S.O.N.I.A. AUTONOMOUS UNDERWATER VEHICLE
CONCEPT AND DESIGN OF THE 2015 S.O.N.I.A. AUV PLATFORM

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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 is translated to Intelligent and Autonomous Nautical Operation System. The purpose of the team is to build an Autonomous Underwater Vehicle (AUV), which goal is to perform an obstacle course at the 18th annual international Robosub competition held in San Diego, California.

The competition simulates real tasks that would be assigned to an AUV in real life, such as pipe inspection, precise navigation, image and pattern recognition or acoustic localisation. In order to accomplish those tasks, the submarine has several navigation sensors, such as an Inertial Measurement Unit (IMU) and a Doppler Velocity Logger (DVL). It is also equipped with two cameras, a 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. ever had.

QUICK FACTS

Dry weight:	39 [kg]	**Thrusters:**	6x SeaBotix Brushless HPDC1507
Dimensions (LWH):	1.156 x 0.548 x 0.419 [m]	**Cameras:**	1x Unibrain Fire-i board Pro
			1x Guppy 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 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. 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 planning, 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.
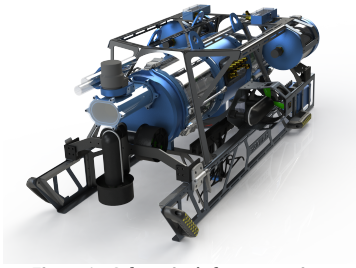

Figure 1 – Submarine's front port view

Methodology

Team S.O.N.I.A. has set up a very effective methodology that is repeated year after year. The competition serves as a starting point to analyze the potential improvements: after each competition, a meeting is conducted to analyze the strengths and weaknesses of the submarine. Different ideas of improvement are grouped in a project management software. The different projects are then regrouped by department and difficulty level. This way, when a new member joins the team, we are able to quickly find a suitable project for him.
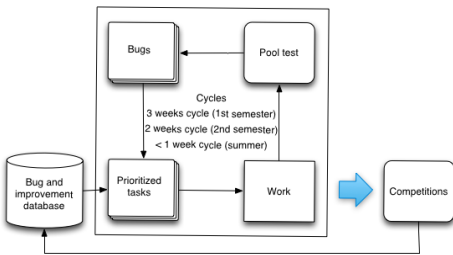

Figure 2 - Development strategy

TESTS

The tests are divided into three periods of four months each: the fall, winter and summer semester.

- From September to December, we have a test each three weeks.
- From January to April, we increase the number of testing with two tests by month.
- From May to August we set up at least one test per week pool. Due to the climate, we have to wait the month of May to perform in outdoor tests. Multiple tests at the Olympic basin must be made during this period.

COMMUNITY OUTREACH

The team tries to reach different communities by helping other teams in their development efforts. It also answers to any questions or help request sent via S.O.N.I.A.'s website. The motto has always been "We are competing against the obstacle course, not the other teams".

VISION SERVER

A new implementation of our vision server was completed this year. We are working towards the upcoming migration of our system to be compatible with ROS. Our vision software was the first milestone of this ongoing project and it was also an opportunity to learn about the ROS features and test the stability with our newly main hull enclosed camera. We relied a lot on the SeagoatVision Open source software as the base architecture while implementing this new software using C++ instead of Python.

⚒ MECHANICAL DESIGN

MAIN HULL

The main hull's form is cylindrical to meet the need of the submarine to move on multi- axis ways. The DVL and the IMU 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 fast removal or replacement of the onboard PC and electronics.
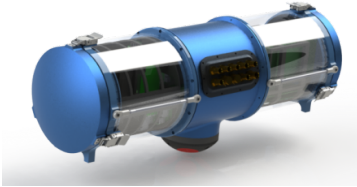

Figure 3 - Main hull

FRAME

Last year, the mechanical team completely redesigned the frame. The vehicle is now more efficient in the water and easier to handle during the transportation. 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 access quickly and safely inner electronic components. The frame was TIG welded so the welds can be made in many positions. It allowed high quality and clean welds.

Figure 4 - Frame

GRABBER

The grabber was redesigned to be simpler to use, lighter 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

The camera chosen for the submarine is a Guppy. It has a better quality, definition and is very robust. The camera was placed inside the vehicle so it allows more stability for the software. The torpedo launcher system and the sonar are directly attached to the camera enclosure, minimizing the displacement calculations when firing.

PNEUMATIC SYSTEM ENCLOSURE

The pneumatic system has been made from a drilled block. This optimizes the overall weight of the submarine and provides better sealing. The design has been redesigned to be smaller.

The enclosure is strategically located in the lower portion of the frame, using its weight to limit the propensity of the submarine to roll.
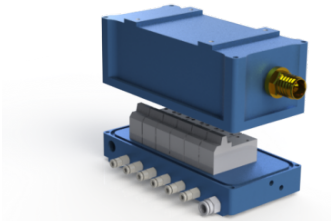
Figure 5 - Pneumatique enclosure

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 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, aluminium machining was used in the fabrication of the hydrophone enclosure. The goal behind this decision was to improve of sealing. They are found under the main hull, protected by the frame.
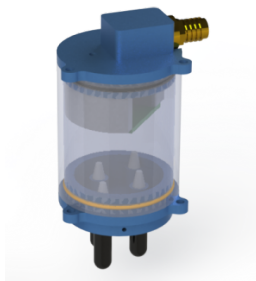

Figure 6 - Hydrophone enclosure

⚡ 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 IMU.
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 to reduce any interfering sounds like the motors vibrations. 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 from everywhere. With this, the team can make tests everywhere.

Nowadays, hards drives have more capacity. This allows the team to save more videos on our computers. That is the reason we no longer use the duck box as a storage unit.

Figure 7 – Dockbox

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 makes the submarine more flexible because the computer with the software no longer have to talk many languages, the CAN language is enough. The computer refers automatically to the navigation board and ignore the motors.

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.
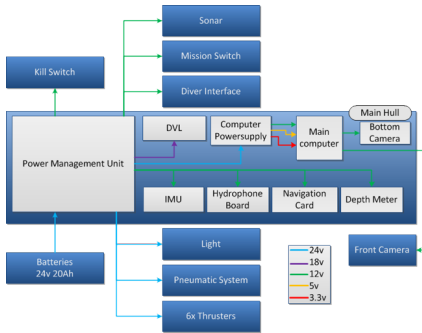
Figure 8 - Power distribution

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. This year, the team has developed a LED interface that allows to manage difficulties more visually. The light system reacted depending upon various elements like the current mission or different alerts (battery discharge, errors ...). All the different alerts are programmable in advance.

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, a major improvement to the signal stability has been made. We now include the camera in the main enclosure, which allows direct connexion with the new firewire 1394B acquisition card. With the new system, we now have an Allied Vision Technology's Guppy Pro F-095C as a forward facing camera and a Unibrain Fire-IX as bottom facing camera. We can now benefit from all the feature, speed and resolution of the cameras that we have.

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. It is possible to have complete vehicle parts to change them in case of an emergency. The interchangeability allow the team to gain a lot of time.
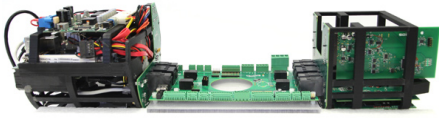

Figure 9 - Backplane system

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.
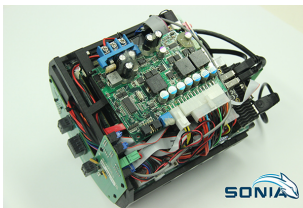
Figure 10 - PC backplane

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, 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

This year, the team has choose to use a Microstrain 3DM-GX3-25 Inertial Measurement Unit. It 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 (I²C) 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 new 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 scan lines are merged into global coordinate, allowing the mission coordinator to use tese 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
- Machine Vision Software
- Control System (AUV6)

Every year, the software team is in charge of improving and maintaining these components. Even after last year's podium, the team decided to bring major changes to some of the tools that are being used. Also the team consolidated the knowledge of the current platform to reach a better competitive level.

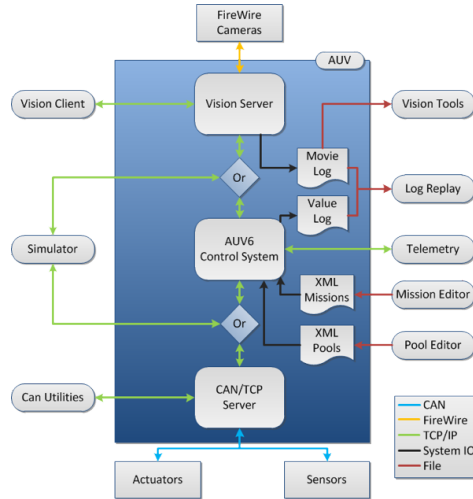The following diagram explains the relation in between the major component and tools.

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
- Machine Vision Software
- Simulation system
- Telemetry

CAN TCP Server

The TCP server links the onboard computers to the CAN 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 our machine vision software.

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.
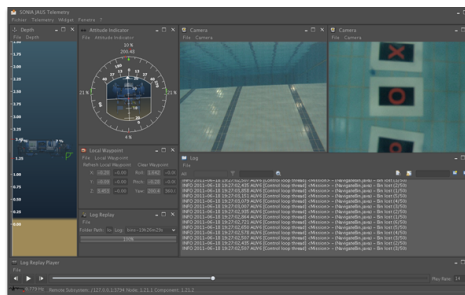

Figure 13 - Log Replay interface

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.
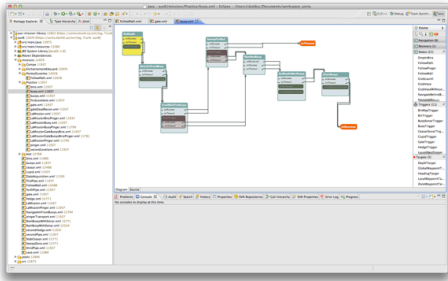
Figure 14 - Mission editor

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 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 telemetry is also capable to act as a command center to operate the submarine.

MACHINE VISION SOFTWARE SUITE

VISION CLIENT

The vision client is a graphical interface developed using QT library in C++ and is also compatible with the Robot Operating System (ROS). 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.

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

This year the team decided to build a new vision server. The goal was to remove some issues that we're met during the last competition. The new vision server is built on top of the ROS middleware. It has almost the same features as the previous vision server, but the decision was taken to build this

software using C++ and ROS in order to get a more efficient vision server.

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 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, ROS to handle client/server communications 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

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 the stability of the platform. The team reach his goal that was to fix all known bugs and start the development of the upcoming S.O.N.I.A. platform. The rigorous test schedule allowed the team to deliver a very stable platform ready to perform at the Robosub competition.

The mechanical team refactor the front section to get a lighter vehicle and an improved stability of the enclosed camera. The electrical team took a major step towards hardware stability by reordering each board and implementing minor and ergonomic fixes.
The software team bring up a whole new vision server for this year. The server itself is much more stable, faster and the resulting quality of imaging is improved.

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 labour.

ACKNOWLEDGEMENT

Contact Information