Concept and Design of the 2010 SONIA AUV Platform

http://sonia.etsmtl.ca
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Abstract

SONIA 2010 is an autonomous underwater vehicle (AUV) built by undergraduate students from the École de technologie supérieure (ETS) to compete at the AUVSI & ONR's 13th International Autonomous Underwater Vehicle Competition. Our vehicle was engineered to be highly adaptable in order to complete several different tasks at the competition. These tasks consist of finding buoys, doing shape recognition, finding an acoustic beacon and several more. In order to perform these real life situations, the AUV is equipped with a Doppler Velocity Log (DVL) sensor, two inertial measurement units (IMU), a passive sonar array, two cameras, a pressure sensor and six thrusters. The sensors mentioned provide a highly efficient situational awareness. The submarine is also able to grab specific objects, release those objects, launch soft markers horizontally or drop markers vertically. This prototype can reach a maximum depth of 10 meters, has a maximum speed of 0.5 meter per second and has an autonomy of approximately 2 hours. At the core of the system is a state of the art software stack. The decision software has been enhanced to be more flexible and robust making the vehicle capable of accomplishing much more complex tasks. The high-level tools help to the reconfiguration of mission task as well as viewing online and offline telemetry data.

Quick Facts

Dry weight:	35[kg]	***Thrusters:***	6x SeaBotix SBT150
Dimensions (LWH):	0.95 x 0.44 x 0.55[m]	***Cameras:***	2x Unibrain Fire-i
Max speed:	0.5 [m/s]	***Sonars:***	Teledyne Explorer DVL
Max depth:	10 [m]		4x Brüel & Kjær Hydrophone
Autonomy:	2 [h]	***IMUs:***	2x Microstrain 3DM-GX1

Introduction

The SONIA AUV (Système d'Opération Nautique Intelligent et Autonome) project was incepted in 1999. The project is managed by a multidisciplinary team composed of volunteer students from École de technologie supérieure (ETS) studying mechanical, electrical, mechatronics and software engineering. The goal of this group is to design and build a highly reliable and efficient autonomous underwater vehicle (AUV) which will participate in the Autonomous Unmanned Vehicle Systems International (AUVSI) and the Office of Naval Research's (ONR) International Autonomous Underwater Vehicle Competition (IAUVC). The team's mission is also to promote ETS as a leading engineering school and to help its members become better engineers for the demanding industry that exists today.

This year is the 13th edition of the AUVSI and ONR's IAUVC and the SONIA team will be attending this competition, alongside several other engineering schools from all over the world. The challenges proposed during the competition emulate real life tasks that civilian and military AUVs have to perform. Those tasks are accomplished using different techniques such as image processing and acoustic sensing.

Figure 1 – SONIA AUV 2010

This year, the vehicles will have to demonstrate their abilities by performing the following tasks:

- Navigate through an underwater gate
- Inspect and follow pipelines
- Find and connect with specific colored underwater buoys
- Navigate over an hedge (Football goalposts shaped PVC structure)
- Drop markers in bins containing specific shapes
- Send a soft projectile through a specific colored upright square
- Locate an acoustic beacon
- Pick up a “counselor” (PVC structure)
- Surface in a recovery zone with the counselor
- Release the counselor

The 2010 vehicle is equipped with all the sensors and equipment needed to accomplish every task of the competition with good results and consistency.

- Two Microstrain 3DM-GX1 Inertial Measurement Units (IMU)
- One Explorer Doppler Velocity Log (DVL) from Teledyne RD Instruments
- Two Unibrain Fire-i Board Pro cameras
- Six Seabotix SBT150 thrusters
- One marker dropping unit
- One soft projectile firing unit
- Four Brüel & Kjær hydrophones with a custom passive sonar signal processing board
- One Kontron 1.5GHz Core 2 Duo ETX embedded computer with 2GB of RAM
- One relative pressure sensor
- One active grabbing device

The vehicle underwent a major overhaul since last year. The external enclosures were completely redesigned. Moreover, the custom electronic components were reviewed and enhanced. Finally, the software platform stability and the intelligence were improved.

Team Objectives

This year the team had three major objectives:

- Improve the understanding of the platform
- Get more deployment time
- Enhance the vehicle

Since the team does not have the support of a faculty advisor, it has to make sure that the knowledge amassed through the years is passed on to the new members of the team. Regrettably, in the last two years, the most experienced members graduated and some of that know-how was lost. Over the last year, the team went to great lengths to consolidate its understanding of the platform. The strengthening of the knowledge base demanded frequent in-field testing. This approach has proven to be most efficient. Because ETS does not have a pool, the team decided to allocate a very important part of its budget to rent pools. Within nine months, from September to May, the submarine was deployed for over 150 hours. All those hours of deployment, lead the team to the identification of much needed enhancements, which were implemented subsequently.

Team Organization

The team employs a 3 level hierarchical structure. The captain is responsible for the coordination of the entire project, including technical and human resources management. To help him do so, three sub-team leaders are elected to guide respectively the mechanical, electrical and software teams. Each member is encouraged to bring up new ideas and most of the decisions are taken through consensus.

Work Methodology

This year, the same approach as the one employed in the last three years was retained. The version control system Subversion (SVN) was used to keep track of the evolution of the project.

As always, in-house training was provided to new team members. ETS staff and seasoned veterans helped new members gain more experience in various fields such as:

- Part machining
- Surface mount welding

- Electrical and mechanical CAD
- Software architecture

Over the years, the explicit inclusion of freshman training in the work strategy as undoubtedly resulted in an increased overall productivity.

Collaborations

This year, the team collaborated with 2 other student engineering teams from ETS by sharing software components with them. As a result, those components had more test runs to find and fix bugs.

Mechanical Design

The team opted to reuse the main components from last year's vehicle while upgrading secondary sub-assemblies. This decision allowed the team to maintain a functional mechanical platform while reducing downtime. The objectives for the mechanical team were:

- Design enclosures for two new (and larger) cameras
- Design new kill switch and mission switch enclosures/mechanism
- Improve the existing dropping mechanism design
- Design an active grabbing device

Frame and Hull

The vehicle is composed of an outer frame supporting all the components. The biggest component is the main hull. It contains the computer and most of the electronics. Last year, the team decided to increase the height of the hull to accommodate the electronic of the DVL.

The hull is made of aluminum alloy (6061-T6). This material was primarily chosen for its high yield strength to density ratio and for its ductility. High availability and its weldability also contributed in the selection of this material. Using finite element analysis (FEM) it was possible to tune the hull design and get an estimate of the stresses involved. At 10 meters (30 feet) the maximum equivalent stress reaches 169 MPa. This design affords a safety facto of approximately 1.6.

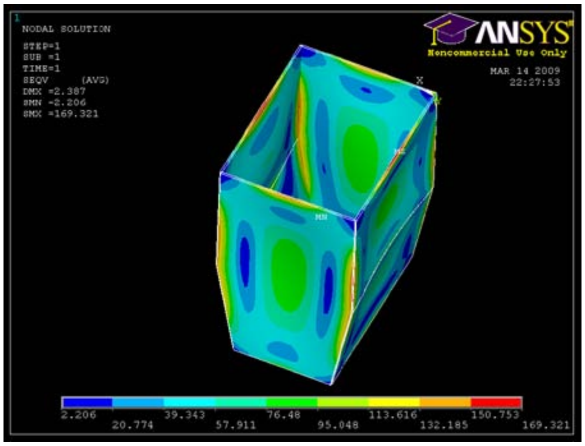

Figure 2 – ANSYS analysis of the 2009-2010 hull

This year, the hull's mechanical resistance was put the test during an exploration test. The vehicle went to a depth of 31 feet without failing, thus validating earlier findings.

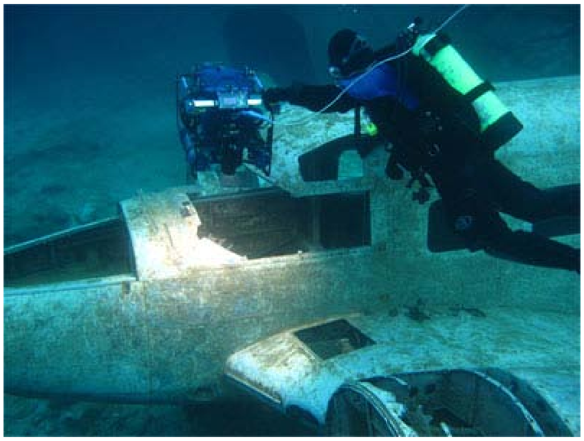

Figure 3 – Morrison quarry exploration – April 4, 2010 31 feet deep

Custom External Enclosures

For the sake of the simplicity of the main hull's design several devices have their own housing. In total six external enclosures were custom designed to perfectly accommodate their content listed hereafter:

- Front facing camera and ambient light sensor
- Bottom facing camera
- Kill switch
- Mission switch
- Diver interface
- Battery compartment (x2)

Team members designed and machined the enclosures out of the same aluminum alloy as the main hull.

This simpler design facilitates assembly and disassembly of the submarine. This is particularly helpful when the submarine requires maintenance.

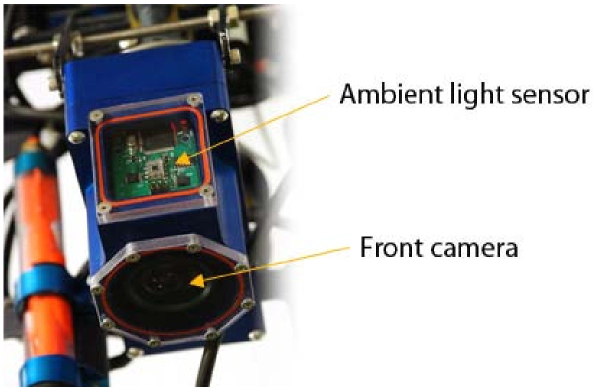

Figure 4 – Front facing camera and light ambient light sensor enclosure.

Kill Switch and Mission Switch

This year, it was decided to design new kill and mission switches (circuit board and housing). For the past several years, permanent magnets placed over quarters activated the submarine. Hidden behind those quarters were Hall Effect sensors to detect the presence of a magnetic field. This design proposed a simple alternative to complicated watertight switches often prone to leaks. This system had to be reviewed because the magnetic fields were interfering with the compass of the IMUs. The concept of using a magnet with a Hall Effect sensor was kept. However, instead of using the magnetic field to hold the magnet in position a ball detent and a pin with grooves was designed to carry out this role. This allowed the use of a much smaller magnet, thus rendering the magnetic interference negligible.

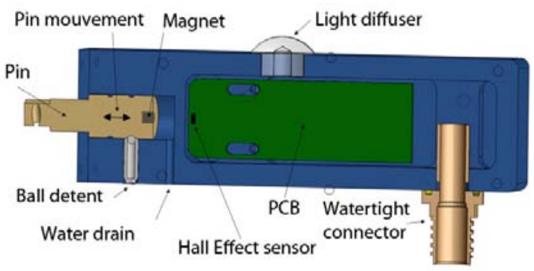

Figure 5 – 2010 kill switch sectional view

Dropping Mechanism

In the previous design revision, the dropping mechanism and the bottom-facing camera were in the same external enclosure. The new cameras occupy a greater space and consequently, the team decided it was best to move the dropping mechanism inside the main hull. In order to drop two markers, two tubular solenoids are installed inside the main hull against the bottom wall. They pull up studs outfitted with a magnet at their lower end. The markers, steel ball bearing, placed on the outer side of the bottom wall, are held in place by the magnetic force. When the stud is pulled up, the marker drops.

Figure 6 – Dropping mechanism

Pneumatic System

The vehicle is equipped with a pneumatic system. Last year it was used to launch torpedo shaped markers. This year, the pneumatic system is used to set in motion the active grabbing device as well. The compressed gas (CO_2) is stored in disposable cartridge and is distributed with a manifold and six solenoid-controlled valves.

Torpedo Launcher

The torpedo launcher is powered by the pneumatic system. A separate solenoid-controlled valve controls each canon. It is important to note that these markers are not self-propelled. The markers have a torpedo-like shape. This profile gives good range, speed and stability. To obtain the correct shape and neutral buoyancy, the torpedoes were fabricated in quick prototyping plastic.

Active Grabbing Device

The active grabbing device is composed of two grippers. Each gripper uses a two way pneumatic cylinder connected to two solenoid-controlled valves, one valve to open it and one valve to close it. Two reed switches, installed on the cylinder, allow the submarine to know if the gripper is opened or closed. There is a third reed switch used to detect the presence of an object in the grabbing device.

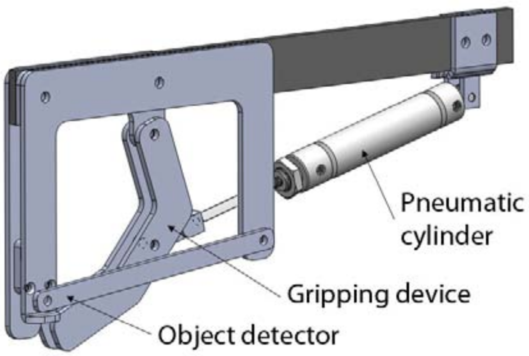

Figure 7 – Active grabbing device

This year's mechanical design is both reliable and efficient. Setting clear goals at the beginning of the year was a key factor in their successful completion.

Electrical Design

The electrical system of the vehicle is divided in multiple independent boards linked together through a communication bus. This topology is used for the following two reasons.

First, by splitting the electronics of the submarine in multiple independent circuit boards, it is easier to split the workload. Also, it is possible to provide every member of the electrical team a project they can design, build and debug. Hence, this helps the students that are involved in the project to learn in a challenging environment and own their skills as engineers.

Second, this system configuration allows for quick and easy maintenance of the system. A defective component can easily be replaced or simply removed without affecting the rest of the system.

System Overview

As mentioned earlier, the system is split into multiple independent circuits communicating with each other through different communication protocols.

The onboard computer acts as the hub. The two FireWire cameras are linked to the computer. FireWire is preferred since it lessens the workload of the processor during data acquisition. For its navigation, the vehicle relies on two IMUs and a DVL. They communicate with the computer via RS232 port. Finally, the remaining components, listed below, are interfaced with each other and the computer with the Controller Area Network (CAN) protocol.

- One power management unit
- Six thruster drives
- One pressure sensor
- One actuator interface
- One passive sonar
- One ambient light senor
- One mission switch
- One diver interface

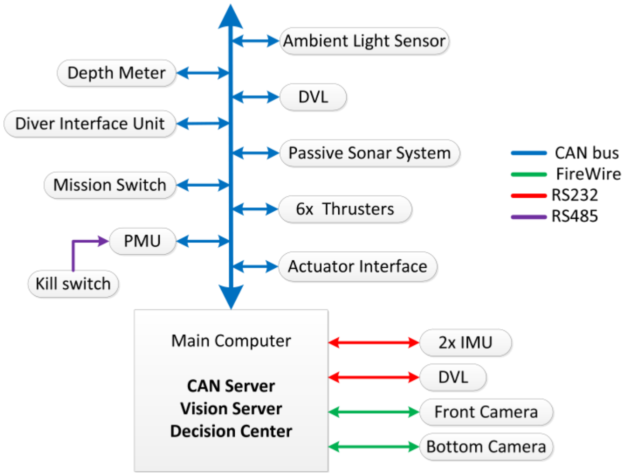

Figure 8 – Communication diagram

Power Management

The vehicle runs on a 24 volt power source. It is composed of two Nickel-Metal Hybrid Cell (NiMH) 12 volt batteries in a serial configuration. This source provides 108 watts of power, giving the submarine about 2 hours of autonomy.

The power is not directly delivered to every component in the vehicle. The most obvious reason is that not every component operates at 24 volts. A second reason to put an interface between the batteries and the different components is to protect the former and the latter.

The power management unit (PMU) is responsible for the following tasks:

- Stepping down the voltage to a suitable level for the different components.
- Separating devices on different power channels for better management. This configuration allows the use of cheaper components.

- Protecting against power surges such as electrostatic discharges.
- Monitoring the current drawn from every channel and shuts down any channel that passes a specific limit. This protects the batteries from being discharged beyond the point of no return.

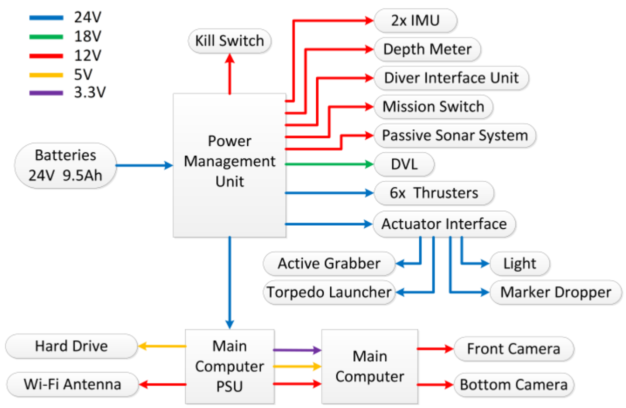

Figure 9 – Power distribution diagram

Onboard Computer

Every sensor sends its information to a main decision center. This decision center is located in the onboard computer.

The use of a computer was chosen over a custom board in the project because of its computational power, versatility and ease of use. With its 2GB of Random Access Memory (RAM) and an Intel Core 2 Duo processor clocked at 1.5 GHz, a great deal can be done without worrying about stack overflows or major control loop overruns.

Controller Area Network

For a few years now, the vehicle has been using the CAN protocol. This protocol allows multiple devices to send and receive small packages of data. It is ideal for the vehicle's sensors. A wide range of identification numbers is available, allowing the many messages sent on the bus to be distinguished easily. Up to now, the different IDs were chosen arbitrarily. As the complexity of the system grew, the system became cumbersome.

Implementing the SONIA CAN Standard (SS-001) solved the problem. Although there are many standards already developed for the CAN protocol, they turned out to add too much complexity to a system that needed to be simplified. The team opted to develop its own CAN standard, inspired in part by the existing industry standards such as CANopen. The goal was to have a logical distribution of the identification numbers. Multiple standard messages were also implemented to allow easy debugging.

A CAN frame ID is twenty-nine bits long. These bits are separated in different sections. Each section serves a different purpose.

1 bit	8 bits	8 bits	4 bits	8 bits
Scope	Class	DID	Type	MID

The scope defines if the frame is sent to or coming from the device. The class separates every sensors and actuators in groups. The device ID (DID) is a unique number associated to every device within a class. The type defines what kind of message is associated with this DID. The message can be standard or device specific. The standard messages allow for easy maintenance and debugging. The message ID (MID) is a unique identifier for each message within a type. Here is a list of standard messages:

- Identification request
- Ping
- Get/Set parameter
- Reboot
- Device fault

With this standard it was possible to have a logical distribution of the identification numbers. Consequently, the system is greatly simplified, thus reducing the learning curve for freshmen.

Passive Sonar System

During the competition, the submarine has to home in on an underwater acoustic beacon. The vehicle is able to accomplish this task with the use of its passive sonar system. As part of this system, four hydrophones are installed at the front of the vehicle. With these underwater microphones, an analog signal of the pressure variations in their vicinity is acquired at all time. These signals are then sent to an acquisition card. Each signal is passed through an amplification and filtering stage. Once this is done, the signal is digitalized in order to be used by a digital signal processor (DSP).

Another series of infinite impulse response (IIR) filter is applied to ensure that only the ping emitted by beacon remains. The signals are then compared with each other to determine the phase difference. The result is sent to the decision center to determine the direction of the beacon.

Sensors

The vehicle is equipped with an array of sensors to be aware of its surroundings. First of all, a pressure sensor is installed on the submarine. The pressure is used to know the distance between the submarine and the surface of the water. A second pressure sensor is used to know the pressure within the vehicles' pneumatic system. An ambient light sensor is used to know the intensity of the light surrounding the front camera, thus allowing automated setting changes of the cameras. There are two cameras on the vehicle. As mentioned earlier, one is up front and the other is located below to see underneath. The submarine also has two IMUs. These are comprised of multiple sensors, including gyroscopes, accelerometers and magnetometers. They are used to know the yaw, pitch and roll of the submarine. The data received by the IMUs is compared with each other for error detection and correction. Finally, a DVL allows the vehicle to know the approximate distance it travelled in three orthogonal axes.

Actuators

The vehicle uses six independent thrusters to control its movements. One pair controls the depth of the vehicle, another controls movements sideways and the remaining two thrusters controls propulsion. The marker delivery system is composed of two tubular solenoids as mentioned earlier in the mechanical section. Six solenoid valves are used to control the active grabber system and the torpedo launcher. Finally, a light is used to adjust the lighting conditions of the bottom camera if needed.

These elements, with the exception of the thrusters, are controlled by a custom electronic card. This card only controls the actuators. It does not take any decision. It receives commands from the decision center.

Software Design

The software architecture of the vehicle consists of 3 main components:

- CAN/TCP server
- Machine vision server
- Decision center (AUV5)

The following diagram explains the relation between the various vehicle's components and tools.

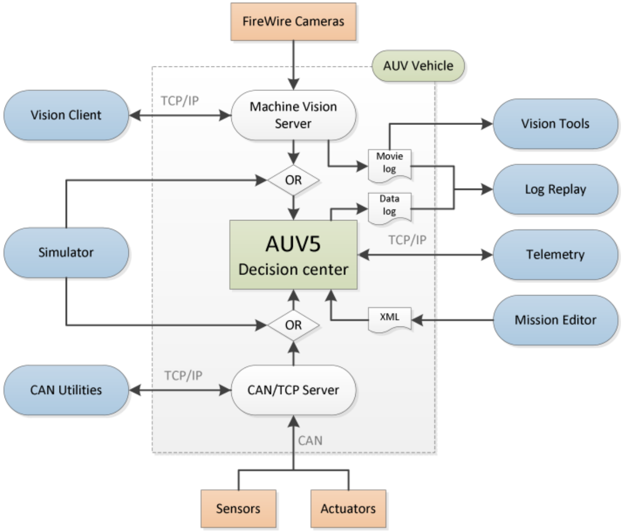

Figure 10 - AUV5 software block diagram

Over the years, the team created a tool suit to help the development and debugging of the project. This suit includes the following applications:

- Telemetry
- Mission editor
- Log Replay
- Vision client
- Vision development tools
- Simulation system
- CAN Workbench
- HydroScope
- CAN Diver interface

The majority of the project's software is build using the Java language. However, some applications such as the machine vision server and the CAN/TCP server are built using C++ to take advantage of existing libraries.

During the year, the software platform for the vehicle went through major cleanup and maintenance to help understand and improve the system.

CAN/TCP Server

The CAN/TCP server is the bridge between the devices of the vehicle on the CAN bus and the vehicle controller on the PC. Without this server, the decision center would not be able to communicate with most of the sensors and actuators. Therefore, it is a critical software component.

Machine Vision

The machine vision system is a standalone application that handles camera input and returns a high level description of the environment in which the vehicle operates. This high level description contains the type of objects that have been detected as well as their characteristics, such as color-based identifiers, distance relative to the vehicle and orientation. Using this high level description, the artificial intelligence contained in the decision center can react appropriately to objects present in the vehicle's field of view.

In order to understand the visual environment in which the vehicle operates, two cameras are used to acquire high resolution imagery which is then processed by the machine vision system. Once the images are acquired, they pass through several filter chains, each of which is able to detect a particular class of object. Thus, there is a filter chain specialized for buoy detection, a filter chain specialized for pipe detection and so on. These filter chains process an image in several steps, using different machine vision algorithms to analyze, extract and filter the image data in order to build a high level representation.

Among the technologies used, an artificial neural network is used for classification of the shapes present at the bottom of the bins. Several objects are reconstructed in three dimensions in order to obtain their orientation and position relative to the vehicle's position. As the cameras are calibrated, the position of objects relative to the vehicle can be determined to a precision of two cm (0.8 inches) using the camera lens' intrinsic parameters.

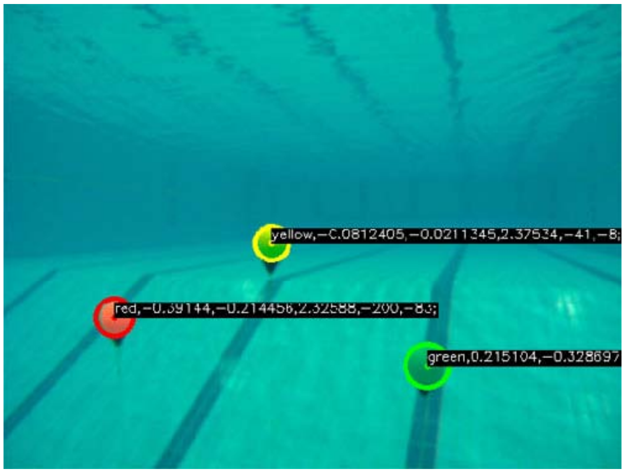

Figure 11 – Debug of the buoy filter chain

In order to build the aforementioned filter chains, a state of the art tool set is used to design, debug, test and deploy the filter chains to the vehicle. They are designed and debugged using a visual editor that allows attaching a debugger at any point during filtering as well as displaying the visual output of each step in the filter. As the filter chains are built and tested against the raw camera data logged from the vehicle, the output from the developed filter is identical to the one in the deployment environment. To facilitate regression testing, a large library of annotated videos is available. The performance of the filter chain is evaluated against known good data. This allows pre-deployment fault detection.

On the deployment side, the machine vision system is fully multithreaded, using most of the processing power available on the two cores of the onboard computer. Should the onboard computer be upgraded with more cores, the computer vision system would scale linearly providing faster processing.

Vision Client

The vision client allows viewing the video streaming of each camera. It is also possible to display the output of each enabled vision filters. Moreover, it allows setting changes for the cameras and filters while the vehicle is active.

A new vision client was designed and implemented this year to resolve all the functionality and usability issues the old client presented.

Decision Center

The decision center, Autonomous Underwater Vehicle 5 (AUV5), is in charge of collecting data about its environment from all available sensors, analyzing the collected data and reacting accordingly to perform its mission objectives.

AUV5 was designed using a multi-layered architecture. Top layers use data filtered by lower layers to control the vehicle and take decisions based on its environment. The processes controlling the vehicle were designed using a linear control loop paradigm. At the beginning of every iteration, a snapshot of the vehicle's state and sensor values is taken to ensure time-determinism.

For control, the software use simple and effective heuristic algorithms on top of classic Proportional Integral Derivative (PID) controllers to optimize control rules during the different phases of navigation.

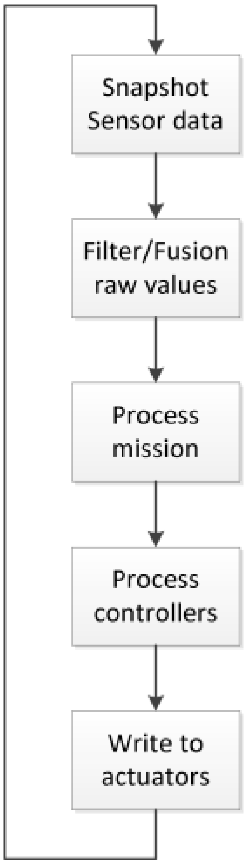

Figure 12 - AUV5 control loop

On top of this low-level control system, a path-tracking control enables the vehicle to navigate given waypoints. This high-level navigation system allows for easy development of search patterns through the enumeration of upcoming positions using a simple Application Programming Interface (API).

The mission system within AUV5 remains the same as the last few years. A finite state machine defines the relationship between tasks that need to be accomplished. States and transitions are defined by an operator using the visual Mission Editor tool and then stored in XML definition files.

The decision center code has been reviewed thoroughly to remove dead code, improve performance and reliability. The main aspects that were reviewed are the CAN communication, the sensors and actuators integration and the PID controllers. This improved the stability and increased the knowledge of the platform among the team members.

Telemetry

The telemetry allows viewing of the vehicle sensor data and setting target values to the actuators. The user interface has been improved to add visual indicators for critical sensor values such as the DVL, battery voltage and pneumatic pressure.

Another tool called the Log Replay allows the team members to view telemetry data offline from logs.

Simulation System

The simulation system was developed to replace the electronics and machine vision of the submarine. It is used to facilitate the development and testing process of the decision center without the need to deploy the vehicle.

Conclusion

The team enhanced the platform's mechanical and electrical aspects. The project's software architecture was push forward to reach new heights. All in all, the design and the engineering of the vehicle are robust and reliable. The SONIA team is eager to deploy its AUV at the AUVSI and ONR's Student AUV competition and see the results of this year's hard work.

The lessons learned and experience gained will help each member of the team in their future engineering career. The team is confident that results will satisfy both our sponsors and our team at the 13th International Autonomous Underwater Vehicle Competition.

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We would also like to thank our sponsors who have made our participation possible: Acces I/O Products inc., Advanced Digital Logic, Aluminum Association of Canada (AAC), Anodisation Verdun, Association des étudiants de l'ÉTS, Batteries Experts, Bert Transmission, Brüel & Kjaer, Centre de plongée Nepteau, Centre Québécois de Recherche et de Développement de l'Aluminium (CQRDA), Circuits Imprimés de la Capitale, Collège Laval, COOP ÉTS, Coupesag, Digi-Key, Eagle CadSoft Computer, École de technologie supérieure, Ej-technologies, Fond de développement de l'École de technologie supérieure (FDETS), Formations Gagnantes, Hydro-Québec IREQ, Innovamont, Instantiations, KGE, Kontron, Kvaser, Meloche Monnex, MicroStrain, Office Québec-Amérique pour la Jeunesse (OQAJ), ORE Offshore, Réseau des Ingénieurs du Québec, SeaBotix, Seacon, Teledyne RD Instruments, Tektronix, Texas Instruments, Thomas and Betts and Vector CANtech.

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- **Treasurer:** Stéphane Franiatte
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