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Remote oil spill detection and monitoring on ice-covered waters

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ABSTRACT

The spillage of oil in Polar Regions is particularly serious due to the threat to the environment and the difficulties in detecting and tracking the full extent of the oil seepage beneath the sea ice. Development of fast and reliable sensing techniques is highly desirable. In this paper hyperspectral imaging is proposed as a potential tool to detect the presence of oil beneath the sea ice. A feasibility study project was initiated to explore the detectability of the oil under ice layer. Some preliminary results obtained during this project are discussed.

I. INTRODUCTION

There is a vast range of techniques available for the open water oil spills monitoring, including various satellite and airborne remote sensing methods [1, 2, 3]. However the detection of oil spills in ice affected waters differs significantly and proved to be much more difficult. Current approaches for oil under ice detection can be divided into two groups: on or above the surface sensing and the detection from underneath the ice. Extensive survey of available techniques for surface remote sensing is presented at [4] while [5] presents focused survey on the oil detection from underneath the ice surface. Various detection techniques, were presented in these reviews, but most of them are described as not applicable for the oil under ice detection. Hyperspectral imaging (HSI) was also included in these studies and similar to the other techniques it was identified as not applicable for this task.

Authors of this work decided to challenge this statement and conduct additional verification of the HSI application for the oil under ice detection [6]. Encouraged by the results of the proof of concept experiment, an extensive feasibility study of HSI application for the detection of the oil beneath the sea ice was initiated and this paper demonstrate the initial results obtained during this work.

II. MATERIALS AND METHODS

The experiments were performed on the premises of Scottish Association for Marine Science (SAMS). The ice was grown in four cylindrical containers (height: 62cm, diameter: 40cm), isolated and placed in a cold room with controllable temperature. The containers were filled with the sea water obtained from Scottish shore. For the ice growth the temperature was set for -30°C (actual temperature readings indicated approx. -25°C) while the temperature maintained during the measurements was approx. -5°C. Crude oil was used for the injections simulating an under ice oil spill.

Two distinct HSI imagers are employed in this study to evaluate the impact of different imaging technologies on the applicability for the oil detection. Both systems were placed in the cold room, approx. 50 cm above ice surface, providing fixed scanning distance for both imaging systems. Figure 1 illustrates the data acquisition setup.

Figure 1. The test setup illustrating both employed hyperspectral systems located above the ice tanks in the cold room.

The first system is a passive hyperspectral camera operating in the near-infrared (Near-IR) wavelength range (900 - 1700 nm) (Red Eye 1.7, Inno-spec GmbH). Since this camera employs a pushbroom scanning technique [7] and the relative movement of the detector versus the sample was provided by mounting the camera on a linear translation stage (Zolix KSA 11-200S4N). Of-the-shelf halogen lamp was used to provide the illumination in required spectral region.

The second hyperspectral system used in this project is an active, laser based, mid-infrared (Mid-IR) (2500 - 3750 nm) hyperspectral imager (Firefly IR Imager, M Squared Lasers) featuring also short range of Near-IR band (1490-1850 nm). As it is a laser based device, providing active illumination during the imaging, no external illumination was required during data acquisition with this system. Additionally, this imager employs a whiskbroom scanning technique [7] and the surface of the ice was scanned by two oscillating mirrors without need for movement of the sample or the detector.

Due to low operating temperature, temperature control is provided for both imaging systems to assure stable performance over the course of the whole experiment.

III. Results

During the experiment a series of measurements was done, comprising from three ice thicknesses (3, 7 and 11 cm) and three thicknesses of oil layer (0.5, 1 and 2 cm) introduced underneath the ice per each ice thickness condition. Each case was imaged with both HSI systems and resulting spectra was analysed. Due to high secularities of the radiation reflected from the ice layer the analysis of the hyperspectral data is always based on the spectra averaged across selected spatial region.

The results from passive system varied significantly between each test condition. Although in most of the cases, it was possible to distinguish the pure ice situation from the one with oil underneath, the features found for one ice thickness were not reproducible for other thicknesses. Additionally there was no consistency between the data sets that could allow drawing any reliable conclusions based on these figures.

The analysis of the data from the active system resulted in the identification of two spectral features that consistently differentiate pure ice from the cases with oil injected underneath the ice, independent from the ice thickness. Figure 2 illustrate the average spectra in the Near-IR region for pure ice and all the oil layer thicknesses for the 11cm thick ice case.

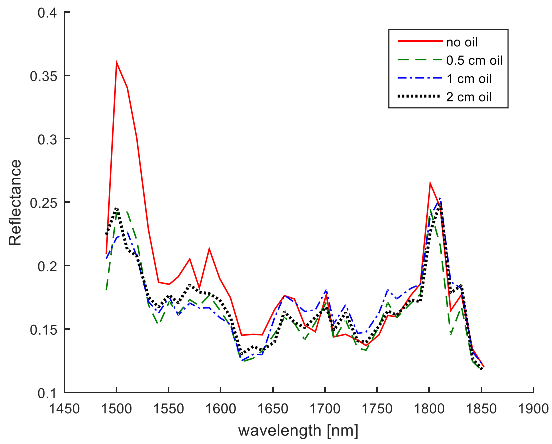

Figure 2. The example of Near-IR spectra of the pure ice and the oil under ice scenarios from the 11cm thick ice condition.

As it can be observed on Figure 2, spectral response of the pure ice case presents a distinct peak at 1500 nm that diminishes as soon as oil is introduced beneath the ice. Similar case is observed in the Mid-IR region with a distinct features observed at approx. 3400 nm, that disappear as soon as oil is introduced beneath the ice. As this phenomenon was observed regardless the ice thickness, it opens a potential to serve as a classification feature for automatic detection of the oil presence underneath the ice.

IV. Conclusions And Future work

The presented, to date obtained experimental results demonstrate that active hyperspectral imager is able to penetrate the ice up to at least 11 cm thickness. Based on the observed spectral features it is possible to distinguish a pure ice scenario from the one with oil layer introduced beneath the ice. The data acquired with the passive system seems to produce inconsistent results in detecting the presence of the oil beneath the ice.

This is an ongoing project and further experiments will aim in confirmation of the observed results, using new techniques such as those in [8-10]. It will also explore the oil detection through thicker ice layers and more diverse oil spill conditions.

Upon the completion of this project we will learn about the limits of presented technological solutions applied for the under ice oil detection.

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