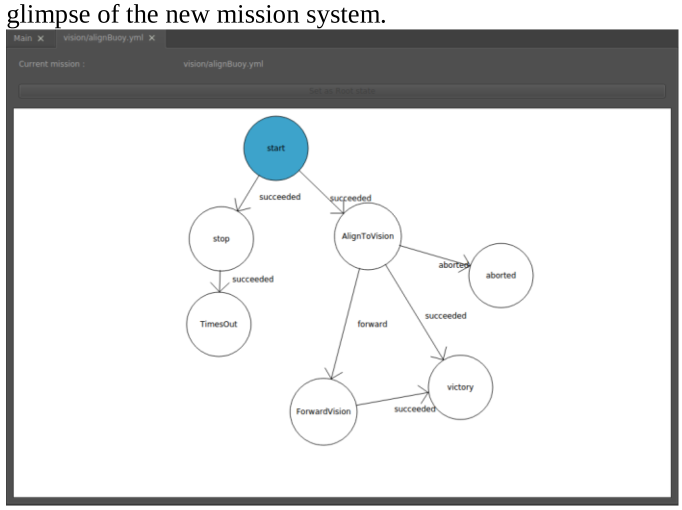

Fig. 4. Mission system.

As seen on Fig. 5, the controller mission lies at the highest level of the AUV7 architecture. On this diagram, each square case is a node, all communications go downward towards the grey cases representing the external devices, and their feedback, or data, goes upwards towards the decisional levels. The blue nodes' layer is the one communicating with these devices. For example, *provider_thruster* tells the thrusters how much power they should output. The green nodes' layer is the decisional layer and sends information to the blue nodes so that they control the external devices accordingly. Simply put, the blue nodes act like translators between the decisional level and the devices. This architecture has the advantage to allow easy improvement and modification since changing a device will only have an impact on the blue node to which is communicates, leaving the other layers untouched. Also, such a decomposition of the processes makes it easy to save *bags* of data used to mock the nodes for out-of-water simulations.

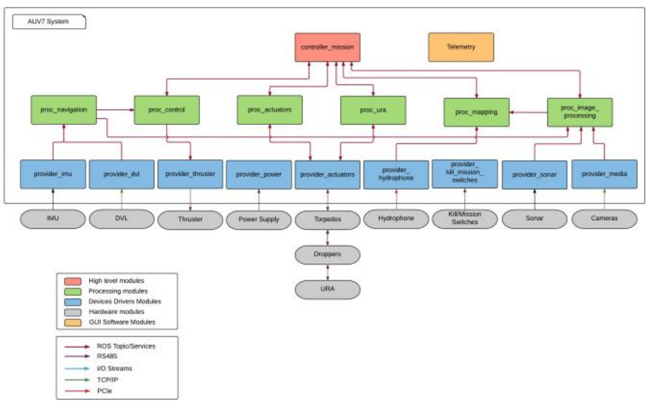

Fig. 5. AUV7 software architecture.

Lastly, by switching the submarine's control to ROS in C++, the telemetry was not compatible anymore. There was therefore no other choice but to make a new one. This new telemetry kept the advantages of the old one (i.e., modularity, functions with plugins) and has some new ones such as the possibility of having more than one telemetry simultaneously on the AUV. For example, three team members could be connected on the submarine at the same time: one controlling it, one managing the vision, and one taking the power readings.

IV. Experimental Results

Since the last competition, despite the many software improvement that had to be made, the choice was made to build a new submarine. Because of this heavy workload, the team was limited to two tests during the fall semester (September to December 2016). These tests were planned principally to allow the new members to experience what a test is like. Afterwards, not a single test was carried out for the whole winter up since the team was mainly working on building the mechanical and electrical components of the AUV.

At the beginning of May, the team started carrying out thorough weekly tests. Fifteen tests have been performed in indoor pools, for a total of approximately 24 hours. The first four were dedicated to the mechanical platform to verify the watertightness of the hull and the static balancing of the submarine. The following testing periods were used to verify the operation of the electronic systems, such as the backplanes and the power supplies, that were progressively integrated to the AUV. In total, about 20 hours were spent testing the electronics.

Since the new mechanical platform was being built, the number of hours of testing designated for software were significantly reduced. To make the best use of these hours, the software team developed a simulator of the submarine's navigation which allowed to test the sequencing of the mission's states. Also, other devices were simulated to increase the stability and the robustness of the software. With such a tight testing schedule, the team managed to squeeze eight in-water tests dedicated to verify the operation of the software.

To make all of these tests happen required some serious pre-test planning to help manage the different projects in progress within the team. This allowed every team member to have a portion of the test to validate his week worth of work as well as gather data for the simulations to be ran before the next test.

V. References

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[2] J. M. O'Kane. (2016, September 6_. A Gentle Introduction to ROS (version 2.1.3) [Online]. Available: https://cse.sc.edu/~jokane/agitr/
[3] G. Gagnon, personal interviews, October 2016.
[4] V. Nerguizian, personal interviews, October 2016.

Appendix A - Outreach Activities

Team S.O.N.I.A. is a proud member of the ROBOSUB community. The team has always been known as one of the most implicated teams in the ROBOSUB community. This is why the team believes in open source and wants to share its knowledge with others. In this perspective team S.O.N.I.A. decided to open the code of AUV7 to everyone on GitHub:

https://github.com/sonia-auv