S.O.N.I.A. Autonomous Underwater Vehicle Concept and Design of the 2016 Prototype

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***Abstract*—Team S.O.N.I.A. is a small team from Montréal, Canada with a long history in ROBOSUB. This year, the team faced many challenges, from the size of the team to allowing the sub to be more aware of its environment. With its small crew, team S.O.N.I.A had to prioritize its goals and keep track of every project's progress in order to achieve timely completion. This year, S.O.N.I.A's achievements include a new camera dome, which provides a better underwater live feed, an almost completed ROS integration with its new software architecture, a semantic map which gives the object's position, thereby enhancing the submarine's environmental awareness, and finally coding the navigation board in C++. Those new features definitely increase the submarine's reliability and robustness. Once again, the team is ready to compete this year at ROBOSUB.**

I. Introduction

Team S.O.N.I.A was founded in 1999 and cumulates 17 years of participation to ROBOSUB. Each year, improvements are made to enhance the submarine's capacity to perform during the obstacle course.

This year was marked early on by a questioning about what the team believed would be the best for future years, not only for this competition. It has been noted that no major electrical nor mechanical modifications have been made over the past few years, mainly because there was none needed. S.O.N.I.A's alumni gave to the future generation an efficient submarine, well suited for the ROBOSUB competition, with a lot of knowledge and ideas to try. This has led to a drawback in S.O.N.I.A's innovation capabilities. Because the team had the submarine to perform, no intensive effort was made to discover a new way of building a submarine. The team decided it was time for a change, but this upgrade had to be done over two years, with a focus on keeping at all time a functional AUV for testing and competing. This year marks the beginning of the new S.O.N.I.A. platform.

After each competition, the team meets and discusses the pros and cons of the approach used during the competition. Failure points and areas of defects have been analyzed and future plans were laid-out for the year to come. This year, the major point that arose from the meeting was the lack of knowledge about the environment in which the submarine evolves. The performance of the platform that performed at ROBOSUB 2015 relied heavily on two devices: the cameras and the Doppler Velocity Log (DVL). If either one of them failed, there was no way team S.O.N.I.A could achieve the course. This has been flagged as our critical failure point. In order to fix this, the team managed to sort out possible software, electrical and mechanical upgrades that should be implemented.

Through all those engineering-oriented details, there was still a major issue that heavily impacted our capacities. Team S.O.N.I.A is composed of at most 12 active students, who must handle mandatory internships, 3 full-length semesters per year, part-time jobs and the submarine. In order to ensure continuity, an initiative to gather newcomers, retain them in the program and train them to the AUV life was launched with success this year.

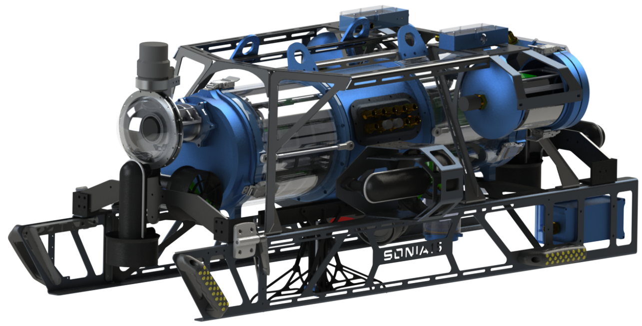

Fig. 1. Team S.O.N.I.A. 2015 Submarine

II. Design strategy

This year's plan is simple: move in the course based on reliable knowledge of the environment. The team plans to have all obstacles' three-dimensional positions mapped dynamically as the submarine navigate through the course. Its purpose is to be self-reliant, with some level of redundancy in navigation and detection, and to have a fail-safe and environment-independent system. Too often, especially last year, the team had a system able to achieve most of the obstacle course at home, and barely able to detect any obstacle whatsoever in San Diego. By introducing a sense of environmental awareness, the team hopes to simplify its algorithms and share the knowledge between different part of the system.

The main focus is reliability, since experience showed that a reliable system is a system on which you can easily build extended functionalities. Since there is a migration to a new system going on, it was a chance to revisit the knowledge basis that was long taken for granted in the AUV design. By revisiting its foundation, the team was able to acquire a much better understanding of the various devices of the submarine, thus building a solid navigation and mapping system. During the design, most parts were oriented towards simplicity and robustness. This is reflected by independent software layers and a well balanced mechanical and electrical system.

These design choices will be reflected in a constant performance from the submarine. The team hopes to create building blocks on which high level of capability is obtained from combining stable and robust subsystems.

A. *Mechanical*

For the design's mechanical side, the team focuses on systems that would improve detection. The major outcome from the research was the integration of the camera dome. The current forward facing camera has a 125 degrees wide-angle field of view (FOV). That much FOV normally comes with a fisheye effect. However, the lens optically corrects this effect, providing well-formed images in the camera. The way the camera tube was conceived did not account for that and was adding chromatic distortion and fisheye effect. With the introduction of the dome, the team hopes to retrieve the quality of the lens, lost in the various optical effects of going through water/plastic/air interfaces.

B. *Electrical*

This year, the sub's electronics custom boards are mostly coded in C++. This design choice has been made to improve readability and maintainability of the software for the entire team. S.O.N.I.A.'s custom boards ensure the best functionality of low-level devices such as the batteries and the thrusters.

C. *Software*

On the software side, a complete remodel has been designed. This remodel focuses on providing stability, repeatability, robustness and redundancy. The migration from a home-made Java-based control system to one that's ROS-based was planned and put into action. The plans call for incremental migration of responsibilities and capacities from Java to ROS. First, a device migration was made, such as the sonar, the DVL and the Inertial Measurement Unit (IMU). The newly migrated devices were interfaced with the Java system and the team verified that the whole submarine was still working properly. By doing so, the team kept a fully functional system and was able to identify problems as they came. The many particularities of the AUV, which had been forgotten, were discovered, documented and handled. The main goal for this year was to have dedicated nodes for mapping obstacle and the submarine's navigation.

The mapping node will include information from the vision element, the active sonar system and the passive sonar system. By running continuously, it will be able to acquire data, store them and process them as the submarine progresses through the course. By keeping past information, it will be easier to weigh incoming information and eliminate noise via statistical analysis. The node will merge different information, using one's reliability to compensate another's lack of precision (e.g. the camera cannot estimate precisely the distance, while the sonar can).

This node is the core of the team's strategy, providing an environment independent system with some level of redundancy. The navigation node would provide a reliable positioning data. By using the three positions-related sensor (i.e. DVL, Magnetometer, Gyroscope and Barometer), the team hoped to filter out noise and discard false data. This will be achieved, in the future, by using a custom Extended Kalman filter that will allow us to reduce the noise on our devices, thus providing more precise positioning information.

D. *Business*

Every team needs new members to pursue its legacy, and thus, recruitment was the main goal of the business team this year. The team had two approach choices: trying to recruit the most people as possible so it can get a strong base of new members for the years to come or try to fill specific needs by recruiting specific people. Since the number of actual members makes it hard to develop a new platform and integrate a large number of new members, the choice was made to go with the strategy of recruiting less new members by targeting our needs. The team came to the conclusion that it did not know how to recruit properly, as all of the current team members had joined by themselves. There was a need to analyze the effects of the different mediums through which the recruitment is made. Bases on the Lean Startup [1] methodology, the business team put forward test-based recruitment efforts, gathering information on what works and what does not.

III. VEHICLE DESIGN

A. *Mechanical*

As mentioned above, the mechanical team had to improve the ability of the submarine to detect objects. One of the first ideas was based on the end of studies project from one of our alumni. The main idea behind the project was to give the submarine the ability to see all the environment around him whenever needed. This idea would materialize in the form of a pan, tilt robotic arm equipped with cameras able to look all around and under the submarine. The team put a lot of thoughts and efforts in trying to develop a first prototype. We were able to achieve a first milestone by being able to control a small set of servomotors and stream from a new type of small factor camera. To help the process of prototyping and quickly building our first small arm, we used 3D printing for all the junctions from the servo-motor and camera holder. This result was really satisfying. However, the real challenge was about to come. The mechanical team needed a way to waterproof all the junction, servomotors and do some cable management. After issuing a few concepts, it seemed that time, costs and problems ahead would be too high for what could be accomplished. Furthermore, the actual conception of the hull and frame of the submarine was not thought to receive the arm. We would need to pull power from the submarine and enclose the board or the small PC to control the arm. Also, most of the time, the frame or the DVL's positioning would cause issues, such as limiting the scannable area of the camera.

The team then explored the possibility of increasing the field of view of the front camera. This would be achieved by redesigning the front camera enclosure on the front cap. Instead of using a flat window, the new approach was to use a dome to provide a bigger viewing angle. This goal here was to reuse the actual cap by replacing only the extrusion in which the camera is mounted. The first step was to find a dome that suited our needs. The choice was a 4.5 inch diameter dome. The goal behind this decision was not only to use the full 135° capability of the lens, but also to eliminate distortion and chromatic aberration. This can be seen in the figure X below. However, this change did not come without drawbacks. First, with this very wide angle view, it is more difficult to isolate one object in the field of view. Also, objects appear smaller, which gives the illusion that the objects are further. These issues were subsequently mitigated by software heuristics.

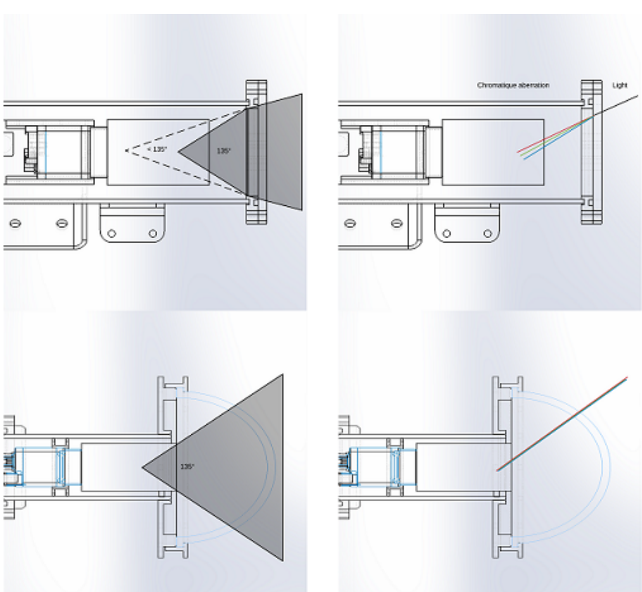

Fig. 2. Diffraction and chromatic aberration correction with the dome

B. Electrical

In order to follow the vision set this year, the electrical team has worked on two major improvements. The first one is the complete refactoring of the navigation board software in C++. The challenge was to be able to structure the code to improve readability without denaturing the previous C functionality. Thus, to overcome reliability problems and make the addition of new electronics functionality easier, the team concentrated its resources in a redundant system. This system is named Dynamic Routing System (DRS). The DRS is an FPGA based custom board which acts like a router for electronic signals. To be able to get recognized and have its signals routed at the right place, the DRS compliant board has to respect a specific form factor. Moreover, the board has to be equipped with a OneWire chip, which stores the board's address. With this system, S.O.N.I.A should be able to add redundancy into its design and add some flexibility for adding special project prototypes, like the pan tilt robotic arm mentioned in the mechanical section. With more pressing issues, and the lack of human resources, members of the electrical team had to implement the DRS in its prototype form.

By doing so, they were able to take on the integration of the sonar, and work on the hydrophone and the CAN network. In recent years, there were more and more issues with our interface with the CAN network controlling some devices of the submarine. The team was able to pinpoint the old KVaser device it has been using for a couple of years by stress testing the network, using simulation and testing it in intensive utilisation condition. The team obtained a sponsorship for a new KVaser device, which solved the stability issue with the CAN.

C. Software

The team proceeded to the bulk of switching from the homemade Java-based system into the ROS-based system. Before any change, a great deal of research and architectural design was made.

There are three layers of the proposed architecture. The lower one is the device and driver layer, called providential. A provider reads and writes to a device, receiving information and translating it into the ROS language, either by topics or services.

The next layer is a processing layer, called "procs". Every node of this layer reads information from the providers and processes them into usable information, providing metadata – in opposition to the raw data provided by the provider layer. The flexibility offered by the ROS framework in terms of dependency management is incredibly powerful. Yet, we wanted to separate the module dependencies in layers in order to provide an even more sustainable system [2]. For instance, the "proc_mapping" node reads from the sonar provider, the media provider and the hydrophone provider to merge all their data into a semantic world map. This map is used in the mission system to achieve the obstacle course. The "proc_navigation"

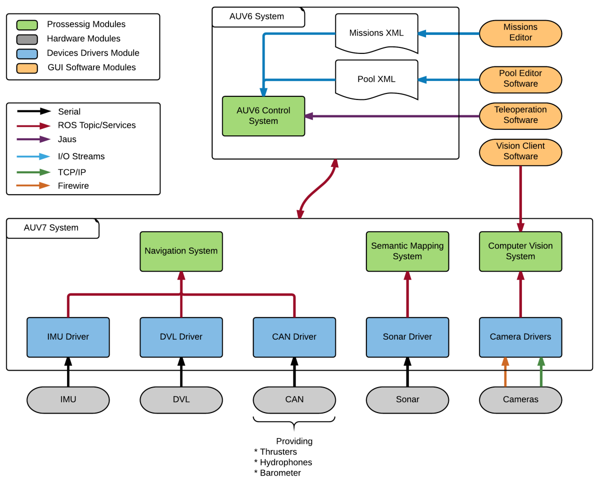

Fig. 3. ROS architecture of AUV6 and AUV7

node reads from the "provider_dvl", "provider_imu" and the barometer (through the "provider_can") to merge information and broadcast an Odometry message, corresponding to a quaternion and a 3 dimensional vector, respectively for the orientation and the world position. The third and last layer is the decision layer. It's ROS implementation has not been well defined yet, as the team focused on the first two layers, as we genuinely believe in the values of agile development. For the moment, the decision layer is the state machine system provided by legacy system AUV6.

In addition to these three layers, we use two others packages categories: the GUI software, mainly implemented as RQT plugins, and the library packages, which can be used by any other ROS package.

There was an extensive use of ROS features to rapidly enhance the capabilities of the different software running on the machine. Namely, RViz was particularly useful for visualizing the various data present on the network. Also, and mostly for the vision server, the team used Dynamic Reconfiguration to enable the configuration of the different camera parameters.

The mission system is still implemented in AUV6, the Java-based control system. However, a big effort has been made to simplify the mission process, separating them into very small and specific task. This helps understanding the submarine's behavior and will facilitate transition to a new ROS-based mission control.

On the mapping side, the team built a solid foundation on which high level algorithms could be easily added to the node without modifying the software architecture. A team member has been in contact with professors who have expertise in adjacent fields, such as medical imaging and computer vision. Before those appointments, basic detection algorithms were used, but this was discouraged by professors, who recommended statistical distribution analysis.

Therefore, with these new bases, algorithms and decision trees have evolved to provide a more accurate detection process[4]. As the mapping node uses data from many sources, it is more susceptible to have problems linked to another node. During the summer, mapping has been tested in different environments. With that, the team identified the different causes of sonar noise and worked to treat it in a right way.

D. Business

With a small business team, the first action was to recruit new business team members. Actual and past members of the team spread the word to their contacts and in their classes. The result was immediate with the recruitment of two new members. The team worked hard to integrate them as quickly as possible in order for them to help the other departments grow.

A new recruitment campaign was launched, which focused on the needs of the different departments. After the campaign, a new member was added to the mechanical team. Obviously, the efforts put on recruitment did not yield the desired effect, as the team has not reached its goal for all departments. However, members have learned from the recruitment operations and will continue their work to ensure S.O.N.I.A.'s legacy.

IV. Experiment results

Team S.O.N.I.A. tries to have as much time as possible in the pool. Each test is carefully planned with specific objectives. By doing so, the team can easily see and analyze its progression during the year. For example, during the fall semester, the team mainly focuses its work on developing new features for the submarine. Tests are less frequent and are used to evaluate performance of new software, and electrical and mechanical components. During the winter semester, tests are conducted every two weeks. This gives the team more time to work on the submarine in between tests. Those tests are used to stabilize the platform and prepare it for the missions and development competition. Finally, during the summer semester, tests are performed at least once a week and time is used to develop the mission and finalize everything for the competition.

During the tests in the pool, the dome stood to its promise as it helped improve the quality of the image. More light can be captured by the camera's sensor, allowing a better image quality in general. The fact that the light hit the dome with a square angle eliminated two other problems. First, the diffraction creates a curvature in the image, which caused problems when came time to identify straight items such as fences. Second, the chromatic aberration which resulted in a fuzzier shape with decoration of the contour.

The software migration to ROS platform has been completely tested and validated during the last 4 months. Although it is not complete, the developed software are now completely reliable and allowed us to develop more efficient missions for

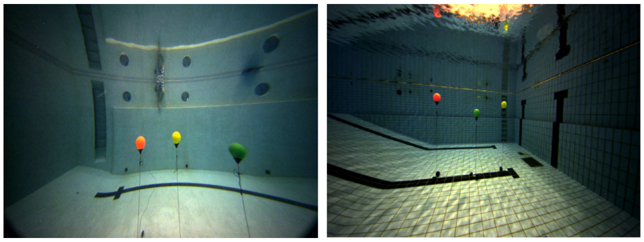

Fig. 4. Transformation of the quality image

this year's competition. This is a major improvement, as it will enable faster development of future functionalities.

Tests on mapping have resulted in the definition of a semantic map. The semantic map is built from data relative to mission objects such as position, size, orientation. In future work, integration of the vision and hydrophone to the semantic map will add data on color, finger position and finger orientation. With those additions, the mapping system will be a great tool for the mission. The fig 5 is a visual representation of the semantic map only used in debug, since the mission only has to know data from map objects. The map is printed in meters and is squared in increment of one meter. The bounding rectangle act as a region of interest which is manually configured. The middle circle is the origin and the three practically aligned circles are buoys. While the "proc_mapping" application is running, the small dot is moving and is representing the submarine.

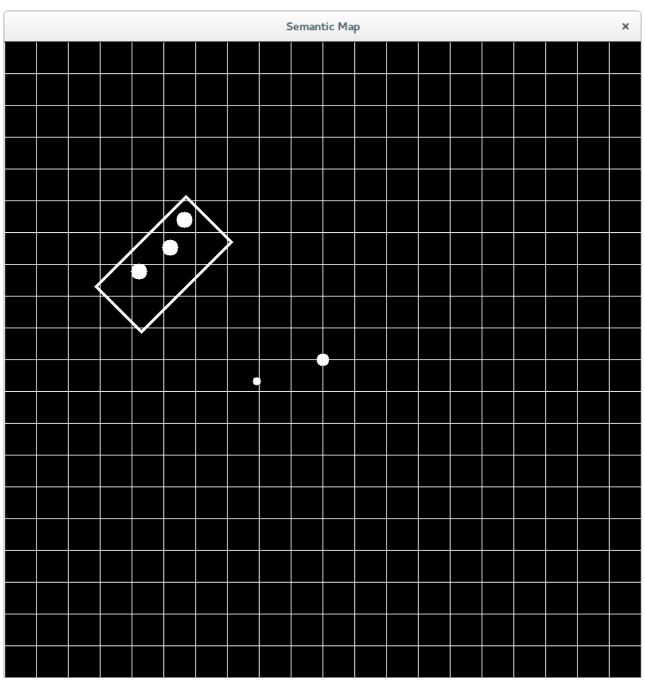

Fig. 5. Sementic map with ROI

The electrical platform is now as reliable as it was in the past years, now running on C++ software. This has been validated during all tests that we've performed, since the electrical boards are constantly used regardless of which mission or functionality we enable.

Many mission executions are now working efficiently. This means the team is ready to get a podium at the competition, and still have time left to develop and test.

V. Acknowledgment

Team S.O.N.I.A. would like to thank all its sponsor for their support during this year. The team would like to give a special thanks to *École de Technologie Supérieure* for their continuous support for the past 17 years.

Team S.O.N.I.A. would also like to give a huge thanks to all its alumni for their work and legacy.

A special thanks to our new sponsors:

- Altium : For their PCB design software
- Kvaser: For the new Kvaser
- Teledyne Dalsa: For their new camera

References

[1] RIES, Eric. The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses. Crown Books, 2011.

[2] LARMAN, Craig. UML 2 and design patterns. Pearson Education, 2005

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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 believe in open source and want to share its knowledge with others. In this perspective team S.O.N.I.A. decided to open the code of auv7 to everybody on GitHub :

https://github.com/sonia-auv