Concept and Design of the 2013 SONIA AUV Platform

Web site: http://sonia.etsmtl.ca
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Team SONIA (Système d'Opération Nautique Intelligent et Autonome), from École de technologie supérieure, is an undergraduate student association that builds an Autonomous Underwater Vehicle (AUV) to perform at the 16th annual Robosub competition held in San Diego, California. The competition consists of an obstacle course of real life tasks that an AUV could do such as following pipelines, navigating through underwater gates, mapping buoys, launching torpedo-shaped markers, dropping markers into bins, locating acoustic beacons, grabbing, releasing and manipulating objects. Each of these tasks requires swift movements and precise navigation. In order to achieve all those tasks, the vehicle must be able to sense its environment. Therefore, the submarine is equipped with three cameras, a Doppler Velocity Log (DVL), an Inertial Measurement Unit (IMU), four hydrophones and a Mechanical Imaging Sonar. These sensors enable the vehicle to hear, see and measure its speed, acceleration and underwater position. It can also accurately measure precise distance of objects ahead. In order to interact with its environment, the AUV is equipped with six thrusters, an active grabbing system and a torpedo launcher. Furthermore, the team members improved last year's design with several modifications in order to reduce mission execution time and enhance overall modularity, resulting in the best autonomous submarine SONIA has ever built.

Quick facts

Dry weight:	44 [kg]	***Thrusters:***	6x SeaBotix Brushless HPDC1507
Dimensions (LWH):	1.30 x 0.56 x 0.40 [m]	***Cameras:***	1x Unibrain Fire-i board Pro
Max speed:	0.5 [m/s]		2x Guppy F-95c Pro
Max depth:	30 [m]	***Sonars:***	1x Teledyne Explorer DVL
Degrees of freedom:	Surge Heave Sway Yaw Pitch		4x Brüel & Kjær Hydrophone
Autonomy:	3 to 4 [h]		1x Tritech Micron DST Sonar
		IMU:	1x Microstrain 3DM-GX3-25

Since its foundation in 1999, team SONIA took part in the annual Autonomous Underwater Vehicle Competition held by the Association for Unmanned Vehicle Systems International (AUVSI). Every year, the team has worked countless hours in order to obtain first prize. This year, there are 25 undergraduate students involved, from electrical, mechanical, mechatronics and software engineering.

Figure 1 – Submarine's front port view

Team Objectives

This year, the team had four main objectives:

- Prepare the new team for the competition.
- Build a new frame to ease access to the main hull.
- Create a new and more optimized vision server.
- Conceive a time redistribution system to maximize chance of success.

Team Organization

The team is divided into three sub-teams. The mechanical engineering team designs and fabricates most parts of the vehicle. The electrical engineering team designs and creates custom-printed circuit boards needed for the vehicle. The software engineering team creates and maintains all the software used in the vehicle such as vision filters, mission programming, integration of the operating system in addition to the software used on the team's computer to control the vehicle. Each department has a team leader who distributes tasks to all members. Moreover, a project manager is responsible for coordinating the crew's efforts. Finally, the treasurer manages the team's budget and invoices.

Methodology
With the purpose of creating a better AUV each year, team SONIA brought together several good work practices. After each competition, all members gather to talk about what went well and what needs to be improved. A database containing all bugs and improvements is then created. To set the team's guidelines for the year, each task is prioritized from the most important to the least. After every pool test, the list of bugs and improvements is updated. This process is repeated all year long until the competition. In addition, peer review is an important aspect of the development process. Each project is reviewed by another team member to improve its chance of success.

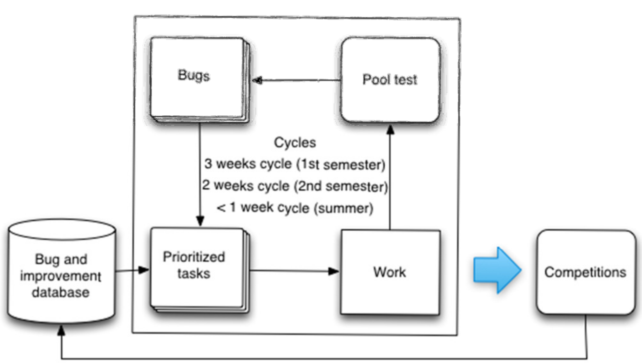

Figure 2 – Development strategy

Tests
The test schedule varies throughout the year. Tests are done every 3 to 4 weeks during fall, every 2 weeks during winter and in summer, the team tests as many times as possible with a minimum of twice a week. ETS does not have a pool, thus the team must rent one at an hourly fee. When the temperature is adequate, tests can be done outside at the Olympic Rowing Basin in Montreal. This outdoor basin provides slightly harder lighting conditions than the competition, making it an ideal test site.

Community Outreach
Team SONIA is really proud and will do everything possible to help other teams or anyone who wants to build an AUV. For instance, Bumblebee from Singapore, a newly formed team, required assistance in several different areas. It was a real pleasure to answer their questions and to provide them with key hints about the competition.

SeagoatVision Collaboration
This year, a new vision server called SeagoatVision was developed by the software team in collaboration with team Capra, also from ETS. Team Capra designs and builds an autonomous ground vehicle (AGV). Coded in Python and C++, SeagoatVision is a free and open-source application available at seagoatvision.org

Mechanical Design
This year, the frame has undergone a complete redesign. To provide modularity and flexibility, a drill pattern is applied to every part of the frame. The structure is made of aluminum and it received a hard-anodized treatment. One of the main constraints for this new design was to have an easier access to the main hull. The front and back parts of the frame can now be lifted up using hinges and draw latches. Each thruster is mounted using rubber dampers in order to reduce vibrations transmitted to the hydrophones array.

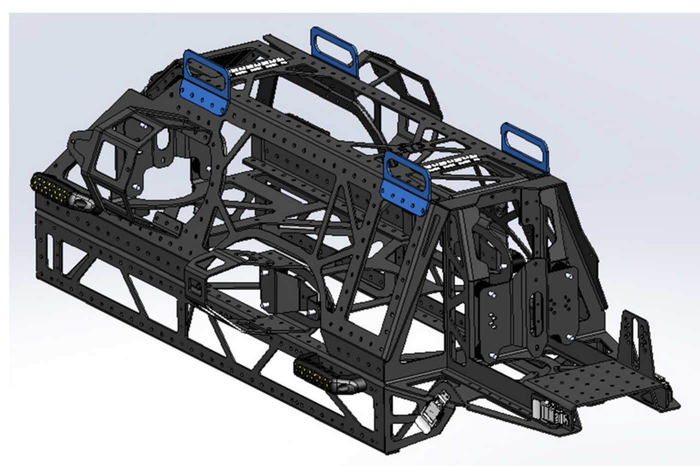

Figure 3 - Frame

Main Hull

The main hull contains most of the electronic components. Seals and spring-tension draw latches are installed at each end. The hull can be separated into three sections. The centerpiece, made of anodized aluminum, contains the DVL's transducer and also receives all the connections from external housings. Both side pieces are made of acrylic and contain the custom-designed electronics and the AUV's main computer. All electronic components are mounted on 3D-printed racks made out of ABS plastic. Those racks are designed to maximize the available space inside the casing.

External Enclosures

The chosen material for all enclosures is anodized aluminum. They were all designed to be closed using stainless-steel screws and a water seal is achieved using O-rings. All of the modular casings include a sealing screw which allows each of them to be tested with a vacuum generator.

Camera Enclosure

The AUV is equipped with 3 cameras. A new front camera enclosure was designed to accommodate the addition of an extra camera. Moreover, it contains a FireWire hub to reduce the number of wires going into the main hull. The cameras are secured into place using adjustable mounts which allows swapping lenses easily.

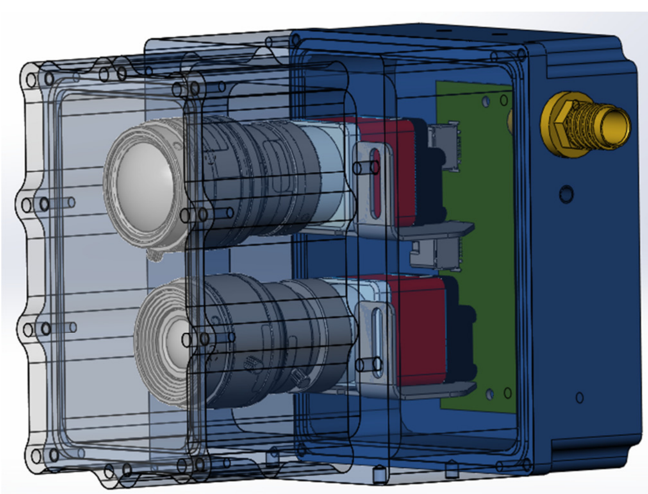

Figure 4 – Front camera enclosure

Pneumatic System Enclosure

The pneumatic system consists of a series of two-way and three-way solenoid valves inside an enclosure with a separated CO_2 cartridge holder. The sonar rotator and grabbing systems use dual-action gas cylinders. As for the torpedo launcher, it uses a two-way valve which, when activated, propels the torpedoes forward.

Battery Enclosures

These enclosures have a polycarbonate tube that connects each cap to mimic the shape of the main hull.

Sonar Rotator

The sonar rotator was created in order to detect the distance of objects under, as well as in front, of the submarine by changing the angle of the mechanical imaging sonar.

Active Grabbing Device

The active grabbing device is composed of two grabbing hands. Each hand is controlled by a pneumatic cylinder installed horizontally.

Electrical Design

The electrical system is the interface between the actuators, the sensors and the control system. It has to be robust and easy to maintain.

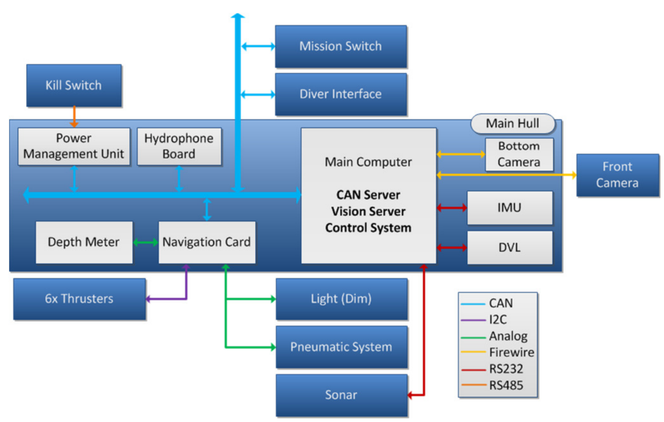

Figure 5 – AUV communication bus

System Overview

In order to sense its environment, the vehicle is equipped with three cameras, a mechanical imaging sonar and a passive sonar system. To measure its accurate position underwater, it is also fitted with with a DVL, an IMU and a depth sensor. Multiple actuators are installed on the submarine, which allows it to accomplish different tasks. Six thrusters allow the submarine to move underwater. A pneumatic grabbing system can grab and release objects. The pneumatic system also allows launching of torpedo-shaped markers. A dropping mechanism is positioned on each side of the bottom camera.

To deliver power to these actuators and sensors, the submarine has a power management system that monitors and limits each channel. In addition, it can shut down any channel upon request.

The decision center of this complex machine runs on a computer that is located inside the main hull. It is responsible for both the control system and the vision server.

Hydrophones

The custom passive sonar array is located at the front of the vehicle. It is composed of 4 pressure transducers called hydrophones.

Figure 6 – Hydrophone array

Each signal is routed to an acquisition card. Signals then go through 3 stages. First, the signal is amplified to boost its magnitude using a preamplifier. The second stage consists of a low-pass filter to minimize the noise caused by the amplification process. Once filtered, an adjustable amplification stage amplifies up to 100 times the signal.

A Digital Signal Processor (DSP) samples each of the 4 channels. Each signal is then filtered again with a discrete band-pass filter. Then a Fast Fourier Transform (FFT) will trigger on the amplitude of a single spectral component of the signal. With this technique, the vehicle is able to detect the frequency despite thruster noise.

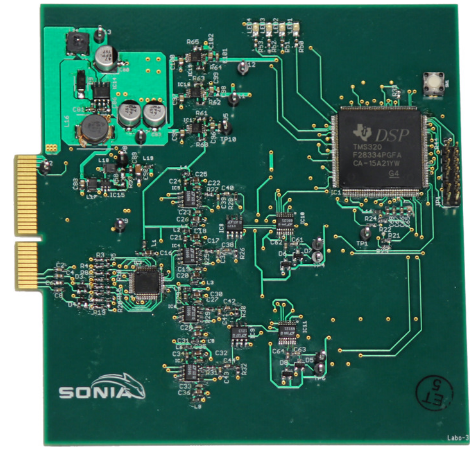

Figure 7 – Passive sonar board

To find the phase difference, all signals are compared with each other. These phase differences are compared to a lookup table. The smallest difference between each signal is used to determine the heading and the elevation of the received sound.

Dock Box

To improve efficiency during pool tests, a compact and portable server was designed. The dock box receives the tether from the AUV and broadcasts it with a Wi-Fi router. This method allows all team members to have a direct access to the AUV. A computer and a screen can be powered up in order to control the onboard server. The keyboard and the screen can also be plugged into the AUV's main computer for debugging purposes when there is no communication with the vehicle. The dock box is powered by two 14.8V batteries in parallel. Each battery has a capacity of 10Ah. It also has a built-in battery gas gauge, which displays current voltage of the battery using a character display and a LED array.

Leak Sensor

The vehicle has an integrated leak sensor to detect possible water leaks. It consists of an array of cables. When those cables become wet, an electrical short occurs which is transmitted by a binary signal to the telemetry software to draw the user's attention.

Navigation Board

The navigation board is tasked with converting the commands from the onboard computer and dispatching them to every actuator. Commands are received through the Controller Area Network (CAN) bus. It can activate the light, the torpedo launcher, the sonar rotator, the dropping mechanism, the active grabbing system and it also receives pressure and temperature information.

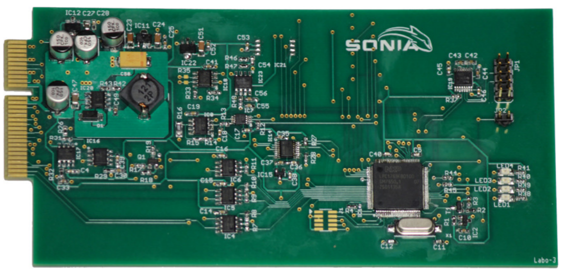

Figure 8 – Navigation Board

Furthermore, the navigation board is also responsible for controlling the thrusters, which is done by using the Inter-Integrated Circuit (I^2C) protocol.

Power Management

The vehicle is powered by two 25.9V batteries in parallel. Each battery has a capacity of 10Ah. The power board receives the raw voltage and converts it into different levels. Each level is then distributed over different channels to every sensor and device. Those channels are monitored and protected in case of an overcurrent or overvoltage.

The power board can also shut down any channel on demand. The power board is responsible for receiving signal from the kill switch. Once the kill switch is activated, it receives a square wave signal at a specific frequency. If the frequency is not detected by the power board, the power channels controlling the thrusters, pneumatic and dropping systems will be deactivated.

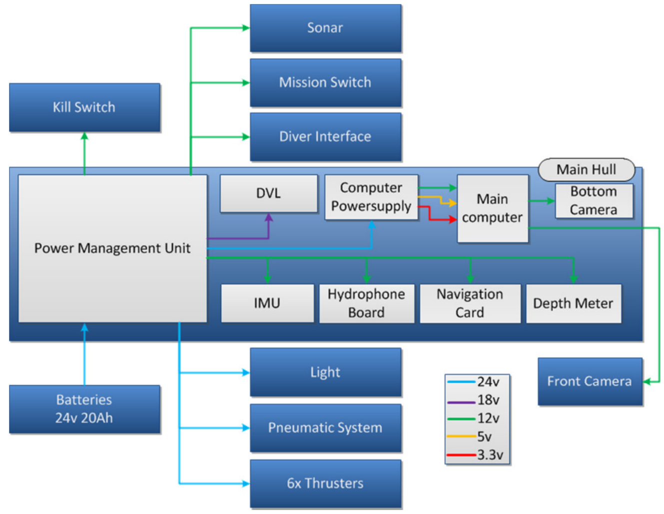

Figure 9 – Power distribution

Diver Interface

The vehicle has an external interface that displays useful information to the diver such as battery voltage, current mission state, inner state and pressure of the pneumatic system. The team can also communicate with the diver 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 are equipped with a Hall Effect sensor. It can be activated with a magnet which is placed at the end of a pin. This pin has two grooves retained by a ball detent, thus setting on or off the switch.

Cameras

This year marks a milestone in SONIA legacy. The team decided to include another camera at the front of the AUV. This upgrade gives multiple possibilities such as High Dynamic Range (HDR) and stereo analysis. Moreover, the vehicle can now have two different lenses, one for near targets and one for far targets. This way, the vehicle can approach an obstacle much closer without loss of sight. The cameras are Guppy F-95c and provide faster frame rate, more calibration parameters and better image quality.

Backplanes

All electronic signals are routed on electronic cards which are on a backplane system. The submarine is equipped with three main backplanes. The central one is the main connection between the PC and the custom electronics which both are on backplanes themselves. In addition to receiving those connections, the central backplane receives all external signals from the sensors and actuators.

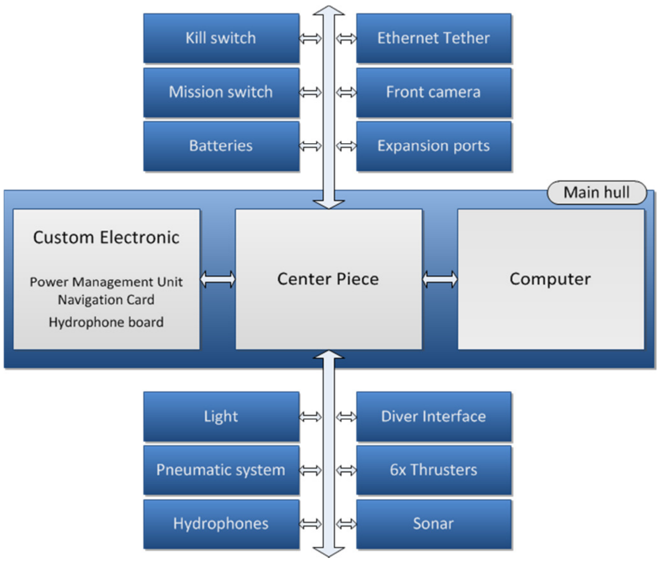

Figure 10 – Connection diagram

Doppler Velocity Log

In order to know its accurate position, the submarine is equipped with a Teledyne RDI Explorer Doppler Velocity Log (DVL). This DVL has two components. The first one is the head containing the piston transducer. The remaining part is the electronic component, which is used to process signals returned by the head. Additionally, data from various sensors can be fed to it to improve velocity measurements. The vehicle's attitude is sent to the DVL. This allows the sensor to adjust the position it returns according to the yaw, pitch and roll of the vehicle. To communicate with the sensor, the vehicle's configuration requires two serial ports. The first one is used to send commands and receive data while the other one is used to feed parsed data containing the attitude of the vehicle. Finally, the DVL requires a power channel of 4W to operate properly.

Inertial Measurement Unit

The Inertial Measurement Unit (IMU) is an array of sensors. It is composed of accelerometers, magnetometers and gyroscopes. The data is combined in order to have an accurate attitude of the vehicle. This includes yaw, pitch and roll. This year, the team is using a Microstrain 3DM-GX3-25 IMU.

Thrusters

The submarine is equipped with six brushless SeaBotix thrusters. Each one is controlled over an Inter-Integrated-Circuit (I^2C) bus. This enables a much more uniform and accurate propulsion by having direct control over each thruster's individual rotation speed. Because of its close proximity with the main hull, the heading thrusters were losing a great amount of efficiency. Propulsion nozzles were added to concentrate the flow of water and therefore reduced that effect.

Controller Area Network

Communication between custom electronic boards and the computer is done over a CAN (Controller Area Network) bus. A USB-to-CAN Kvaser device is used to connect the computer on the bus. A custom communication protocol was designed to enable complete control over each custom electronic board. As an example, an identification request allows identifying every device present on the bus. If a device that is expected to be present does not respond the operators will be notified of a fault.

PC Power Supply

In order to improve airflow inside the main hull, a custom power supply was designed. The power supply, 3 times smaller than a regular off-the-shelf power supply, is equipped with two 12V 6A channels, one 5V 2A channel and one 3.3V 2A channel to power the main computer and all components that are connected to it.

Onboard Computer

The vehicle is equipped with a Kontron KTQM67/mITX motherboard with a 2.3-GHz Intel I7-3610QE processor and 8 GB of RAM. For reliability and speed, two solid-state drives are used, one for the operating system and SONIA's software, the other for data logging.

Sonar

A Tritech Micron mechanical imaging sonar is used to detect and map objects. This sensor can be placed in two different positions to see objects in front or under the AUV. Communication with the onboard computer is done using RS-232 communication protocol.

Software

The software team is responsible for improving and maintaining the submarine's operating systems. The software architecture is laid out into 3 main components:

- Control system (AUV6)
- CAN/TCP server
- Vision Server (SeagoatVision Suite)

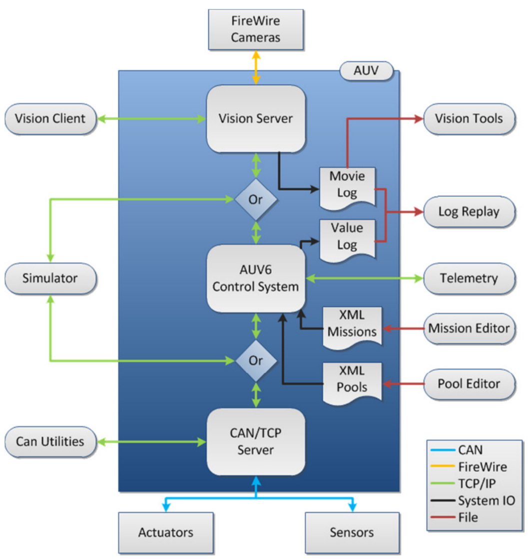

Figure 11 – Software architecture

After last year's competitions, the team had 2 main objectives to improve the platform:

- Add features enabling time management
- Develop a new vision server

In the past years, each task had an amount of time allotted for execution, after which the control system would timeout and jump to the next task. A mission scheduler was created; it monitors time that was not used in executed tasks. This extra time is distributed to the remaining tasks.

The previous vision server was designed eight years ago. The key factors which motivated the team to develop its successor, SeagoatVision, were the difficulty to debug and maintain the old server, the missing multi-core CPU support and the low amount of information sent to the mission system.

Control System

Coded in Java, AUV6 is the core application running on the vehicle. Its main function is to collect and analyze data from all available sensors to take a decision and then communicate the specific action through the provider interface. The provider connects via the TCP/CAN Server or serial ports. The system is running at 14 Hz, which is twice the DVL`s speed. Every loop, data is logged, which allows replay through an in-house application. Parameters of the state machine are loaded from an XML file. Communication with the actuators and sensors is achieved over the CAN bus protocol. AUV6 is also communicating with the new vision server to start and stop the filter chain execution, start recording cameras and receive data relating to the position and characteristics of an object.

Mapping

Using all its sensors, the vehicle is able to map the position of obstacles. This provides the control system with information that allows it to take better decisions when an obstacle is lost. Furthermore, characteristics of obstacles like color or shape can be added. It also allows the mission manager to create zones of interest to reduce false positives in obstacle detection.

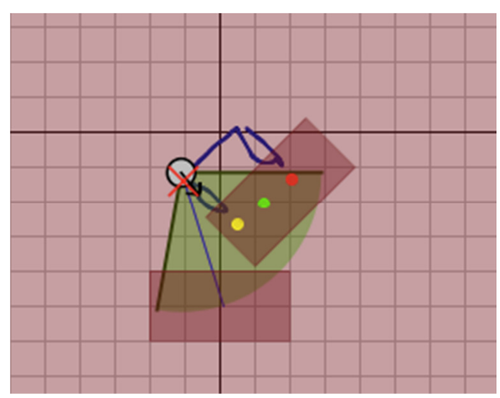

Figure 12 – Navigation map

PID Controller

The vehicle is controlled by 5 PID loops (surge, heave, sway, yaw and pitch). Each loop activates the appropriate thrusters at a specific speed in order to reach a waypoint as fast and as smooth as possible.

Mission Scheduler

This year, the team developed a new feature called the mission scheduler. This new approach uses time features that are already running on the platform to accomplish a simple but crucial goal: redistribute previously unused time to future tasks. The scheduler monitors every timeout activity during mission execution to simply recuperate any spare time. Once a task is completed with time to spare, this extra time is redistributed between other currently active tasks, thus ensuring that every task is completed with maximum efficiency. Time allotted to each timer is calculated using a priority function based on the point value of each task.

Telemetry

The telemetry is used to operate and monitor the submarine. It was designed with extensibility in mind. It displays many useful widgets like a navigation map, an attitude indicator, a target widget and many others. All those widgets communicate using the Joint Architecture for Unmanned Systems (JAUS) architecture. Standard JAUS messages have been extended to fulfill custom needs of the team.

Moreover, the telemetry is also used to send commands to the control system like changing the current mission or modifying information related to zones of interest.

CAN TCP Server

The CAN/TCP server is the bridge between the control system on the main PC and the actuators and sensors on the CAN bus. Every actuator's action and data gathered from sensors is converted from CAN to TCP or TCP to CAN by this server.

CAN Workbench

This tool is used to monitor and debug communication with all custom electronic boards. It allows the team to monitor every message passing through the CAN bus. Furthermore, the software is able to emulate behaviors of electronic boards by creating messages. The tool can also send identifier requests to quickly validate that all devices are correctly responding.

SeagoatVision Suite

Coded in Python and C++, SeagoatVision is a new addition this year. It surpasses its predecessor regarding several aspects. Maintenance of the old vision system was becoming daunting; a redesign was necessary. An improved error handling system was also developed. The server's new multi-core CPU support allows for parallelization of vision filters and the ability to have different processes running at the same time. In addition, an emphasis was put on optimization. For instance, the server won't use the CPU's processing power when it is not active. Furthermore, communication with the mission system has been improved.

Vision Client

The vision client is a software that centralizes all useful vision tools such as recording and editing videos, viewing results of a filter execution, managing the server and video logs. It is also a fast editing tool for filters which can be reloaded without restarting the software.

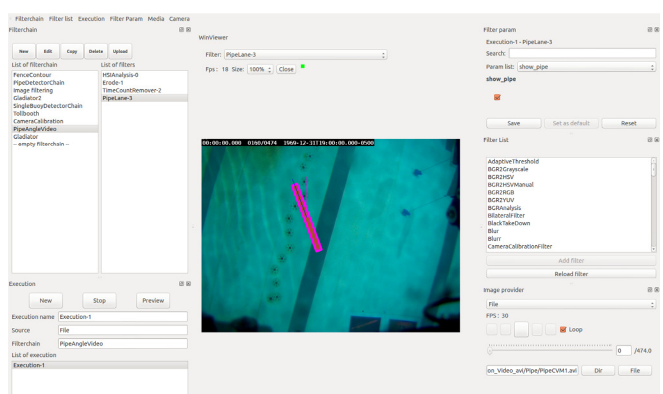

Figure 13 – SeagoatVision client

Vision Server

The vision server itself includes several new features. Filter creation is now much easier and time-efficient. The stability has been improved in different ways. Filters that are not compiling or containing errors are simply excluded from the server. Furthermore, the server handles most exceptions and errors that can happen before and during runtime. This means the server is less prone to fatal errors and unforeseen crashes during mission execution. It also provides a debugging system using a command-line interface.

Vision Filters

With the arrival of SeagoatVision, it is now possible to greatly improve filter performance and efficiency. The previous vision system was based on OpenCV 1. A long overdue update was applied to bump the library up to version 2.4.5. This update alone greatly improves image processing performance. It also provides a great reliability improvement for all detection algorithms used in filters such as edge or circle detection.

Filters which could quickly be modified and have more settings were created. This was accomplished with a pipeline approach, each filtering steps are separated into different filters. Those filters are then applied one after the other to create a filter chain making those chains highly modular. Moreover, all filters can be individually parameterized, making them very versatile.

Mission Editor

The mission editor is an eclipse plugin that has been developed in-house which simplifies mission development. Instead of writing XML mission files, the mission editor provides a graphical interface. In addition, a UML file is converted into an XML file when saved. This customized mission editing workbench was developed using Eclipse's user interface features, thus 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.

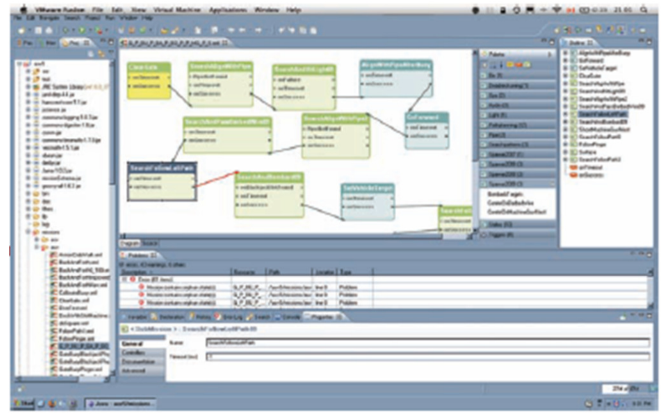

Figure 14 – Mission editor

Log Replay

The log replay provides an interface similar to the telemetry's but instead of getting data live from the AUV, it is preloaded from log files and videos. This tool allows the team to study what happened in previous tests. Logs can also be analyzed more thoroughly with common stop, play and rewind features.

Hydroscope

In order to monitor and configure the passive sonar system, the hydroscope was developed. Connecting directly to the TCP/CAN server, it enables operators to quickly change settings of the passive sonar board. The hydroscope allows setting different algorithms and thresholds used to detect the wanted frequency. Finally, it displays useful graphs to allow the operator find optimal settings.

Conclusion

This year has been huge for the team. The mechanical engineering team members used all their knowledge to create a brand new frame that can accommodate every vehicle components without modifying previously fabricated parts. The electrical team raised the quality of integration on both the mechanical and software aspects. Finally, the software team designed a new vision suite in order to be more efficient and continued to improve the vehicle's capabilities.

SONIA is proud of this year's platform and of all their hard-earned accomplishments. The team is eager to start the competition and show everyone the fruits of their labor.

Acknowledgement

Team SONIA would like to thank École de technologie supérieure's staff for their support: Claire Babin, André Bisson, Patrice Dion, Youri Juteau, Robert Lemieux, Robert Moreau, Réjean Tétrault, Tony Wong and every technician who offered their help. Thanks to Walking Machine's members for their help with parts manufacturing. Thanks to Éric Arseneau who helped with competition logistics.

Thanks to the AUVSI and to the Office of Naval Research (ONR) for organizing this challenging event.

Special thanks to all the sponsors, who made this project possible:

- **Diamond :** Centre d'éducation physique et de sports du Cégep du Vieux Montréal, École de technologie supérieure
- **Platinum :** Association des étudiants de l'ÉTS, Collège Édouard-Montpetit, Eagle CadSoft, ÉTS fond de développement, Kontron, Labo circuits
- **Gold :** Bruël & Kjaer, QNX software systems, Teledyne RD instruments
- **Silver :** AssetScience, Association des ingénieurs-conseils du Québec, Digikey, Isabelle Carrier designer graphique, Minicut International, Rio Tinto Alcan, Theia technologies, Thomas&Betts
- **Bronze :** Verdun Andizing, Concept Syma, Esterline CMC Électronique, Hoskin scientifique, Intel, MicroStrain, Ocean, Parc Jean-Drapeau, Solaxis, Vortex CM LABS

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- **Treasurer :** Marc-André Bolduc-Goulet
- **Movie Director :** Laurent Ulrich
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- **Software Engineering Team :** Mathieu Benoit, Jean-Philip Delorme, Vincent Desjardins, Maxime Lachapelle, Karl Ritchie, Jérémie St-Jules-Prévost
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