S.O.N.I.A. Autonomous Underwater Vehicle
Concept and Design of the 2014 S.O.N.I.A. AUV Platform

Web site: http://sonia.etsmtl.ca

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Team S.O.N.I.A. is an undergraduate team of engineering students from *École de Technologie Supérieure (ETS)* in Montreal, Quebec. S.O.N.I.A. stands for "Système d'Opération Nautique Intelligent et Autonome", which translates to Intelligent and Autonomous Nautical Operation System. The purpose of the team is to build an Autonomous Underwater Vehicle (AUV), which is built to perform an obstacle course at the 17th annual Robosub competition held in San Diego, California.

The course simulates real tasks that would be assigned to an AUV in real life, such as pipe inspection, precise navigation, image and pattern recognition and acoustic localisation. In order to accomplish those tasks, the submarine has several navigation sensors, such as an Inertial Navigation System (INS) and a Doppler Velocity Logger (DVL). It is also equipped with two cameras, mechanical imaging sonar and four hydrophones. In order to move in the water, the submarine uses six brushless thrusters, allowing navigation in five degrees of freedom. Major improvements have been made to the control system, resulting in the most precise navigation system Team S.O.N.I.A. has ever had.

QUICK FACTS

Dry weight:	39 [kg]	***Thrusters:***	6x SeaBotix Brushless HPDC1507
Dimensions (LWH):	1.270 x 0.508 x 0.406 [m]	***Cameras:***	2x Unibrain Fire-i board Pro
Max speed:	1 [m/s]	***Sonars:***	1x Teledyne Explorer DVL
Max depth:	30 [m]		4x Brüel & Kjær Hydrophone
Degrees of freedom	Surge Heave Sway Yaw Pitch		1x Tritech Micron DST Sonar
Autonomy:	4 to 5 [h]	***INS:***	1x SBG IG-500N

This year is S.O.N.I.A.'s 15th anniversary. It has been contending in Robosub since 1999. The team is composed of 20 students from different backgrounds, studying in mechatronics, electrical, mechanical, industrial, logistics and software engineering.

TEAM OBJECTIVES

- Recruit and prepare S.O.N.I.A.'s future
- Reach a better hardware stability
- Optimize the control system
- Prepare next year's big changes

TEAM ORGANIZATION

The team is divided into four teams. The management team oversees budget planification, testing schedules, external communications and event organization. The mechanical team is tasked with the conception, fabrication and installation of the different parts of the submarine. The electrical team designs all the subsystems responsible for power management, actuators and thrusters control, as well as the overview of the inter-device communication. Finally, the software team is responsible of maintaining the current software suite, managing the information technology systems (IT) and developing the autonomous aspect by using the AUV captors. The team captain directs the team effort, making sure everyone steers in the same direction. He makes sure all important information is shared across departments, and enforces the different projects deadlines and due dates.

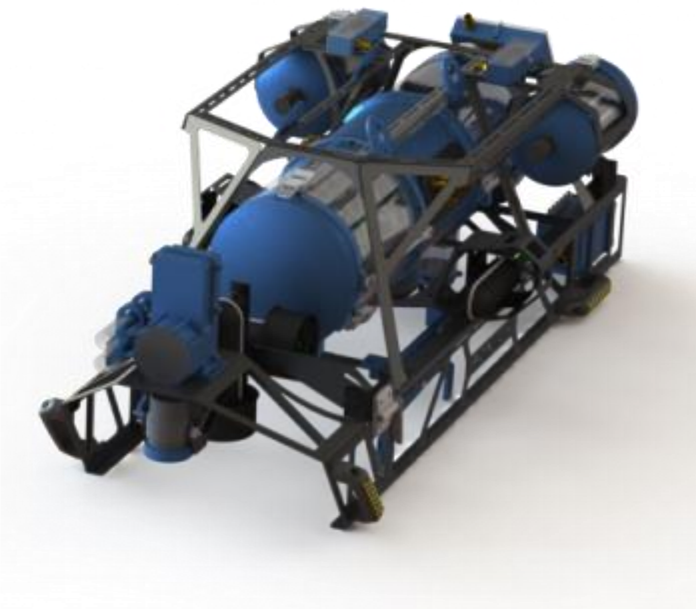

Figure 1 – Submarine's front port view

METHODOLOGY

Team S.O.N.I.A. keeps the same robust methodology year after year. At the end of each competition, the team holds a general meeting to assess the progression made during the year. It is also the occasion to discuss future development and improvement ideas, aggregating them into a project management software. The different projects are then regrouped by department and difficulty level. This way, when a new member joins the team, the team is able to quickly find a suitable project for him.

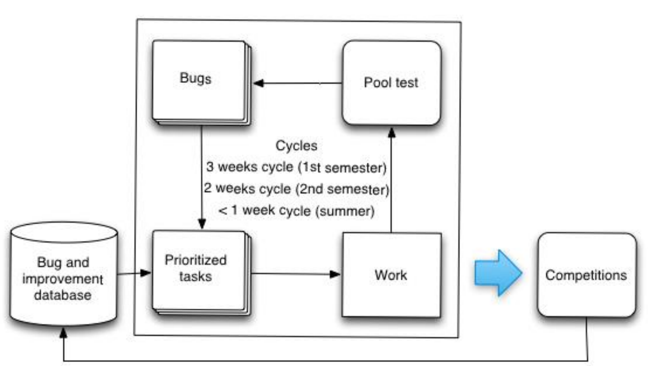

Figure 2 - Development strategy

TESTS

Team S.O.N.I.A. follows a three semester development schedule. During fall, most members leave for an internship semester, which is required by ETS. During those four months, we maintain a tri-weekly testing schedule. During winter, we ramp up the testing to a bi-weekly schedule.

Being based in a nordic country, S.O.N.I.A. have to wait until summer to start outside testing. During this period, the test frequency is increased to one weekly pool test minimum and multiple tests in an outside olympic rowing basin.

COMMUNITY OUTREACH

The team tries to reach different communities by helping other teams in their development efforts. It also answer to any question or help request sent via S.O.N.I.A.'s website. Last year, the team started working on a new computer vision platform (SeagoatVision), distributed freely under an open source license. The motto has always been "We are competing against the obstacle course, not the other teams".

SEAGOATVISION COLLABORATION

To complete Robosub's obstacle course, multiple elements are needed, such as cameras. The conception of SeagoatVision was done in collaboration with the scientific group Capra, another ETS group developing an autonomous ground vehicle. The team encourage different teams from the circuit to use this platform and contribute to it, as it will increase the community base and ease development for everyone. <seagoatvision.org>

MECHANICAL DESIGN

MAIN HULL

The main hull's form is cylindrical, because it is the best shape for the submarine's needs of multi-axis movement. The DVL and the INS are in the middle part, close to the gravity center, providing good balance. The main hull was fabricated with two quick accesses in the front and in the back.-Those accesses allow for fast removal or replacement of the onboard PC and electronics.

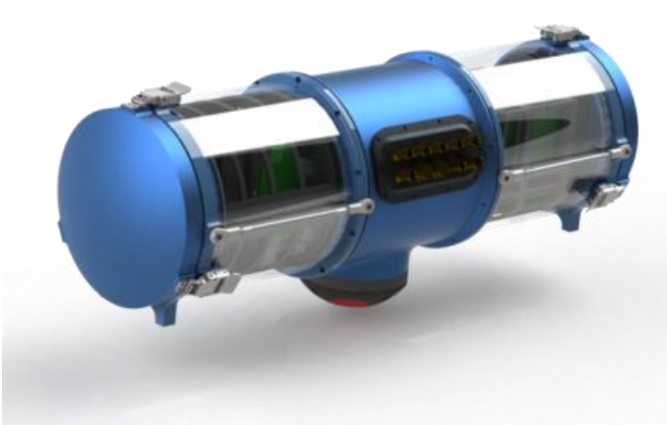

Figure 3 - Main hull

FRAME

The mechanical team completely redesigned the frame to be more efficient in the water and easier to handle during the transportation of the vehicle. The end result is that the frame is lighter than ever. Both the front and the back depth and heading motors are mounted on a movable support. This enables the team to quickly and safely access inner electronic components.

Figure 4 - Frame

GRABBER

The grabber was redesigned to be simpler and to provide a better reach for smaller objects. The main goal was to come up with a design simple enough to repair and assemble in any situation. A bigger pneumatic cylinder was used, because the grabber's moving part needs to travel a larger distance than in the past.

CAMERA ENCLOSURE

This year, Unibrain cameras have been chosen for the final design. Their "L" shape constrained the mechanical team in their front camera enclosure geometry choice. Nonetheless, the final design is lightweight, and has enough room to allow flexibility in the optical lens setup (different lens apertures). The torpedo launcher system is directly attached to the enclosure, aligned with the center of the axis of the camera lens, minimizing the displacement calculations when firing.

PNEUMATIC SYSTEM ENCLOSURE

The pneumatic system was designed using a manifold model. This results in a reduced footprint and a lighter system. The enclosure is strategically located in the lower portion of the frame, using its weight to limit the propension of the submarine to roll.

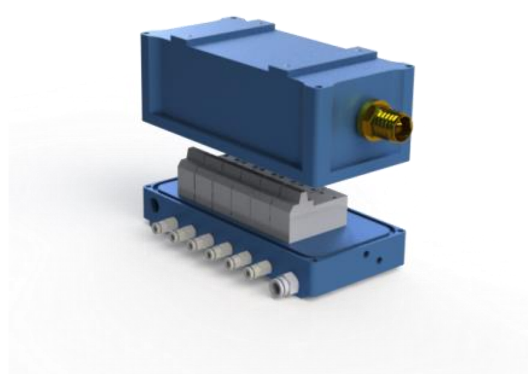

Figure 5 - Pneumatique enclosure

BATTERY ENCLOSURES

The device's batteries are installed in two separate cases. They are placed above the center of mass, on each side of the vehicle, to add to its floatability. Each battery enclosure is mounted on the external frame, which allows for easy interchangeability.

BATTERY CHARGING SYSTEM

A new recharge box was designed to fit the battery system. This allow for a safe way to charge the batteries and eliminate wire and connector manipulations.

HYDROPHONE

For the first time, 3D printing technology was used in the fabrication of the hydrophone enclosure. The goal behind this decision was weight reduction and faster manufacturing time. The position of the hydrophones has also been altered. They are now found under the main hull, protected by the frame.

Figure 6 - Hydrophone enclosure

ELECTRICAL DESIGN

The electrical system acts as a secondary treatment unit of the control system (main computer), processing data from the sensors and managing the communication for all the devices that can't be directly controlled by the main computer.

The electrical system has to be robust so it can resist the harsh conditions of a marine environment. As main design requirement, the electrical system must be easy to maintain and modify. Having such requirements brought Team S.O.N.I.A. to a backplane system, which enables direct access to electronics and easy PC replacement.

SYSTEM OVERVIEW

In order to accomplish its tasks, the submarine must be equipped with a variety of sensors. The position is monitored by a DVL, a depth sensor and an INS. The obstacles are then detected with the cameras, the sonar and the passive sonar system. Following the acquisition of all the data, it moves toward its goals with its six thrusters. Finally, the pneumatic system allows many actions to take place like grabbing objects and launching torpedoes.

Since the wide variety of devices aboard, the submarine requires different voltage and power. The power management system spreads the electrical demand across different power channels. Every system is located inside the main hull. The commands are given by the computer, but in case of any emergency, the diver can easily kill the submarine with the kill switch. A mission switch is also installed, enabling an easy activation of the autonomous mode.

PASSIVE SONAR SYSTEM

One of the major tasks an AUV would be asked to do is to retrieve an acoustic beacon, like a flight recorder. For the competition, one of the main course challenge is locating such beacon, emitting a specified frequency every two seconds. Beacon's localisation is made by a custom passive sonar system, made of an array of four hydrophones. The distance between each hydrophone is half a wavelength of the highest frequency the submarine would have to find. This year, the hydrophones are placed at the back of the AUV, protected by the frame. The signals from the beacon are passed through a two stage amplification system, separated by a 10th order low-pass filter.

Those amplification stages have a 190 gain and 100 gain respectively. After those analog processing, the signal is digitized to be treated through a Digital Signal Processor (DSP). Since the hydrophones are constantly listening, a Fast Fourier Transform (FFT) determines when the beacon emitted its frequency, by looking at the frequency's magnitude. Further treatments are made on each hydrophone signal in order to have reliable, almost noise-free data. The signals are compared to a reference in order to retrieve the heading and the elevation of the beacon.

Dock Box

To improve efficiency during pool testing sessions and facilitate interactions with the vehicle, a waterproof, compact and portable server was designed. It connects the AUV tether into its integrated network switch, and broadcasts the signal over WiFi with the integrated wireless router. This setup allows all team members to have direct network access to the AUV. The main objective of this portable server is to host all the source code, which will allow the team to commit and perform changes without the need of an internet connection.

An integrated computer with its own screen can be powered up in order to control the onboard server, which offers external Solid State Drive (SSD) interfaces to directly plug in the AUV drives for analysis. The keyboard and the screen can also be plugged into the AUV's main computer to allow for quick and improvised debugging sessions when there is no communication with the vehicle.

Figure 7 – Dockbox

The box is powered by two 14.8V batteries in parallel. Each battery has a capacity of 10Ah. It is also equipped with a built-in battery gas meter, which displays the batteries' current voltage using a character display and a LED array.

Controller Area Network

In order to communicate with the submarine's devices, all messages are sent through a CAN bus and processed on custom boards. In order to send data on the bus, the computer sends every command through a USB-CAN Kvaser. The communication passes a series of steps in order to coordinate the devices present, such as identification requests.

Navigation Board

The navigation board receives the commands from the onboard computer through the Controller Area Network (CAN) bus and dispatches them to devices such as the light, the torpedo launcher, the sonar rotator, the dropping mechanism and the active grabbing system. Its main goal is to give directives to every active device and transmits voltage, temperature or pressure to the telemetry through the CAN bus. Moreover, the thruster's rotation speed and direction are controlled by the Inter-Integrated Circuit (I2C) protocol. The navigation board enhances the modularity of the vehicle by interfacing the computer and the submarine's devices.

Power Management

The Power Management Unit (PMU) is responsible for the distribution of power to every sensor and devices of the vehicle. It receives its power from two 25.9V batteries of 10Ah connected in parallel. Each device needs different voltage, so the power board needs to condition the voltage in three different values, such as 24V, 18V and 12V. The PMU controls a total of nine channels. The thrusters are separated over three different 24V channels. The DVL has it's own dedicated channel of 18V. The light, pneumatic system and the PC are each on a separate channel. Furthermore, there is two 12V channels for the electronics.

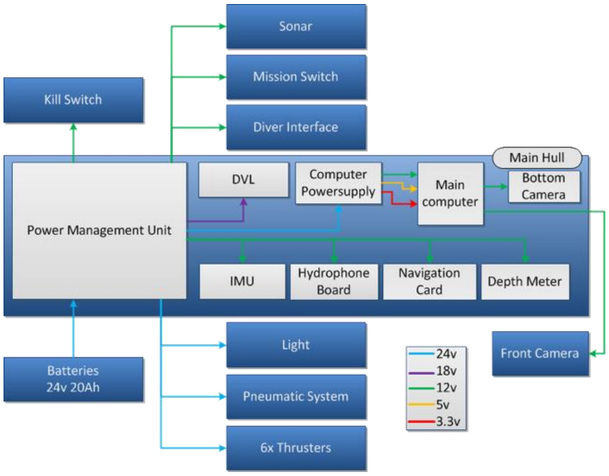

Figure 8 - Power distribution

The six thrusters use the raw voltage of the batteries but they have a current limitation on their respective channel. The channels are protected from overvoltage and overcurrent. Furthermore, divers can manually shut them down at any time with the kill switch. When it is activated, the kill switch sends a square wave signal to the power board. After analysis, if the board is not able to detect it, it will deactivate the channels controlling the active devices that could damage the submarine such as the thrusters and the actuator.

DIVER INTERFACE

S.O.N.I.A. has an on-vehicle graphical interface in a separate enclosure. Its purpose is to display useful information to the diver such as battery voltage, current mission state and sub-states, as well as the pressure of the pneumatic system. The team has the ability to communicate with the driver by displaying text on the screen or ask questions with predetermined answers which can be triggered by tapping on the screen.

KILL/MISSION SWITCH

Both the kill and mission switches work with the same system. A magnet is placed at the end of a pin and a Hall effect sensor can capture the magnetic field. This pin has two grooves retained by a ball detent, thus locking it in the “on” or “off” state. The kill switch shuts down the devices’ channels of the PMU and the navigation board receives a CAN message from the mission switch, which is sent to AUV6. The mission switch, when activated, also send a CAN message to the control system, which then activate or deactivate the mission control.

CAMERAS

This year, there are two cameras Unibrain Fire-IX on the submarine, one facing downward and the other one facing front. The new front camera enclosure enables the use different lenses, optimizing the output of the vision system. Those cameras also use less I/O bandwidth, improving the tolerance to high speed signal failure, a constant menace with altered FireWire cables and homemade splices.

BACKPLANES

The backplane system gives the opportunity to have more maneuverability because all the wire connecting the different component are contained on a Printed Circuit Board (PCB). The vehicle is equipped with three backplanes. The central backplane is the connection between the electrical and the PC backplane. It receives power from the batteries and all external signals from the sensors and devices.

Figure 9 - Backplane system

Those signals come from the watertight connectors which interface the main hull and its external components. The electrical backplane connect three PCBs to the system: the navigation board, the hydrophone board and the power board. The motherboard, the hard drive, the RAM memory, the KVaser, the droppers and the down-facing camera are located on the PC backplane.

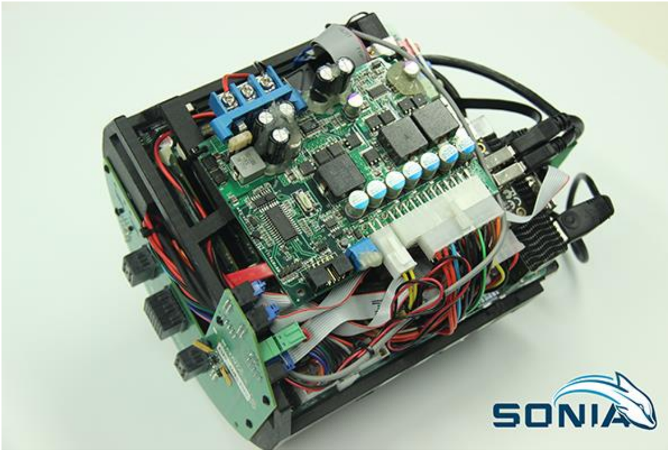

Figure 10 - PC backplane

Doppler Velocity Log

At the center of S.O.N.I.A.'s navigation system resides the Teledyne RDI Explorer Doppler Velocity Log (DVL). Used as a bottom-tracking device, in combination with the Inertial Measurement Unit and a software-emulated Honeywell HMR3000 Digital Compass, it allows for precise position tracking of the submarine in all situations.

The Explorer DVL consists of two physical components. The first one is the head, which contains the piston transducers to emit and receive the sound waves. It is located on the outside of the main hull and faces downwards towards the basin floor. The second one is the electronic unit, placed inside the main hull. Its job is to process the information sent back by the head, and to adjust it according to the various other information regarding the AUV attitude (yaw, pitch and roll) that is fed to it via external sensors (namely the INS and the compass).

The DVL is constantly polled by the AUV6 operating system in an independent control loop running at 14Hz, providing frequent updates on the submarine's current speed. As it is a relative measurement device (which measures speed, not position), the team need to use an arbitrarily fixed point as origin of a cardinal coordinate system to accurately map the AUV position in the pool.

Inertial Measurement Unit

The navigation system also uses the SBG Systems IG-500N Industrial Grade Inertial Navigation System with Embedded GPS (OEM version). This Inertial Measurement Unit integrates three gyroscopes, three accelerometers and three magnetometers to precisely measure the submarine's attitude in every rotation axis (yaw, pitch and roll).

Depth Sensor

The last physical component of S.O.N.I.A.'s navigation system is the depth sensor. In fact, being able to know with precision the depth of the vehicle at any moment is a crucial characteristic of an AUV. A simple pressure sensor is used to calculate the pressure exerted by the total mass of the column of water above the submarine. Using Pascal's law of pressure, it is possible to calculate the depth of the vehicle.

Thrusters

The submarine is equipped with six SeaBotix BTD150 brushless thrusters. Each of these thrusters are controlled using an Inter-Integrated Circuit (I^2C) bus. This enables uniform and accurate propulsion, since it allows for individual control of each thrusters' rotation speed. Each thruster is paired with another thruster from a different axis to form three distinct channels. This setup increases the power management efficiency and helps preventing overload.

Onboard Computer

The AUV is powered by a fully-featured x86 computer. Its main task is to run the AUV6 in-house submarine operating system, the CAN server and the SeagoatVision vision server. This year, the team upgrade the computer to a Jetway NF9G-QM77 motherboard with Intel Core i7-3610QE (2.3GHz Quad-Core with Hyperthreading) and paired with 8GB of RAM. This increase in processing power and computing resources allows the software team to go even further in their development efforts.

For storage, a single Solid-State Drive (SSD) is used for both the operating system and data logging. The OS currently powering S.O.N.I.A. is a slightly modified Ubuntu Server 14.04 LTS, an upgrade from the 12.04 version used last year.

Sonar

This device acquires data on both vertical and horizontal axes in order to detect surrounding objects. The data is then sent to the computer using RS-232 communication protocol and buffered. The scanline are merged into global coordinate, allowing the mission coordinator to use these global information together with the map. The sonar provides a reliable distance estimator, adding to the data available to the system. A position estimation system is a major advantage for tasks that require close interaction with an object.

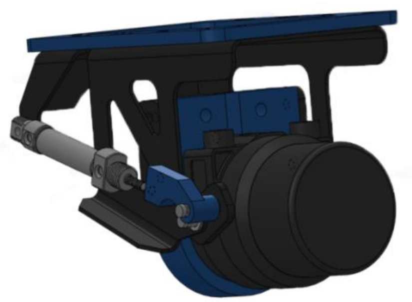

Figure 11 - Sonar

Software

S.O.N.I.A.'s software architecture is divided in three main sections:

- CAN/(TCP) server
- SeagoatVision Suite
- Control System (AUV6)

Every year, the software team is in charge of improving and maintaining these components. After last year's competition and some major changes in the team's core, a decision was made to only undertake minor improvements on the software, and concentrate the efforts on consolidating the knowledge of the current platform to reach a better competitive level.

The following diagram explains the relation in between the major component and tools:

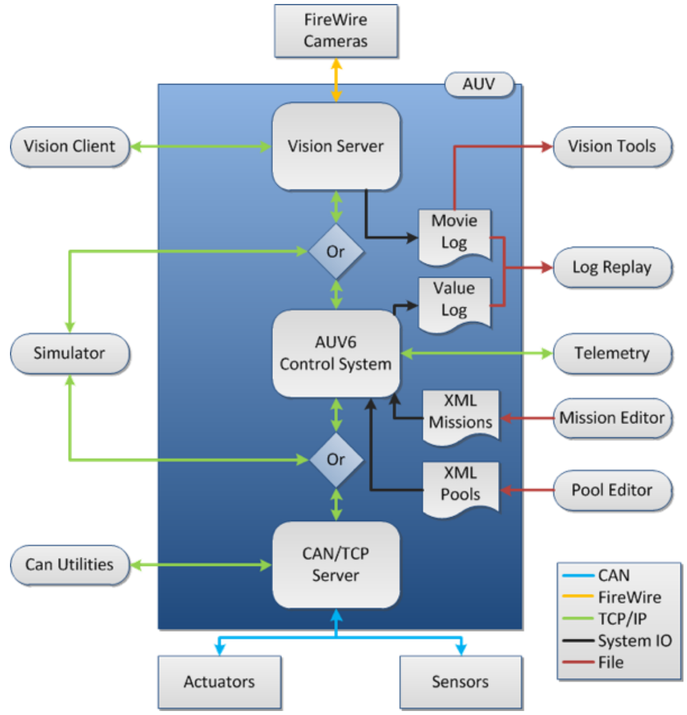

Figure 12 - Software architecture

Throughout the years, the team has developed a series of tools to help the development of the project:

- CAN Workbench
- CAN diver interface
- Hydroscope
- Log replay
- Mission Editor
- SeagoatVision Suite
- Simulation system
- Telemetry

CAN TCP Server

The TCP server links the onboard computers to the CAN bus. It broadcast and dispatches the CAN messages on the bus.

CAN Workbench

The CAN Workbench application is an interface between the user and the CAN bus. It monitors every message, emulates electronic boards and enables debugging capabilities of all devices attached to the CAN server.

CONTROL SYSTEM

The current control system is based on the finite state-machine model. It is the 6th of its kind and was named AUV6. The control system was developed using the JAVA technology and the Eclipse workbench, upon which the mission edition software suite is based.

Mission sequences are built on top of the abstractions used by the control system, therefore making the mission's creation process much faster and efficient. This creation process starts with defining what kind of maneuver will be required by the vehicle to perform a specific task. The different sensors and actuators connect to the control system using the CAN/TCP protocols or serial interface. A mission file is then created containing the logic in form of code lines using a combination of XML and JAVA to communicate with sensors and actuators.

Each of these mission files is then viewed as a block-statement in the state-machine model, which allows to connect several blocks together to create a chain of events, which will allow the vehicle to complete required tasks.

The system's cadence is 14Hz, which is twice the DVL's speed. Every time the system loops, data is logged into the system files, allowing to replay everything in the Log-Replay software. AUV6 also hosts every telemetry services and communicates with the SeaGoat vision server.

HYDROSCOPE

The passive sonar system needs an extensive user interface because of the numerous settings that need to be adjusted. The hydroscope was developed to fulfill this role. Connecting directly over CAN/TCP, it allows the operators to change settings and different combinations of values. These values are the building blocks of the algorithms and thresholds used to detect the wanted frequencies. It displays the data received into graphs and lists the different values for the operator to find the optimal values and settings.

LOG REPLAY

The log replay software provides an interface similar to the telemetry's. Although the look and feel is almost identical, the data used by the log replay is not live data. This data comes from log files recorded during previous runs or tests. These log files are then loaded into the log replay and the data can be analyzed more thoroughly with common stop, play and rewind features.

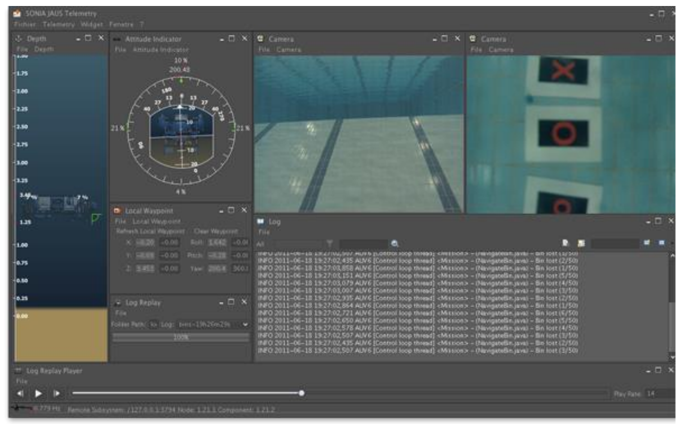

Figure 13 - Log Replay interface

MAPPING

The mapping is realized through a series of sensors. It allows the submarine to locate obstacles and position them according to its local coordinates. The positioning system also yields global coordinates, hence providing a way to keep information relative to a map. A zone system has also been implemented in order to eliminate the majority of false positives encountered. The information is then used by the mission manager in order to accomplish the obstacle run.

MISSION EDITOR

The mission editor is an in-house software deployed as an Eclipse plugin. The goal behind its design was to simplify mission development, edition and adjustment. In its raw format, a mission is simply a collection of states arranged in a predefined order and stored as an XML file. Working with an XML file is not intuitive, and doesn't provide a good abstraction of mission components. Instead of writing XML mission files, the mission editor provides a graphical interface and allows to work with a UML representation. The UML is then converted into an XML file when saved.

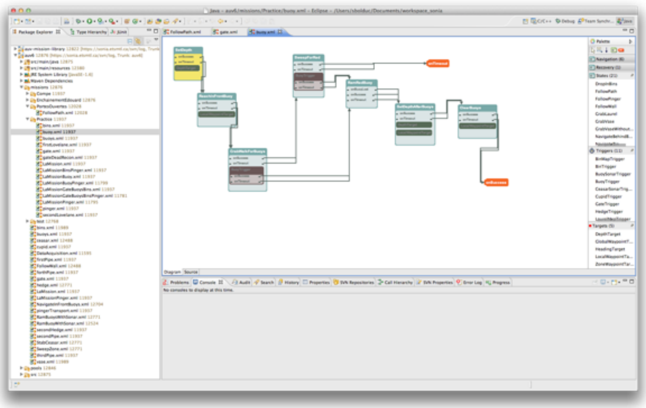

Figure 14 - Mission editor

This customized mission editing workbench was developed using Eclipse's user interface features, giving the opportunity to any member of the team to create and edit missions. The editor offers several drawing and property tools to fully edit and customize a mission sequence and its properties. The Eclipse environment also handles exceptions and user-related events ensuring the integrity of the tool.

Thrusters Control System

The propulsion system of the submarine is driven by a PID control system. Each degree of freedom has its own independent control loop, allowing for more fine-grained adjustments. All the parameters are directly accessible and modifiable in real-time through the telemetry software suite.
This year, a lot of efforts were put into bench testing and data analysis of the thrusters response to improve the mathematical model of the control system. The end result is a new, simpler controller design that allows for a much better control over the AUV propulsion. This allows for the submarine to be more stable and less prone to overshooting than in the previous years.

Telemetry

The Joint Architecture of Unmanned System (JAUS) telemetry is the tool to monitor all devices from the submarine in real time. Its standard message structure has been extended to satisfy the team's needs. It displays many different widgets that communicate using this protocol. Each device has its own widget, although some of them have been regrouped since correlating the data forms more useful widgets like Navigation map, Attitude indicator, Mission, Pool and many more. The JAUS is also capable to act as a command center to operate the submarine.

SeagoatVision Suite

Vision Client

The vision client is a graphical interface developed using QT library in Python. It allows users to control processing done by the vision server. It handles filterchain modification, filter calibration, media selection and control, recording and live recompilation. This tools focuses on providing fast development capabilities and efficient tools for the vision team to work with.

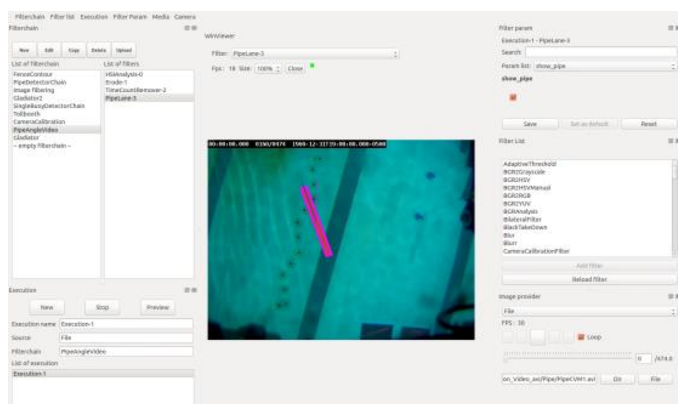

Figure 15 - Seagoat Vision client

The client is also the tool used during tests to calibrate filters. Live calibration gives access to the dynamic result of vision computing, with minimal latency time.

Vision Server

SeagoatVision is the new vision server, developed in Python to handle many simultaneous clients. Within the vehicle, the mission control and the vision client are connected to Seagoat server. It can execute filters in C++ and in Python, and gives clients easy access to filter parameters.

The filterchain editor provides an interface to add, move and delete filters from the chain. It gives the user the ability to manipulate the order of processing to its taste. The dynamic filter reloading support enables the vision team to modify the code of any filter and see the result without having to close the server. Media selection and control gives the ability to choose the source in real time (front camera, bottom camera, file, etc.). It also handles, for the cameras, control of hardware and firmware parameters, such as shutter time and white balance.

This tool uses standard technology to allow for easy modification by everyone, like Json for configuration, JsonRPC to communicate with client, ZeroMQ socket to send information to client, FFmpeg to record video and OpenCV to transform images.

Vision Filters

The vision filters are built on top of OpenCv 2.4.8 library and S.O.N.I.A.'s own vision lib. It is a mix of built-in functions, common to computer vision, and custom made algorithms that are more attuned to the reality of underwater imaging. Filters can be coded either in C++ or Python. This flexibility allows for performance and optimization on a per-need basis. This year, more intelligence has been implemented in filters, using neural network in a different way than previous years.

Vision Library

On top of OpenCv and Fann library, a new vision library was created this year. This library deals with the obstacle as objects, not images from the camera. The approach enables a whole new range of possibilities from intelligent algorithms to object tracking and object mapping. It also provides an easier interface, allowing the use of neural network for more advanced treatment than just image recognition, like feature-based recognition. This gives the possibility to add a time dimension to the algorithm, enabling far more robust detection.

Conclusion

This year, Team S.O.N.I.A. has focused on its legacy, giving project to new members, putting a lot of efforts into improving the documentation process and pushing recruitment. This transition year allowed the team to analyse and understand the needs in prevision of the upcoming S.O.N.I.A. platform.

The mechanical team learned from last year frame design valuable lessons. They came up with a simple design that is both lightweight and efficient. The electrical team took a major step towards hardware stability by resoldering each board and implementing minor and ergonomic fixes. The software team enhanced the vision library and stabilized and improved the vision server. It also refactored the control system, resulting in much simpler control algorithms and better response.

S.O.N.I.A. is proud of what it accomplished with this year platform. With a new team, a solid vehicle and precious support from previous members, the team is ready to take the dive and show what it can do.

Acknowledgement

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- **Gold :** Bruël & Kjaer, Coop ÉTS, QNX software systems, Teledyne RD Instruments
- **Silver :** AssetScience, Association des ingénieurs-conseils du Québec, Digikey, Design Numérik, Gestion Férique, Isabelle Carrier, Minicut International, MultiCam Québec, Rio Tinto Alcan, Savoir-Faire Linux, Solaxis, Theia Technologies, Thomas&Betts
- **Bronze :** Verdun Andizing, Esterline CMC Électronique, Hoskin Scientifique, Intel, Loctite, MicroStrain, Ocean, Parc Jean-Drapeau, Vortex CM LABS

2014 Team Members (Grouped by Sub-Team, in Alphabetical Order)

- **Team Leader:** Jérémie St-Jules-Prévost
- **Sub-Team Leaders:** Mathieu Benoit, Vincent Desjardins
- **Treasurer:** Marc-André Bolduc Goulet
- **Administration Team :** Marc-André Bolduc Goulet, Florence Bouchard-d'Haese
- **Software Engineering Team:** Mathieu Benoit, Mathieu Fortier, Frédéric Langlois, Etienne Boudreault-Pillon, Vincent Renauld-Lépine, Karl Ritchie,
- **Electrical Engineering Team:** Racha Bouzidi, Jean-Philip Delorme, Vincent Desjardins, Élodie Couturier, Jean-François Simard
- **Mechanical Engineering Team:** Julien Carrier, Antoine Dozois, Anh Nam Phan, Pierre-Antoine Roy, Pierre-Olivier Thérien

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