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# Development of a Sensor Testbed for Maritime Autonomous Surface Ship Situational Awareness

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## ABSTRACT

The National Research Council of Canada's Ocean, Coastal and River Engineering Research Centre (NRC-OCRE) and Automotive and Surface Transportation Centre (NRC-AST), along with Transport Canada's Innovation Centre (TC-IC), have been collaborating over the past three years to develop systems and methodologies for investigating sensor performance on marine vehicles. A large portion of this effort has been dedicated to the development of a so-called "Maritime Autonomous Surface Ship (MASS) Sensor Testbed" - a platform for evaluation of various sensors utilized for marine vehicle situational awareness, particularly in the context of harsh environmental conditions.

Equipment suitable for deployment on model-scale and full-scale vessels in harsh environments was developed, and was deployed on a physical model-scale Offshore Supply Vessel and on a 5.5-meter Rigid Hull Inflatable Boat (RHIB) designed for autonomous surface research and development. Tank tests were performed in 2021 with a model-scale sensor testbed that informed the development of a full-scale sensor testbed. In 2024 and 2025, field trials were conducted in varying environmental conditions near port infrastructure while docking and maneuvering both in isolation as well as in coordination with an additional autonomous vessel platform (also capturing sensor data).

KEY WORDS: MASS; ASV; LiDAR; EOIR Camera; Image Processing

## INTRODUCTION

As operations of marine vehicles become more autonomous, the requirements for situational awareness increase. Not only does more need to be known in real-time about a vehicle's immediate environment and relative uncertainty, but in order to maintain similar operational envelopes to manned marine vehicles, immediate environments must be discernable in increasingly harsh conditions (e.g. rain, snow, ice, fog, heavy waves, night, etc.) Even with sensor capabilities which can overcome these conditions, many existing approaches for environmental perception from sensors (such as those which fuse information from optical cameras and LiDARs) rely on assumptions which are unsuitable in presence of environmental disturbances and large periodic vehicle motions. Moreover, it is becoming important to better understand sensor selection requirements for any given marine vehicle, its level of autonomy and desired operational envelope.

The goal of this work was to develop a testbed for the data collection and evaluation from common marine sensors in realistic harsh conditions, and for it to be deployable across a range of marine platforms. TC-IC and NRC-AST collaborated in prior projects related to the development of a sensor framework for the autonomous surface transportation sector. The experience gained by NRC-AST in these efforts was used to catalyse this work, providing the base platform for data collection and evaluation as well as a suite of sensors similar to those used in the autonomous automotive research sector. Physical model-scale tests were performed in St. John's in the Offshore Engineering Basin utilizing scaled harsh sea states and plastic ice. Data was collected from LiDAR, cameras (optical and near-wave infrared/projected depth patterns), and Inertial Measurement Units (IMUs) with the intention of assessing Simultaneous Location and Mapping (SLAM) performance, while ground truth six degree-of-freedom motions were captured by the basin's optical tracking system.

Effort was undertaken to scale this testbed to full-scale, and sea-trial activities to support MASS research efforts were performed. Data from cameras (optical and medium-wave infrared) and LiDARs in these environments is presented and discussed. Finally, a discussion of the ongoing work within this project is presented, particularly with respect to sensor selection for a given autonomous application.

## PHYSICAL MODEL SCALE TESTBED

### Overview

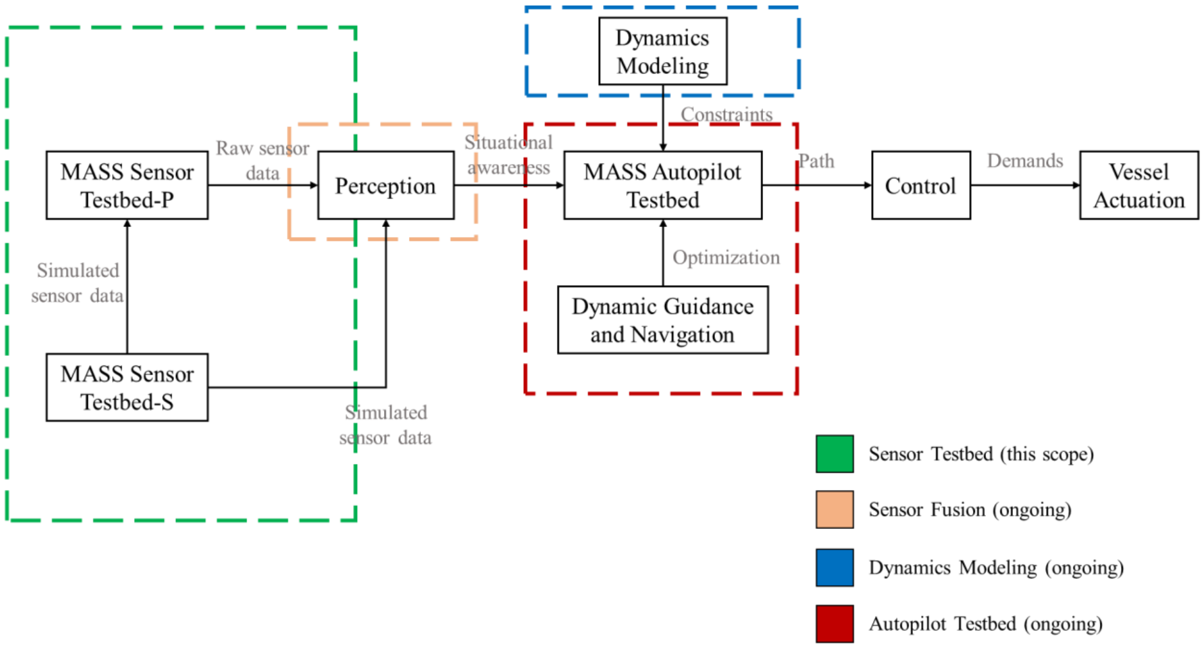


Figure 1. High level architecture of the sensor testbed

Significant software development activities facilitated the integration of a set of sensors with a framework implemented within the Robot Operating System (ROS, *Open Robotics*), as well as the integration of the MASS Sensor Testbed with an existing control system evaluation testbed (the NRC MASS Autopilot Testbed, *Murrant et al. 2021*).

Figure 1 illustrates the overall architecture of the MASS Sensor Testbed system developed herein. It contains two components, Testbed-P (physical) and Testbed-S (simulated), each interfaced to both perception algorithms as well as the MASS Sensor Testbed (designed for autonomous control development). The right-hand side of this illustration represents future application of this work, integrating the interpreted data of this testbed directly into planning and control. It also highlights other ongoing research areas for MASS within the NRC.

A physical model testing effort was performed using the sensor testbed package in the NRC St. John's Offshore Engineering Basin (OEB) in varying sea states and with simulated ice pieces. Effort was undertaken to assess the sensor performance in these conditions as it pertained to required autonomous functions.

## Sensor Components of Testbed-P

MASS Sensor Testbed-P represents the physical implementation of a testing platform for MASS sensor performance benchmarking. This system is composed of hardware and software elements. The hardware elements include different sensors, computing hardware, data and power sub-systems. The software elements include drivers for the sensors, perception algorithms, data processing algorithms, etc. under the ROS framework. ROS was selected as the preferred framework because of its scalability, open-source support community and wide adoption by industry and academic researchers.

As a demonstration of its capabilities, Testbed-P was developed for testing in the NRC’s OEB to identify sensor performance as a function of varying sea states. Major components of this system are listed in Table 1.

## Physical Model Scale Testing

The model chosen for this testing program was a representative Offshore Supply Vessel (OSV - shown in Figure 2), fabricated for a previous testing program performed in the NRC St. John’s Ice Tank test basin.

This model is manoeuvrable and is large enough to easily accommodate a large sensor payload both in terms of weight as well as available electrical power.

The physical model testing component of this work occurred from November 29th to December 17th, 2021. The vessel followed a prescribed track circuit around the OEB, all while collecting data from the sensor testbed. Sensor data was collected as a function of various sea states.

Fixed obstacles in the basin, as well as floating obstacles (yellow surface buoys shown in Figure 3) were deployed and surveyed for position. As manoeuvring space was limited, and as obstacles were relatively densely spaced, tractor path circuit (a zig-zagging path that covers the entire basin surface area with the same start and end point) was manually designed for this testing effort. This allowed for good sensor coverage of these obstacles from multiple view-points.

Table 1. List of Testbed-P equipment

| **Equipment** | **Specifications** | **Remarks** |
|---|---|---|
| LiDAR × 1 | Velodyne VLP-32C<br>360° horizontal FOV<br>40° vertical FOV<br>200m maximum range | Provides point cloud representation of the operational environment.<br><br>Susceptible to weather-induced performance issues (e.g., rain, snow, fog). |
| Infrared Camera × 3 | Intel RealSense D415<br>850nm wavelength<br>65° horizontal FOV<br>40° vertical FOV | Enhances image sensing in challenging photonic conditions.<br><br>Provides redundancy to RGB camera. |
| RGB Camera × 3 | Intel RealSense D415<br>69° horizontal FOV<br>42° vertical FOV | Acquires high-level features from the operating environment.<br><br>Enables object recognition using ML-based and traditional CV-based techniques. |
| Radar Array × 1 | Texas Instruments mmWave 76-81 GHz radar<br>Single plane sensing with ±60° horizontal FOV per element<br>3 elements providing ±150° horizontal FOV | Provides sparse point cloud.<br><br>More resilient to weather conditions than LiDARs. |
| IMU × 1 | - Xsens MTI-100-2A8G4 IMU<br>- MEMS implementation<br>- Up to 2000Hz data rate | Facilitates LiDAR-based HD-map generation.<br><br>Enables dead-reckoning capabilities. |
| Computer × 1 | - High-performance computer<br>- Intel Core i7 CPU<br>- NVIDIA RTX GPU | Runs Ubuntu 18.04 OS with ROS-Melodic system.<br><br>Requires high performance for lossless recording of sensor data streams. |

Figure 2. Model as-instrumented during basin trials

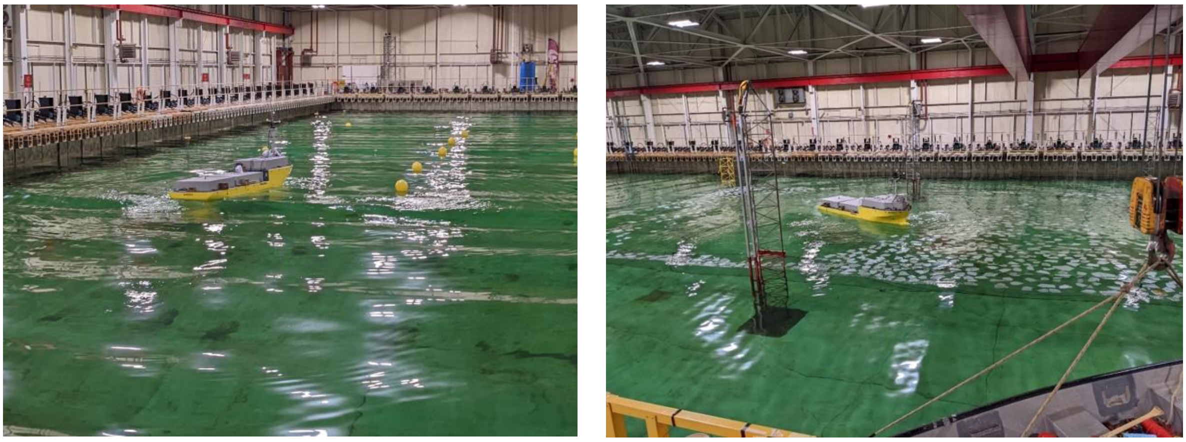

Figure 3. Model vessel traverses medium sea state with buoys (left) and plastic ice (right)

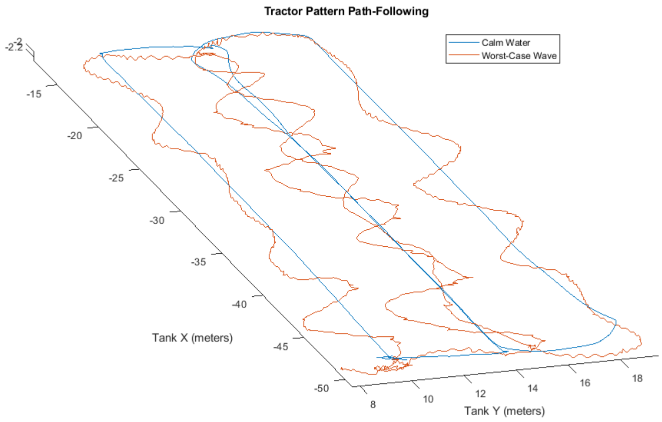


Figure 4. Tractor pattern path following in different sea states

The tractor path was configured within the MASS Autopilot Testbed, and a Dynamic Positioning control scheme was implemented to maintain a tight manoeuvring performance, reducing drift from path and risk of damage to equipment.

Figure 4 compares the results of track-keeping in the calm and worst-case sea state conditions. While the vessel struggles to maintain its sway-keeping in the worst-case sea, the controller successfully maintains the track, allowing for a comparison of the same sensor observations.

An opportunity arose in January 2022 to use simulated managed ice pieces in the OEB composed of polypropylene. While not possessing the material properties of scaled sea ice, polypropylene is similar in density, allowing for reasonable approximation of momentum-type interactions of unconfined ice-covered waters.

Sensor data was collected as the vessel performed various manoeuvring operations in the basin as shown in Figure 5 and Figure 6.

It was determined during preliminary analysis of the data that the Xsens IMU specified for this project did not have the capabilities required to successfully perform coupled IMU/LiDAR Simultaneous Location and Mapping. As such, analysis considered LiDAR-only SLAM.

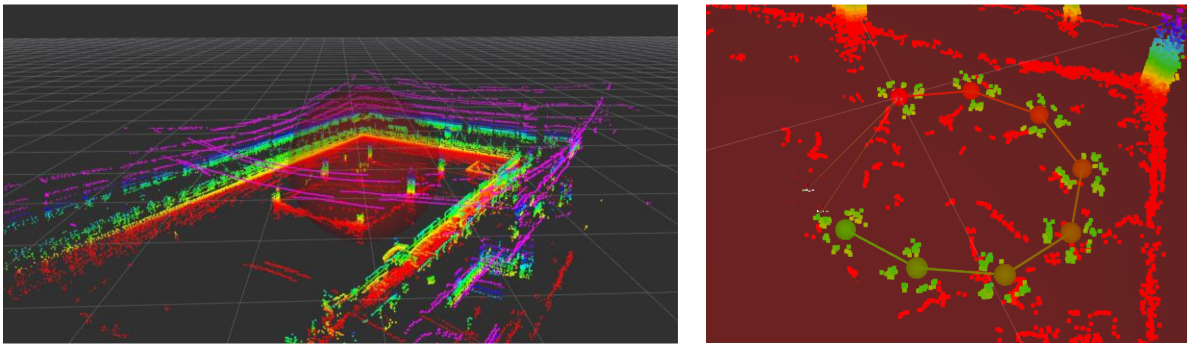

Figure 5. Detected features from LiDAR in ice configuration (left) and SLAM partially estim ated path (right)

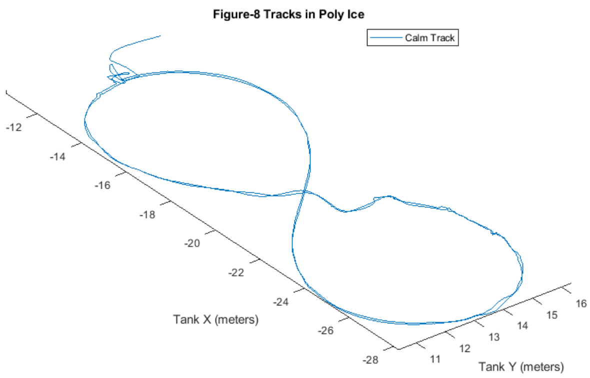


Figure 6. Baseline path measurement from optical tracking system.

Figure 5 shows a small portion of the LiDAR-only SLAM tracking results of a “figure-eight” track in the ice field setup, while Figure 6 shows the results of the complete manoeuvre as measured by the Qualisys optical tracking system. For calm water scenarios, LiDAR-only SLAM performed well. For heavy wave conditions, however, performance was poor.

## FULLSCALE TESTBED

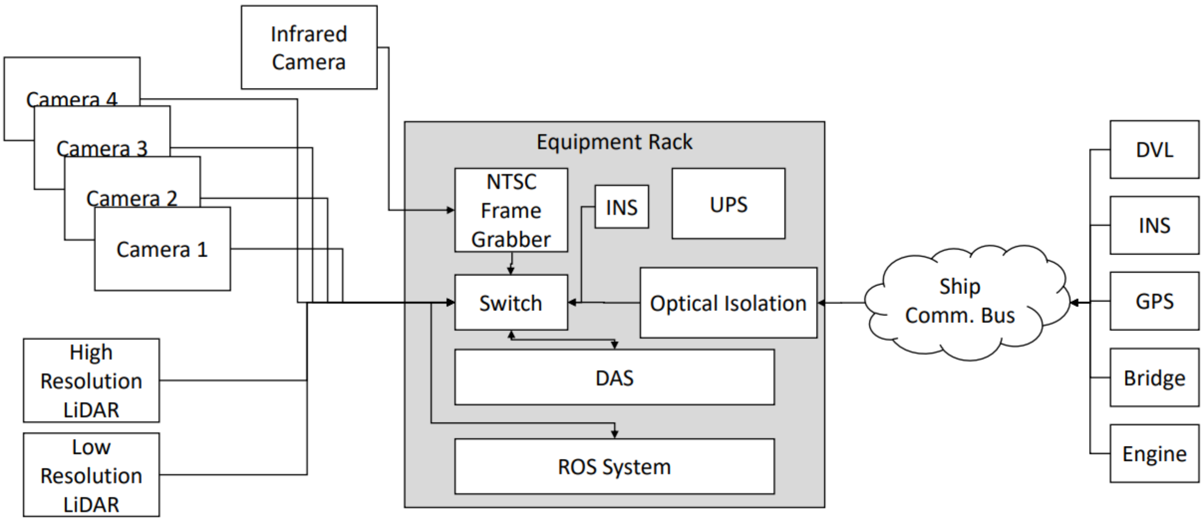


Figure 7. Sensor testbed augmentation for sea-ready deployment

In order to deploy the MASS Sensor Testbed onboard a full-scale vessel, several additional design requirements had to be met over requirements specified for previous laboratory testing work. An overview is shown in Figure 7.

Specialized marine-rated Data Acquisition Systems (DASs) and ROS PCs, ship power conditioning as well as optical isolation equipment (for interfacing with existing ship-board data streams from NMEA 2000 devices and other equipment) were acquired, along with harsh-environment-rated optical and infrared camera equipment. These are deployed along with the instruments described in Table 1 (with the exception of non-marine rated such as the mmWave RADAR and RealSense cameras).

## TRIAL ACTIVITIES

The original intended deployment platform for this testbed was to be a large ice-class ship. As previous phases progressed, it was determined that access to large ice-class ships posed a large risk to project completion. As such, effort was undertaken in this phase to adapt equipment from the full-scale deployment Testbed-P to an existing 5.5-metre Rigid Hull Inflatable Boat (RHIB, Figure 8) - a Marine Thinking Acadia - designed for autonomous deployment.

Two primary testing locations on the Northeast Avalon region of Newfoundland were chosen for deployment and data collection activities (Figure 9). As the Bell Island Tickle location is near the St. John’s NRC facility, it was used for short day durations while the Holyrood Bay site was used, for multi-day.

The original testing requirements for this project were to perform data collection activities that emphasize challenging localization problems for autonomous ships. The desired activities included:

- Navigation around vessels,
- Navigation through congested ports,

Figure 8. NRC-OCRE's Marine Thinking Acadia Platform

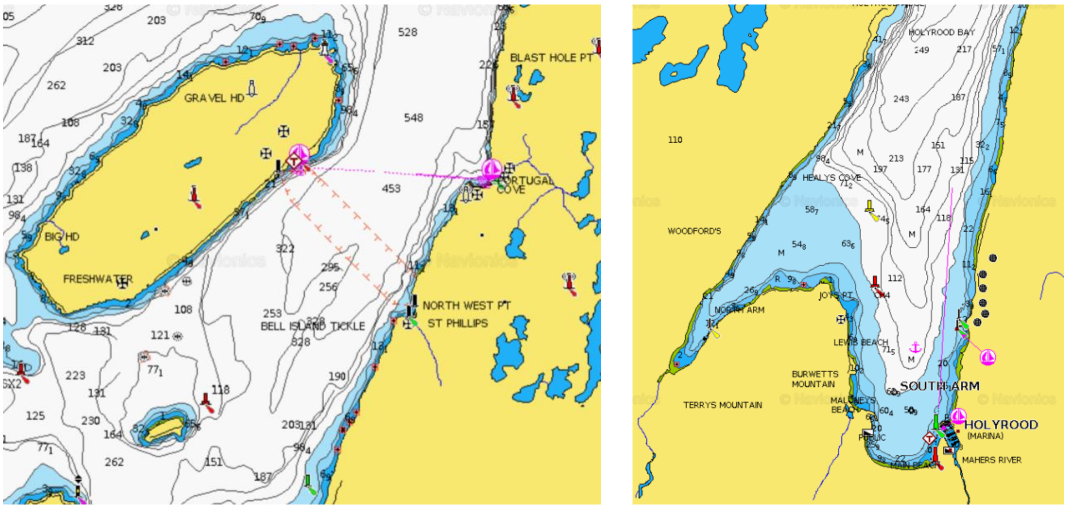


Figure 9. Test site locations (left - Bell Island Tickle, right - Holyrood Bay)

- Navigation through ice-covered waters (seasonally and vessel dependent),
- Docking.

Due to imposed limitations from environmental factors, the testing areas remained free of significant sea ice this season, and no data collection activities were performed during times of high port congestion. However, data was collected in and around other vessels and during docking activities.

**Overview of Trials**

A general trials concept was developed to support the aforementioned data collection goals. In essence, for every testing scenario (e.g., varying environmental conditions, varying vessel traffic and encounters, etc.), effort was made to obtain as many of the following events as possible:

- Data collection craft overtakes other vessel(s) (at varying speeds),
- Other vessel(s) overtake data collection craft (at varying speeds),
- Data collection craft encircles other vessel(s),
- Other vessel encircles data collection craft,
- Multiple craft transit side-by-side,
- Multiple craft move towards each other and evade,
- Data collection craft transits near shore and/or harbour infrastructure, and,
- Data collection craft leaves and enters a dock.

These events provide a rich dataset of practical scenarios for localization and craft detection. Trials were conducted both with opportunistic craft (such as field support craft) as well as in tandem with other data collection platforms (as in Figure 10). Marine Institute's Autonomous Surface Vessel (ASV) was utilized in some data collection activities at The Launch in Holyrood Bay. This allowed for the collection of data which could be used for future development work related to collaborative vessel localization, mapping, and detection.

Figure 10. Two vessels (NRC-OCRE Acadia, left, and MI ASV, right) independently sensing each other and surrounding environment from different perspectives

**Representative Data**

LiDAR and optical camera data is presented in Figure 11 for the scenario of head-on craft interaction near shore. As shown, the LiDAR demonstrates a very feature-dense dataset, ideal for SLAM and vessel detection analysis.

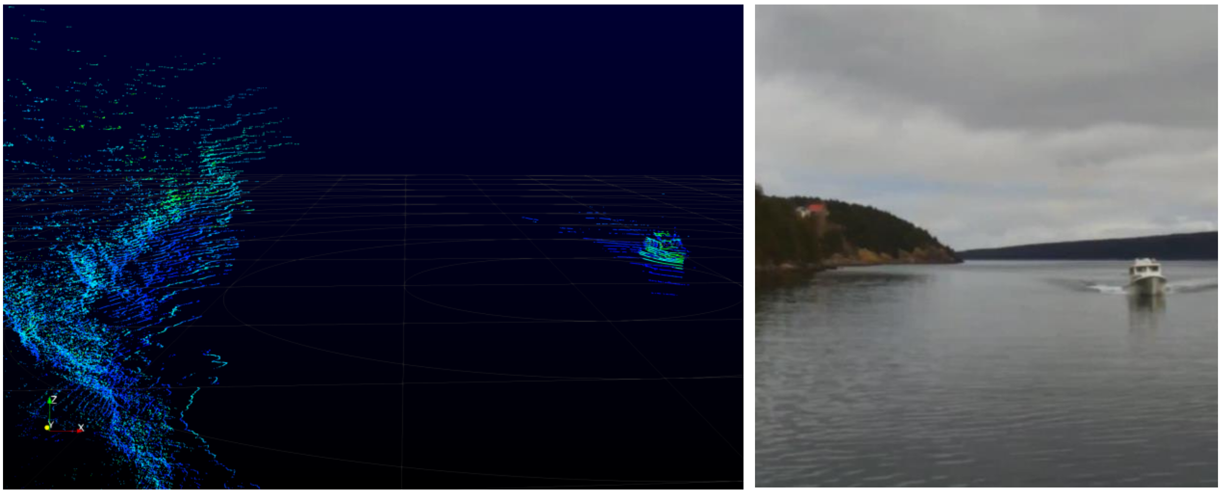

Figure 11. LiDAR and optical data from head-on interaction near cliff-side

## CONCLUSIONS AND ONGOING EFFORTS

Over the past four years, and through a staged development process, NRC-OCRE has successfully developed a sensor testbed platform which shows promise for MASS sensor and algorithm development and evaluation going forward. Data collection activities over the past year have advanced NRC-OCRE capabilities, and has provided a good initial dataset for situational awareness-focused algorithm development.

Effort to process this data with popular SLAM approaches utilized within the robotics research community is ongoing. It is expected that some harsher conditions will provide challenging localization and detection scenarios, and that this will lead to marine-specific development.

Finally, NRC-OCRE looks to continue data collection activities on an opportunistic basis to expand upon environmental conditions (e.g., night, fog, rain, heavy sea state, etc.), sensors, and other vessel types.

## ACKNOWLEDGEMENTS

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## REFERENCES

Murrant, K. & Gash, R. & Mills, J., 2021. Dynamic Path Following in Ice-covered Waters with an Autonomous Surface Ship Model. *IEEE Oceans 2021: San Diego – Porto*.

Open Robotics, 2025. *ROS* [Online] Available at: https://www.ros.org/ [Accessed 4 March 2025].