Remote oil spill detection and monitoring beneath sea ice - Appendix

Use of infrared hyperspectral imaging techniques for oil-under-ice detection is a highly challenging task. The infrared region of spectrum is an obvious choice of bandwidth for oil detection, since oil as a hydrocarbonate has rich absorption features in this spectral region. However, high absorption coefficient in the near and mid-IR and high scattering properties from the crystal-like structure of the ice, makes it very unfavourable environment, nearly opaque for electromagnetic radiation in this spectral range. This phenomenon leaves only small portion of illumination penetrating through the ice into the object located underneath. Additionally sea water, making a background for the observation of the oil through the ice, has similarly very high absorption coefficient in this region and provides barely any reflection for scanning radiation (see figure 1).

Accepting this difficult environment we aim to find spectral window (one or more spectral ranges) where this technique could be successfully used for field operation of oil-under-ice detection. Our preliminary laboratory experiment showed promising results that the use of HSI techniques can provide confident detection of the oil under thin layer of the ice. Scan of 15mm thickness layer of oil under 15mm layer of ice allowed to acquire hyperspectral data needed to run classification techniques. Based on differences of the data we were capable to distinguish container with ice only and the one with oil underneath its surface. (see figure 2a and 2b demonstrating imaging targets).

Two hyperspectral imagers are considered in this study – active, laser-based, mid-IR imager, and passive, near-IR push broom hyperspectral camera. Active equipment is based on Optical Parametric Oscillator technology where radiation from fixed wavelength near infrared source is converted into broadly tunable mid infrared source. However, acquisition of hyperspectral data with this device is based on spatial scan of laser beam and slow tuning of the wavelength over the selected bandwidth.
Therefore this technique is ultimately relatively slow for collection of data with high spectral resolution and due to the lack of access to cold room facilities, ice was melting rapidly and scanning with active hyperspectral imager was not feasible in this short trial run. However, imaging was possible with near infrared push broom technology based passive system, which equipped with linear translation stage and external illumination was able to produce high quality hyperspectral data before room temperature was able to affect the ice structure. Based on gathered data we were able to extract spectral signature of both scan conditions (see Figure 3). Despite the fact that both spectra are nearly identical for human eye, raw data from camera was subsequently processed and analysed with use of Support Vector Machine, providing us with classification of two different scenarios – pure ice and oil-under-ice (see Figure 4). This small scale experiment demonstrate that even with very small training set, with moderate margin of error we are able to detect oil under ice. Encouraged by this experiment we anticipate that equipped with professional facilities of temperature and ice growth control at SAMS and access to two state-of-the-art hyperspectral imagers, we will be able to perform thorough feasibility study and define limits of oil under ice detection with use of hyperspectral imaging.
Figure 3. Reflectance spectra extracted from hyperspectral data acquired with pure ice – Image a) – and oil under ice – Image b), where picture on the left represents single wavelength intensity image and red circle indicate region of data used for extraction of spectra presented on the right.

<table>
<thead>
<tr>
<th>Training data (Ice on the left, Ice and Oil on the right)</th>
<th>Classification result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low amount of training data (~5%)</td>
<td><img src="image" alt="Classification result" /></td>
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<td></td>
<td><img src="image" alt="Classification result" /></td>
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<tr>
<td>Medium amount of training data (~25%)</td>
<td><img src="image" alt="Classification result" /></td>
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<td><img src="image" alt="Classification result" /></td>
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Figure 4. Table representing classification results with two different sizes of training data. Column on the left represents single wavelength intensity images, where colourful ellipses illustrate training data provided to the classifier. Red colour illustrate pure ice situation, green colour illustrate oil-under-ice situation and blue colour depicts the background. Column on the right presents result of classification using the colours described above.
Full scale experiment will be performed in cold room where ambient temperature can be fully manipulated and therefore ice growth and maintenance can be controlled. Figure 5 depicts ice tank similar to the one which may be used for this experiment and Figure 6 the diagram of the experimental setup idea.

*Figure 5. Photos of the ice tank available at SAMS*

*Figure 6. Diagram of experimental set-up for full scale feasibility study experiment.*
It is expected that this feasibility study will deliver unambiguous answer about limitations of HSI for oil-under-ice detection. Figure 7 demonstrate possible result of the dependency between oil density and ice layer thickness creating a map of hyperspectral imaging application for oil-under-ice detection.

Figure 7: Expected dependency of oil density and ice thickness on oil-under-ice detection

Similar map with defined optimal settings of HSI devices for oil recognition and initiation of spectral library of different scenarios will constitute set of deliverables of proposed feasibility study project.