Characterization and delineation of oil-in-water at the Scott Inlet seeps through robotic autonomous underwater vehicle technology

1. Background

In recent years, there has been an increase in offshore oil and gas as well as shipping operations in the northern Atlantic and Arctic Oceans of Canada. These activities include a high risk of marine pollution, particularly oil spills, which have severe adverse environmental and socio-economic impacts. This risk has highlighted the gap between the need for oil spill countermeasures and current oil spill response capability. As such, there is an urgent need for state-of-the-art technologies in these fields to ensure our readiness for any emergency. The primary objectives of this multi-year project are to develop and characterize autonomous underwater technology to enhance marine robotics capability for oil spill response operation in the oceans.

Among such technologies is advanced subsurface data collection: information about oil in the water column is critical to understanding subsurface oil plume behavior, which can drastically improve the efficiency of an oil spill response. Its importance was highlighted during the Deepwater Horizon blowout in the Gulf of Mexico, one of the largest oil spills in history. In that event, an autonomous underwater vehicle (AUV) was safely and successfully used to characterize the submerged oil plume and provide a comprehensive analysis of the impacted areas. AUVs enable communication of spill information in near real-time, while minimizing personnel exposure to toxic oil spill substances. Such high-resolution (spatial and temporal) subsurface data collection cannot be achieved using traditional methods. By addressing the operational gaps in AUV technology and considering the realistic behavior of oil in water, our project will result in a substantial step forward in delineation of subsurface oil plumes using AUVs. This has the potential to represent a significant improvement in oil spill response capacity and enhances knowledge of marine oil contaminants and monitoring.

2. Research Objectives

The primary objectives of this multi-year project are to develop and characterize autonomous underwater technology to enhance marine robotics capability for oil spill response operation in the ocean. This project, with collaborations from domestic (International Submarine Engineering and Fugro Canada) sector partners, will improve data collection performance and efficiency of AUVs and provide short- and long-term benefits to Canada and local communities.

The long-term objectives of this project are:

- To contribute to the establishment of robotic systems in environmental research that keeps Canada at the forefront of the unmanned underwater vehicle design field and sensing technology.
- To improve marine environmental response protocols using underwater vehicles and developed systems which will be readily available in case of events that bring about pollution.

The short-term objectives are:

- To research AUV based Backseat Driver (BSD) adaptive missions planning for delineation of polluted masses in the water column of varied strength such as potential Polycyclic Aromatic Hydrocarbons (PAH) concentration in the water adjacent to Scott Inlet.
- To extend the capability of autonomous underwater vehicles to enable significantly enhanced artificial intelligence of these vehicles.

3. Research Methodologies

Phase 1: Planning and design of oil detection strategies

Memorial's Explorer AUV will be overhauled for its design rated depth of 3,000m, commercial-off-the-shelf (COTS) oil sensors will be sourced and assessed, and adaptive sampling approaches will be assessed to ensure that the latest and most efficient technologies and methods are applied. The oil detection strategy will consist of both the AUV-sensor system and the adaptive sampling algorithms; these are tightly interrelated, as the decisions to alter the mission file in the BSD approach are made using sensor data. Both sensor choice and the advanced mission control algorithms will be developed for the patchy nature of oil in the water. Our strategy will be designed based on our detect, track, and sample method developed earlier around using sonars to detect and track oil in the water from a distance followed by the use of in-situ oil sensors. The method has been tested in simulations. In field practice, the ability of this method to detect and capture plume features such as boundary and oil concentrations (measured by in-situ oil sensors) within the detected patches of oil will be validated against water samples collected by the onboard multi-water sampler. Search parameters will be established that are practical for the AUV, so that it is able to provide reliable spatial and temporal information of oil in the water column while avoiding frequent deployment and recovery.

Phase 2: Integration of state-of-the-art oil detection sensors on the AUV

Once oil patches are detected by high-frequency sonars, sensors will be used to sample within these patches of oil. Sensors will be selected based on the types of data required, accuracy, and compatibility with the AUV (size, weight, and data transfer method). A range of sensors is required to increase the probability of detection, reduce occurrences of false positives, and help differentiate oil from other substances. Sensors include: a fluorometer to detect the fluorescence of polycyclic aromatic hydrocarbons (PAHs) typically found in significant amounts in the liquid phase of crude oil; a sniffer to detect methane as the main component in the gas phase; a particle analyzer to detect oil droplets and measure their sizes; and water samplers to confirm the presence of oil and provide insights on composition and dispersion of oil. Our engineers will lead the sensor integration required, with support from ISE and sensor suppliers. Integration with the AUV will require hardware and software changes: installing the sensors and brackets on the AUV, re-ballasting the AUV to compensate for the weight of the sensors, connecting the sensors to the AUV's computer, and developing software for real-time processing and access of sensor data.

Phase 3: Development of adaptive mission/sampling for the AUV

An advanced adaptive mission control and sampling algorithm will be developed to optimize mission operations in delineating oil plumes and collecting subsurface spatiotemporal data. The algorithm will use a BSD approach and the middleware MOOS-IvP, a widely used software that facilitates development of autonomy in autonomous marine vehicles. The AUV mission will be adapted in real-time based on decisions made from the payload section. During detect and track modes, the AUV will change its path to move closer to the plume based on the backscatter information provided by the high-frequency sonars. Once the plume location and extent are found, the mission will be adapted from navigating around the plume to entering the plume to take samples. This will enable the AUV to stay in information-rich areas and spend less time searching: important for delineating patchy and discontinuous plumes.

Phase 4: Field deployment

Oil and gas released from natural seeps are believed to realistically represent and behave to some extent like oil spills. We assessed a site on the west coast of NL but did not find sufficient oil in the water column for our research. The next closest extensive subsurface natural seep site is Scott Inlet on the east coast of Baffin Island. This large-scale system has been confirmed by satellite radar imagery, which indicated oil slicks spanning over 250 km^2, representing over 50,000 barrels of surface oil. With significant oil in the water, this is potentially an ideal site to test our AUV's capability, and to obtain data in the canyon extending from Scott Inlet at depths of 1,000 m or more.

We plan offshore field trials for late summer 2023 to facilitate logistics and to avoid winter ice. Before this, during 2022 and up to mid-year 2023, we will test our methods in local in-water trials at the Holyrood Marine Base, NL. For Baffin, several vessel options have been explored depending on cost and their availability. Our preferred vessel is the ex-CCG icebreaker *Canada C3*, now M.V. *Polar Prince*, recently acquired by Miawpukek-Horizon Marine.

Data collected will include sonar images, fluorescence intensity (proportional to PAH concentrations), and sizes of oil droplets. Water samples will be collected using the on-board multi-water sampler, to be analyzed after the mission and used to ground-truth data for sensor measurements collected in-situ. The final result will be an indication of the levels of oil in the water column in the survey area where the AUV is operated. Results from the mission will be assessed to identify issues or adjustments required to improve the AUV-sensor system, as well as the risks associated with the mission.

Phase 5: Risk assessment

This task will provide risk assessment for our field trials. A risk assessment method for AUV missions will be developed using the field trials as a case study. A dynamic risk analysis approach will be established for AUVs during oil spill response. In addition to the AUV's technical factors and payload characteristics, the approach will address risk factors that are often neglected in AUV operations, including human and organizational factors, oil spill environmental factors and navigational risks. These factors will be evaluated based on identified risk variables and quantitative risk levels. The overall risk level will be dynamically updated as new evidence of risk variables are incorporated. For operational risks there are two key risks that must be controlled: first, there is the risk that the vehicle navigates inside the plume during sampling, which may lead to faults or failure; second failure may result from the AUV's intrinsic reliability. We will develop a risk quantification algorithm to diagnose the risk of navigation and internal faults.

4. Progress to Date

We have already set out on the first stage of the project, which includes allocation of the human resources, development of a risk analysis algorithm involved with field trials in Scott Inlet, planning of AUV integration in terms of hardware and software, and the field deployment planning and permit included in this application. The approximate timelines for the project activities are shown below.

Tasks	Year 1 (2022)												Year 2 (2023)												Year 3 (2024)											
1 Research planning																																				
1.1 Technology reassessments																																				
1.2 Design of oil detection strategies								X																												
2 Sensor integration																																				
2.1 AUV modification																																				
2.2 Sensor integration																		X																		
3 Development of mission control																																				
3.1 Develop adaptive algorithm																																				
3.2 Interface with AUV																		X																		
4 Field deployment																																				
4.1 Planning & permit application																		X																		
4.2 Field trials (Holyrood Bay)											X																									
4.2 Field trials (Scott Inlet)																					X												X			
4.3 Data and sample analysis																																				
4.4 Assessment of results																																				
4.5 Improvement of AUV																																	X			
5 Risk assessment																																				
5.1 Develop navigation risk algorithm																																				
5.2 Develop risk algorithm																																				
5.3 Integrate and test algorithms																		X																		
Deliverables & communications																																				
Reports																								X												X
Meeting with Clyde River community								X										X															X			

5. Data Management

We will store data generated on Memorial University's computer systems. Memorial is starting to put in place centralized data management processes in line with Tri-Agency policy and discussions and we will make use of these facilities as they are developed.

6. Research Outputs

The mid-term report will highlight the AUV-based strategy for oil detection with raw results from the field missions. The final report will include the final field trial results and assess the outcomes against objectives. Results will be presented at appropriate meetings, workshops, and conferences (as possible in a post-COVID-

19 world), and at least three publications per year, including in conference proceedings and leading journals.

7. Mitigation Measures

All operations will be carried out from onboard the MV Polar Prince, and waste materials will be carried back to St. John's onboard the vessel. During the operations of the AUVs in water, no discharges are expected to be made into the ocean.