SigMa Lab – A Signature Management System Simulator

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ABSTRACT

In partnership with the Centre for Ship Signature Management, DRDC developed a prototype signature management system (SMS) for real-time monitoring and management of ship signatures under the COSIMAR project. Using a network of onboard sensors and signature models, the system estimates the ship's acoustic, magnetic, electric, infrared, radar, and pressure signatures, estimates the vulnerability of the platform to a library of threats, and makes suggestions to manage or reduce signatures. This international project was conducted with the Netherlands, Germany, and Norway and was completed in September 2017. To offset the loss of CFAV Quest (the expected demonstration platform), DRDC created SCORSim, a real-time simulator which replaces the ship and its onboard sensors to provide the necessary data streams to any signature management system. The entire simulation is run within the DRDC-developed SigMa Lab (Signature Management Laboratory) and is nominally a "free-play" simulation with the capability of placing and navigating the ship anywhere in the world under a wide variety of environmental conditions. Ship machinery can be operated, and ship states may be varied and the results reflected in the changing signatures and vulnerability. While established for a particular ship and SMS, the simulation can be modified for any naval platform and could also be used to evaluate potential future signature management systems.

1.0 INTRODUCTION

As both above water and underwater ship signatures are crucial information for own-ship operational decision making, all navies make considerable effort to measure these signatures on a regular basis but, for a variety of reasons, these measurements (rangings) are often not performed at optimal intervals. As well, between rangings, signatures can change and ships may either not be aware of these changes or may not be able to revisit the range to measure them. In partnership with the Centre for Ship Signature Management [1] [2] and, in particular, Norway, Germany and the Netherlands, Defence Research and Development Canada (DRDC) developed a prototype signature management system (SMS) for real-time monitoring and management of ship signatures under the COSIMAR (Continuous Operational Signature Monitoring, Awareness and Recommendation) project [3]. Using a network of onboard sensors and signature models, an SMS estimates the ship's acoustic, magnetic, electric, infrared, radar, and pressure signatures, estimates the vulnerability of the platform to a library of threats, and makes suggestions to manage or reduce signatures. COSIMAR was conducted with both defence departments and contractors from the Netherlands, Germany, and Norway and was completed in September 2017 [4]. The original plan involved demonstrating this system on the Royal Canadian Navy's research vessel CFAV Quest; however, CFAV Quest was laid up during the COSIMAR project and ultimately scrapped. To offset the loss of CFAV Quest, DRDC created SCORSim, a real-time simulator which replaces the ship and its onboard sensors to provide the necessary data streams to any signature management system. The entire simulation is run within the DRDC-developed SigMa Lab (Signature Management Laboratory) which is nominally a "free-play" simulation with the capability of placing and navigating the ship anywhere in the world under a wide variety of environmental conditions. Ship machinery can be operated, and ship states may be varied and the results reflected in the changing signatures and vulnerability. While established for a particular ship and SMS, the simulation can theoretically be modified for any naval platform and could also be used to evaluate potential future signature management systems.

1.1 CSSM and COSIMAR

The Centre for Ship Signature Management organization was started in 2008 to coordinate research activities in the area of ship signatures. One of the most significant projects was the 2011 RIMPASSE (Radar Infrared Magnetic Pressure Acoustic Ship Signature Experiment) trial which included the demonstration of signature monitoring onboard CFAV Quest [6]. Working within CSSM, in 2013 a project to develop a prototype signature management system was started as a follow-on to the RIMPASSE work, focussing on signature management rather than signature monitoring. The COSIMAR project's final deliverable was to be a demonstration of this prototype system onboard CFAV Quest during a series of dedicated sea trials. The overall goal of the project was not to develop SMS as a naval deliverable, but rather to demonstrate the potential capabilities of such a system and to develop requirements for national procurement programs. Unfortunately midway through the project, the Royal Canadian Navy (RCN) decided to lay-up and ultimately retire CFAV Quest, leaving the COSIMAR project without a viable replacement.

1.2 Quest Replacement

After an unsuccessful extensive search for a replacement ship, DRDC Atlantic offered to develop a simulation of CFAV Quest that would allow for completion of the COSIMAR project. This would enable the experience gained and data gathered during RIMPASSE to continue to be used within COSIMAR, thus avoiding new extensive supporting sea trials. Included in this offer was the understanding that DRDC would also be required to develop the network infrastructure to support both the simulation and the prototype SMS. This overall environment was called the Signature Management Laboratory and the simulation of CFAV Quest was called SCORSim (Signature COntrol Room Simulator).

This paper outlines the various components of the SigMa Lab and SCORSim developed by DRDC, the capabilities available from these components and their expected modes of operation. As noted, while the system was developed for CFAV Quest and COSIMAR, possible future uses of the system are also discussed.

2.0 SIGMA LAB

As noted above, SigMa Lab was conceived in response to the decommissioning of CFAV Quest. It should also be noted that trials data from the RIMPASSE trial were available and became the underpinning of the SigMa Lab concept.

The SigMa Lab is a completely simulated environment in which atmosphere, ocean, and all aspects of the ship may be completely controlled. The basic concept is to create a virtual Quest operating in a virtual environment and also includes the communication between different entities and the hardware infrastructure required. Note that it is not expected that the entities will reside on one computer. An integral part of the ship simulation is the ability to mimic the sensors which would be applied to the ship to inform the signature calculations. The availability of RIMPASSE trial data allowed the creation this high-fidelity sensor data to be recreated in the simulated environment over a wide range of conditions.

The SigMa Lab also includes several modules that do not directly contribute to simulation, but are vital for testing signature management systems, including the Sensor Error Notification System (SENS) and the SigMa Acquisition Sensor Server (SASS). Figure 1 shows a schematic of the overall system including the relation of the SMS. Note that, in this concept, both the virtual ship and the SMS can be replaced. To complete the integration of the SMS, it was also necessary for the SigMa Lab to be able to respond to the SMS. For example, the operational SMS may recommend a change in ship state or ship speed or heading and the simulations must be able to respond to these messages.

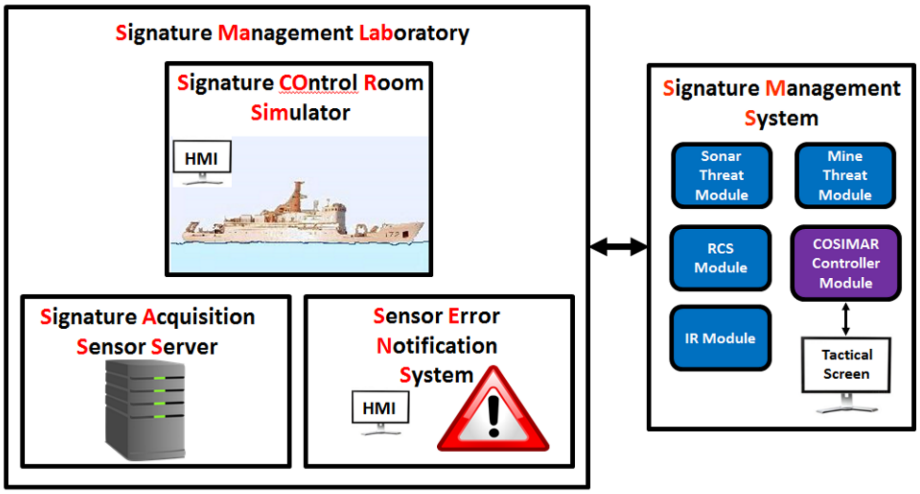

Figure 1: SigMa Lab schematic

In the overall COSIMAR concept, the SMS would reside in the ship's Operations Centre for use by the relevant Combat Systems officer. The Sensor Error Notification System is used to monitor the various sensors used for signature predictions to insure they are functioning correctly and also has a capability for investigating signature errors arising from platform issues (e.g., a malfunctioning pump). The Signature Acquisition Sensor Server is the basic data server for the entire system storing data for recall, error investigations, and future analysis. Both systems would likely reside in the ship's Machinery Control Room for use by the ship's engineering staff.

3.0 SCORSIM

The Signature COntrol Room Simulator (SCORSim) is the heart of the SigMa Lab. This simulator must be able to estimate the ship state, the environment, and sensor information and be able to follow a variety of realistic scenarios. SCORSim provides the virtual ship used in the COSIMAR project and is a high-fidelity model of the decommissioned CFAV Quest. The virtual ship is composed of models that interact in a publish/subscribe framework. From this framework, sensor data for each signature modality is then generated and published to the simulated ship's network. The format of this data is as it would appear during a sea trial on Quest itself. Note that the key point that distinguishes SCORSim from other naval simulators is that the SMS requires sensor data to be able to predict the ship signatures (e.g., hull vibrations for acoustic signatures and hull temperatures for infrared signatures). Modules within SCORSim simulate this sensor data for all sensors which were installed on Quest. These include hull and machinery accelerometers, magnetometers, Active Shaft Grounding (ASG) voltages, Impressed Current Cathodic Protection (ICCP) currents, and hull temperatures.

The simulator also simulates the environment in which the ship is operating. This includes data such as bathymetry, sound speed profile, air and water temperatures, sea state, wind, rain, visibility, and the local earth magnetic field. For ship state, simulations include speed, heading, ship motions (dependent on sea state), and machinery configurations (including simulated errors such as a faulty pump).

Figure 2 shows a schematic of all the entities contained within SCORSim. The system works under a High Level Architecture (HLA) [7] distributed simulation environment with various federates or simulation entities contributing. The green boxes indicate separate modules or controllers for the environment and sensors which will be described in the sections below. Note that on Quest the platform management system was called an Integrated Machinery Control System (IMCS) and the associated boxes are shown in blue. The orange boxes show the separate federates for operating the ship (helm) and viewing the ship on the water (viewer). The purple boxes are the ship motion broadcaster and the ship data broadcaster (required for other components of the SMS) and the red Simulation Controller allows modifications to environment, sensors and assets during the running of the simulation.

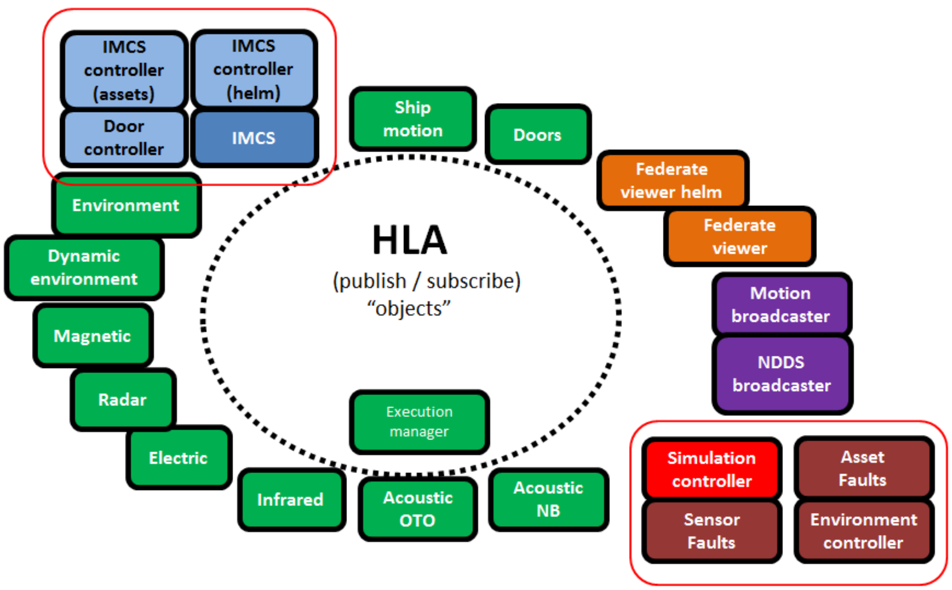

Figure 2: SCORSim schematic

While SigMa Lab currently has only CFAV Quest as its virtual ship, it is possible to further develop it with other ships provided a model and data are available. Such additional work has not been undertaken as of the completion of COSIMAR.

3.1 SCORSim Controllers

The virtual ship and its environment are controlled with six separate applications. Their names and primary functions are described below. Except for the helm controller (used for changing speed or heading, for example), changes to the ship or environment must be registered with a "send command" button click before the changes take effect.

- IMCS Assets: All machinery (e.g., diesel engine, pump, propellers) on the virtual ship are designated as "Assets" and may be toggled on or off from this application (see Figure 3). Assets are assumed to have an impact on acoustics and are viewable by category in separate tabs. By design, the virtual ship defaults to an all-off state.

Figure 3: IMCS Asset example

- Assets Fault Controller: Each machine on the virtual ship may be made to fail from this application. Varying failure modes are possible including an overall noise increase and a single frequency noise spike.
- Environment Controller: All environmental data can be manipulated from this application. SCORSim can automatically extract environmental variables such as bathymetry and sound speed profiles from stored databases based on ship location. Key environmental parameters that may be adjusted include shipping density, rain rate, surface temperature, water and bottom conductivity and reference location (the location from which the simulation begins). Note that sea state is allowed to range from SS0 to SS5 assuming that signatures in very high sea states are less relevant. Exact replication of ship location from one scenario to the next is currently impossible without restarting the federation.
- IMCS Helm: The virtual ship's heading and speed may be adjusted from this application (see Figure 4). If the propellers have been turned off in IMCS Assets, making a speed change in the Helm application

overrides this and turns one of them on. To achieve full speed for Quest, the diesel generator buttons must both be illuminated in the Helm control panel. Ship's heading may be set by course or rudder angle and an autopilot is available.

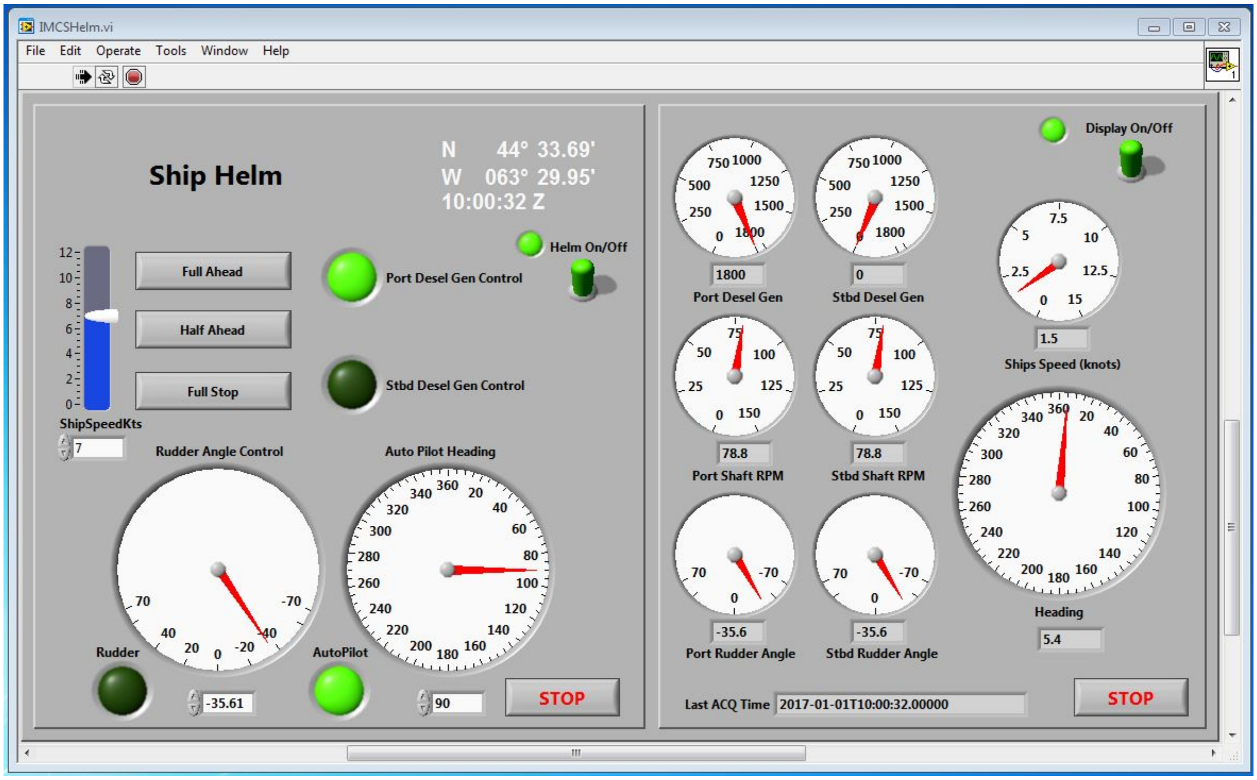

Figure 4: IMCS Helm

- Door Controller: To adjust the radar cross-section (RCS) of the ship, external doors may be opened and closed. This is achieved through the Door Controller. This controller also sets the state of any radar absorbing panels such as crane hoods.
- Sensor Fault Controller: To examine the use of both the SMS and, in particular, SENS, faults in the various sensors (e.g., accelerometers) may be introduced. They can include a loss of signal, an abnormally high signal level or a signal frequency spike.

All controllers are manipulated by similar interfaces available to the operator of the simulation. The values created by the controllers are published to be available to those simulation entities that require them.

3.2 SCORSim Federation

As noted above, SCORSim is based around the HLA distributed simulation environment and, as such, is composed of a number of federates or simulation entities. Each federate subscribes to the information it requires and then publishes the information produced within it for possible use elsewhere. In the HLA environment, a Run Time Infrastructure (RTI) is required to control the overall simulation timing and, in this case, the particular RTI used is CERTI 3.5.1. In this section, some of the various federates that are used in SCORSim are described.

Note that the federate "names" are the actual nomenclature used for the executables.

- FedExecutionManager.exe: This federate does not subscribe or publish any of the HLA models. It is responsible for controlling the HLA interactions that start, stop, and time step the simulation.
- FederationController.exe: This federate subscribes and publishes all the HLA models. It also subscribes to topics from various GUIs that allow the SCORSim HLA models to be modified while the simulation is still running.
- FedAcousticSensor.exe: This federate subscribes to the simulated ship, environment, and various assets and acoustic sensor HLA models. It publishes data for use by the acoustic sensor HLA model. The same federate can be used with either the one-third octave or narrow band data. Based on ship speed, heading, wind, wind direction, and asset states, it calculates acoustic sensor (accelerometer) values.
- FedDoorSensor.exe: This federate subscribes to the environment, door assets, crane hood, and contact sensor HLA models. It publishes for the contact sensor HLA models. Using the given door and crane asset states, it calculates the contact sensor values (for the RCS calculation).
- FedDynamicEnvironment.exe: This federate subscribes to the surface vessel, propeller, rudder, and environment HLA models. It publishes the environment HLA model. It calculates the environmental factors that change as the ship moves, such as bathymetry, water temperature, local magnetic field values, water density profile, ambient temperature and position of the sun relative to ship's world location, year, date, and time of day.
- FedElectrometerSensor.exe: This federate subscribes to the surface vessel, environment, and hull ICCP asset HLA model. It publishes the electric signature sensor HLA model. It uses the current ship speed and water resistivity to calculate the hull ICCP currents at the electric sensors.
- FedEnvironment.exe: This federate subscribes to the environment HLA model and publishes the initial environment HLA model. Using the configuration files provided, this federate will load the static environmental data for the simulation (from the controller) including the starting time and position of the simulation.
- FederateViewer.exe: This federate subscribes to the surface vessel and environment HLA models. It publishes nothing. Depending on the configuration file loaded, this federate will display either the world map with the ship track or the 3D ship model.
- FedIMCS.exe: This federate subscribes to the surface vessel, propeller, environment, and all asset HLA models. It publishes helm controller and asset HLA models. This federate also subscribes to the asset state and helm control topics.
- FedMagnetometerSensor.exe: This federate subscribes to the surface vessel and environment HLA models. It publishes magnetic signature sensor HLA models. Using the position of the surface vessel, it calculates the change in the magnetic field around the ship.
- FedNDDSBroadcast.exe: This federate subscribes to the surface vessel, propeller, rudder, environment, and all the sensor and asset HLA models. It does not publish any HLA models. This federate translates the HLA model traffic to a format useable by the COSIMAR system, and publishes it to the appropriate topics on the simulated ship's network.
- FedShipMotion.exe: This federate subscribes to the environment and controller HLA models. It publishes the surface vessel, propeller, and rudder HLA models. This uses the wave data from the environment and the ship helm controls to predict the ship motions (calculated using a pre-defined

Bretschneider spectrum wave train through DRDC's ShipMo3D software [9]).

- FedTemperatureSensor.exe: This federate subscribes to the surface vessel and environment HLA models. It publishes the temperature sensor HLA models. Using the ship's position and the sun position from the environment, the federate calculates the temperature at various points on the ship.

As can be seen from this partial list, SCORSim calculates and maintains the ship motions and manoeuvring, the machinery states, the various sensor readings, and the environment around the ship and makes them all available to either other federates within the simulation (e.g., ship motions for accelerometer readings) or to whatever Signature Management System is attached. In practice, SCORSim has become a virtual ship to which you can attach any SMS to test its functionality without taking a "real" ship out for sea trials. Note that the content of some of the federates may have to be changed to accommodate a different ship, but the structure of the system can remain fundamentally the same.

4.0 SASS

Another key component of the SigMa Lab is the database used for both short- and long-term storage of data from the entire system. The SigMa Acquisition Sensor Server (SASS) module can log any specified topics published by any module on the COSIMAR gate network. SASS logs these published topics to a file structure that may be queried at a resolution of one minute via a standard HTTP web request. Since the published data is logged as a string, the returned data is in the format in which it is originally published. The original published data is visible as a JSON message [10] within the returned XML format.

The primary use of such functionality is likely to assist with either signature or sensor diagnostics. For example, if there is a sudden change in a particular signature, the database may be examined to determine when the change occurred and the ship conditions when it changed. It could also be used to examine a particular topic over a specified time period or to save the signature-related data for later analysis.

Currently databases for such topics such as bathymetry, ocean temperatures, and earth magnetic fields are loaded as required. It is possible that a shipboard version of the overall COSIMAR project would tap into existing shipboard databases, but a future capability for preloading static information could also be incorporated into SASS.

5.0 SENS

The Sensor Error Notification System (SENS) was initially designed as an aid to identifying faulty sensors during trials at sea. It remains a part of the SigMa Lab for its usefulness in testing and troubleshooting, but has been redesignated as the SEnsor Monitoring System (SEMS). The new SENS design now focuses on a display that would appear in a warship's Machinery Control Room (MCR). SENS' primary use is to notify the ship's crew of potential issues with the ship's suite of signature-related sensors.

Figure 5 shows SENS' main interface. The interface is designed to be simple and occupy minimal screen space, enabling the user to determine sensor status at a glance. Each sensor suite has a light (LED) associated with it; a green LED indicates that the suite of sensors is error free.

Figure 5: SENS main interface

SENS will notify the user when a sensor error has been detected (e.g., a limit has been exceeded) by changing the appropriate suite's LED colour to amber. Figure 6 shows SENS indicating that at least one limit has been exceeded on the acoustic sensors. Clicking on the appropriate signature's button brings up an incident board for the ship as seen in Figure 7.

Figure 6: Potential acoustic error

The incident board displays sensor status and location. The sensor colour indicates its status: red means confirmed error, amber means limit exceeded (error encountered), green means good working order. Sensor data can also be viewed, and errors investigated, by clicking on the sensor. The user may also view current and historical sensor data, and manage errors by changing their status between the three possible states, which are confirmed, encountered, and ignored. A change in sensor status invokes a change the associated sensor indicator colour and icon shape (square versus triangle versus circle).

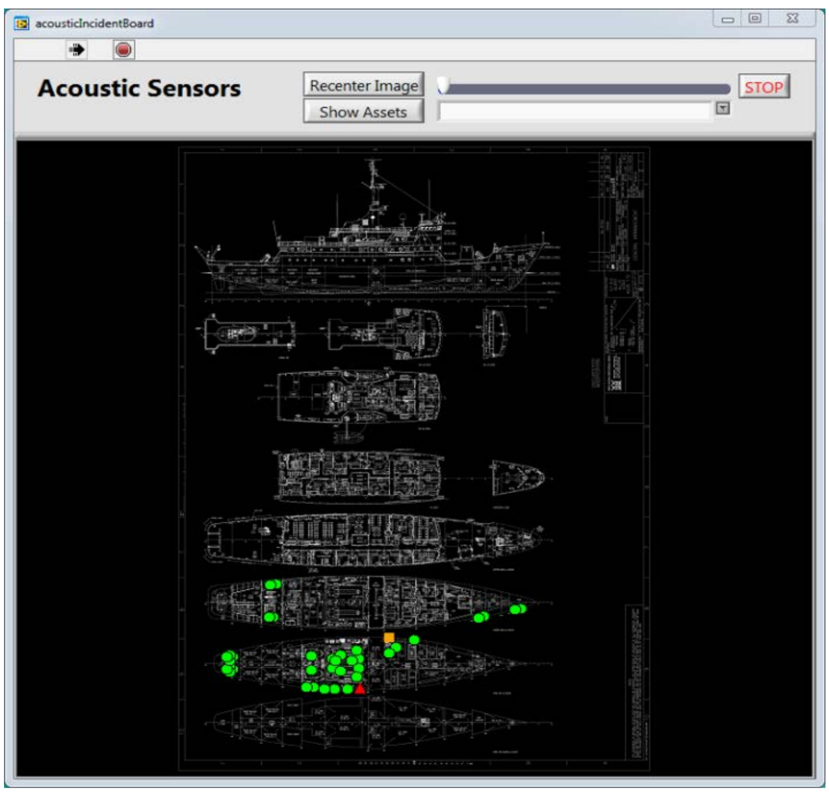

Figure 7: Acoustic incident board

An example of the 1/3-octave band accelerations for a particular accelerometer (current values shown in black, limit values in red) is shown in Figure 8 as well as the latest history (which can be scrolled through).

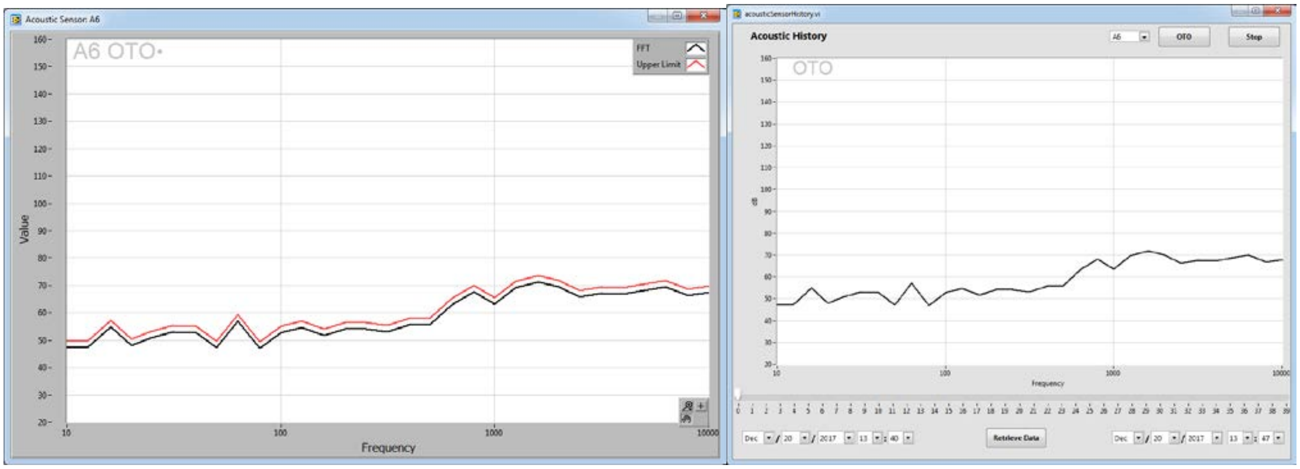

Figure 8: Live sensor data and history

6.0 CONCLUSION AND FUTURE USES

As shown here, the SigMa Lab provides a capability for demonstrating a prototype signature management system, replacing planned sea trials aboard CFAV Quest. The SigMa Lab is a completely simulated environment in which atmosphere, ocean, and all aspects of the ship may be completely controlled and includes the Sensor Error Notification System (SENS), the SigMa Acquisition Sensor Server (SASS), and the Signature Control Room Simulator (SCORSim). The SCORSim simulator is able to estimate the ship state, the environment, and sensor information to effectively recreate a model of a ship (CFAV Quest at this time) sailing through an environment and also reproducing all the components necessary to estimate the ship's signature in real time.

This capability was demonstrated in September 2017 at the CSSM Signature Management Conference in Ottawa, Canada. However, there would not have been sufficient justification for the development of the SigMa Lab if this was the only application. Overall, the SigMa Lab environment provides a unique capability for examining the performance of any signature management system in general without taking one to sea. While the current system is based on Quest, future Canadian work could include modelling of the current RCN frigate or the future naval combatant which would allow testing of planned signature management systems in advance of installation or trials.

Note that, aside from the SMS testing capability, the SigMa Lab components are also generating actual ship signatures in a simulated environment. This capability could be included in engagement modelling or tactics development using "live" rather than "canned" signature data for a variety of vessels or environments which may not be accessible to the operational platforms. The acoustic portion of the signature capability could also potentially assist with monitoring of ship noise for environmental concerns or monitoring ship vibrations for equipment health.

Finally, the development of the SigMa Lab and the COSIMAR SMS can provide significant guidance in setting requirements for future acquisitions of both naval platforms and signature management systems.

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