

EVALUATION AND PERFORMANCE ANALYSIS OF HYDROCARBON DETECTION METHODS USING HYPERSPECTRAL DATA

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ABSTRACT

Different methods for the detection for hydrocarbons in aerial hyperspectral images are analyzed in this study. The scope is to find a practical method for airborne oil spill mapping on land. Examined are Hydrocarbon index and Hydrocarbon detection index. As well as spectral reidentification algorithms, like Spectral angle mapper, in comparison to the indices. The influence of different ground coverage and different hydrocarbons was tested and evaluated. A ground measurement campaign was conducted with controlled contaminations and manual definition of ground truth data, to evaluate the performance of the detection methods. Additionally, the discriminability between wet ground and oil-contaminated ground is investigated, along with the temporal influence on oil spill detection.

Index Terms— Hydrocarbon index, Oil spill, Mapping, Hazard, Environment monitoring, Airborne hyperspectral imaging, Spectral reidentification, Otsu threshold, Limiting performance

1. INTRODUCTION

Detection of hydrocarbons (HC) is an important task in disaster management. For instance oil spills on land or water may cause great damage. Hydrocarbons like crude oil and diesel remain essential for industrialized societies, but infrastructure for their production, processing and transportation are a potential environmental threat. Cost efficient monitoring of these infrastructures, e.g. pipelines, is a significant ongoing problem for disaster prevention, as well as fast hazard mapping in case of an accident to coordinate counter measures.

Purpose of this work is to estimate the limiting performance for the detection of hydrocarbons with hyperspectral (HS) sensors for airborne applications. A terrestrial experiment with HS sensors is conducted to determine how HC detection methods perform for different types of land coverage like soil and sand, given the two most important types of HC, crude oil and diesel and the quantity of the contamination.

2. HYDROCARBON DETECTION METHODS

[1] showed that oil detection can be done with Hydrocarbon Index (HI) and Hydrocarbon Detection Index (HDI). Both indices utilize an absorption minimum in the SWIR range of a spectrum, caused by the presence of hydrocarbons. Similar to the well-known NDVI, both indices are based on a band ratio and can be used without any knowledge of occurring materials or reference spectra. Further information has to be used to distinguish between oil and other materials that contain hydrocarbons, such as bituminous roofing felt or plastic [Fig. 1]. This has to be done by classification of HS images, by a plausibility check or additional use of spectral reidentification algorithms.

A different approach is to identify oil containing areas by spectral reidentification methods like Spectral Angle Mapper (SAM) [2] or Spectral Information Divergence (SID) [3]. Since spectral reidentification methods may be too difficult to apply because reference spectra may be too dangerous to collect during an oil spill event or a catastrophe, these are included in the presented study only to compare their performance with HI and HDI.

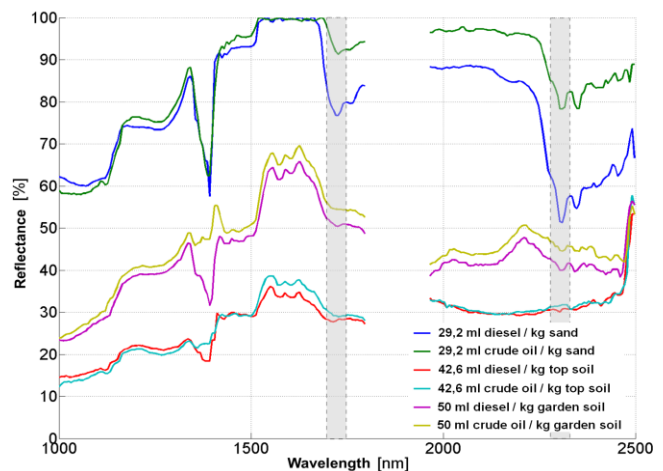


Figure 1: Spectra of different hydrocarbon contaminated ground types. The grey boxes show HI (left) and HDI (right) features. The strength of the features depends on the ground type and the concentration of the HC.

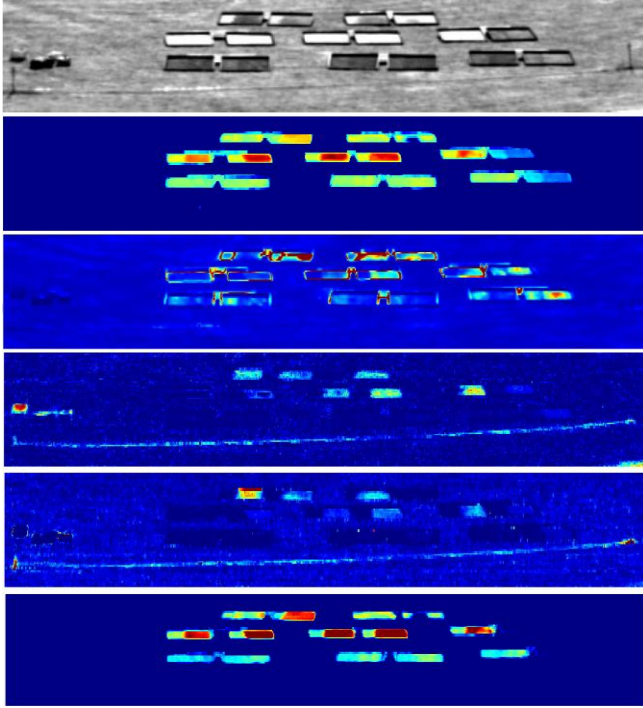


Figure 2: One channel of a hyperspectral SWIR image, showing oil catch pans filled with different materials, contaminated with crude oil and diesel on the right side in each pan, visible is also a plastic caution tape in the front and other plastic objects in the left. Below are the index images of SAM, SID, HI, HDI and at the bottom a combination of SAM and HDI.

2.1. Hydrocarbon Index

Hydrocarbon Index [4] uses the absorption feature of hydrocarbons at 1730 nm wavelength. For every pixel of a hyperspectral image, the length of a vertical line between the absorption feature and a connecting line between the neighboring reflectance values on left and right side in the spectrum are calculated:

$$HI = (\lambda_B - \lambda_A) * \frac{R_C - R_A}{\lambda_C - \lambda_A} + R_A - R_B$$

R_A , R_C and R_B are the reflectance values from the hyperspectral bands left, right and at the absorption feature at $\lambda_B = 1730 \text{ nm}$. In case of presence of hydrocarbons, HI is positive, otherwise negative. The atmospheric water absorption band starting near to 1730 nm may impair the calculation of HI, since the absorption feature is overlapped by the atmospheric absorption band.

2.2. Hydrocarbon Detection Index

Similar to HI, Hydrocarbon Detection Index [5] uses an absorption feature around $\lambda_B = 2310 \text{ nm}$. Regarding the neighboring sensor channels, left λ_A and right λ_C , HDI is

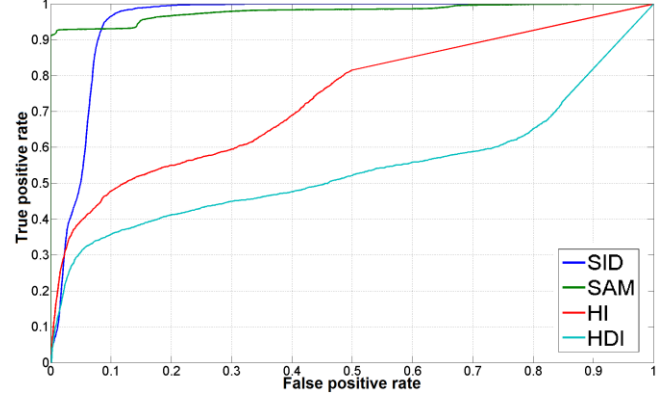


Figure 3: This figure shows ROCs for every detection method of the results shown in [Fig. 2]. The whole scene is taken into account. SAM and SID search for a spectrum of sand contaminated with 45 ml/kg crude oil. HDI and HI seem to perform worse than SID and SAM, because of the plastic objects in that scene, which also contain HC.

calculated by:

$$HDI = \frac{R_A + R_C}{2 R_B}$$

A value $HDI > 1$ is a detected hydrocarbon, while values < 1 mean the absence of hydrocarbons. The absorption feature used by HDI is less distinct than HI's feature, on the other hand it is not near an absorption band like HI.

3. STUDY

A terrestrial measurement campaign has been conducted to provide the necessary data to evaluate the performance of different oil detection methods and estimate the limiting performance. As airborne HS sensor, we used Specim's AISA HAWK [6]. This sensor covers the spectral range from 1 μm up to 2.5 μm with a spectral resolution of 6.3 nm, which is sufficient to detect both hydrocarbon features.

To ensure a controlled environment, the sensor was mounted inside our institute's building in the third story on a pan/tilt unit to simulate the forward movement necessary for pushbroom sensors. The sensor faced the lawn outside. Oil catch pans with a size of 1 m² and 15 cm of depth were placed outside to contain the probes. The ground sampling distance (GSD) of the HS image was approx. 0.1 m. So that one oil catch pan is covered by enough pixels to ensure a stable sample size, though leaving out mixed pixels. Sample materials are natural sand, top soil and gardening soil, which were contaminated in a controlled fashion with different amounts of crude oil and diesel. Only two thirds of a pan is contaminated in order to evaluate the detection quality and separability. Also one oil catch pan is contaminated by water instead of HC as a control sample.

To provide ground truth information and reference data, all spectra were also measured with a field spectrometer. This

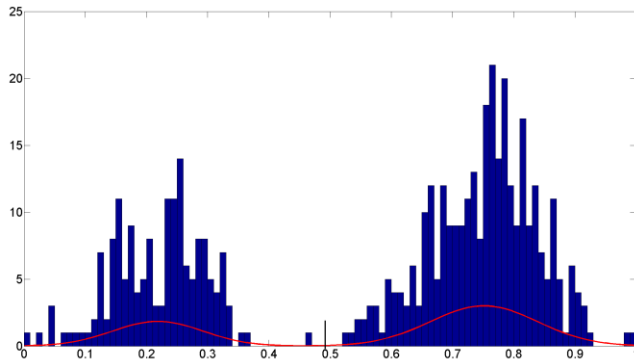


Figure 4: A normalized histogram of a detection result showing uncontaminated ground on the left and contaminated ground on the right. The Otsu threshold is around 0,5 on the horizontal axis. This figure shows the histogram for a combination of SAM and HDI for sand contaminated with crude oil (45 ml/kg). This is an example for a very clear separability of two classes, between contaminated and pure material.

data is also used for atmospheric correction by a modified flat field correction method, to analyze the influence or necessity of atmospheric correction of the acquired HS data.

4. EVALUATION

The quality of the detection method is determined by a manually defined ground truth mask for each sample (oil catch pan). Receiver-operating-characteristic (ROC) curves show the relation between correct detections and false positives [7], for different contaminated materials with different quantities of relevant hydrocarbons [Fig. 3]. Also the resulting index images I_{HI} and I_{HDI} are taken into account for visual analysis [Fig. 2]. Analysis methods for future hydrocarbon hazard mapping considering different situations or parameters were investigated.

Considering the whole HS-scene yields a first overview on the results, which will be further studied. [Fig. 2] shows a scene of different oil catch pans with detection results of HI and HDI as well as spectral reidentification with SAM and SID of a sand-crude Oil-mixture of 45 ml/kg. [Fig. 3] shows the corresponding ROC. The ground truth region covers every contaminated oil catch pan in this scene.

The contaminated two thirds of a pan are manually defined as ground truth data to provide data for ROC analysis. A precise definition of the ground truth data is crucial for quality this performance analysis, since it delivers the reference data. Especially, sand and diesel-contaminated sand is hard to distinguish for a human operator. A threshold found by Otsu's method [8] helps defining a qualified ground truth area without taking mixed pixels into account [Fig. 4].

At a first glance, SID and SAM seem to be performing much more effective than HI and HDI in this overall test. HC can

be clearly distinguished from water, though SID shows a slight false alarm in watered gardening and top soil. HI and HDI also detect HCs in a plastic caution tape and other plastic material visible in this HS image. This causes a higher false alarm rate than SID or SAM. HI and HDI nearly fail to detect HC on dark ground like top soil. SAM completely fails detecting HC on top soil, even with the highest tested amount of contamination, while SID performs the best on dark ground.

Next sections give a more detailed assessment of different parameters like ground material, type of HC, amount of contamination and temporal factors. One oil catch pan is taken into account for a combination of parameters.

4.1. Gardening soil mixtures

Crude oil and diesel are well detected by SAM for a low HC concentration of 25 ml/kg. SID fails detecting HC in gardening soil even for high concentrations. HI and HDI perform sufficiently for concentrations over 50ml/kg.

4.2. Top soil mixtures

Top soil delivers only slightly better results compared with the darker gardening soil. HDI detects diesel and crude oil even for a low contamination of 20 ml/kg, while SID and SAM fail. HI, SID and SAM only detect HC for high concentrations above 65 ml/kg.

4.3. Sand mixtures

Sand mixtures are the easiest to detect. Absorption maxima of HC are the most clearly visible in light sand. SAM and HDI detect HC even for a low diesel contamination of 7,5 ml/kg. Crude oil is harder to detect than diesel. For contaminations over 30 ml/kg, HDI outperforms the other detection methods.

4.4. Limiting performance: Contamination

Examining different concentrations of HC for all three ground samples, the minimum detectable amount of contamination is determined. [Tab. 1] shows the result of this study. The focus lies on the minimum HC concentration, which is necessary to be detected by either HI or HDI and SID or SAM in comparison. HDI outperforms HI. For dark soils like gardening soil, SAM works the best, but at high HC concentrations HDI works as well.

4.5. Temporal change of HC

Measurements were repeated 25 days after initial study and spectra were compared for the sand based mixtures. Spectral signatures became lighter, but were still detectable because

Table 1: This table shows the limiting performance subject to the HC concentration for different ground and HC types. Last column suggests the best performing detection algorithm based on ROC analysis.

Material	HC	Minimum contamination [ml / kg]	Detection method
Sand	Crude oil	7,5	SAM
		30	HDI, SAM
	Diesel	7,5	HDI
		30	HDI, SAM
Top soil	Crude oil	25	HDI
		40	HDI, HI
	Diesel	25	-
		40	HDI
Gardening soil	Crude oil	25	SAM
		50	SAM, HDI
	Diesel	25	SAM
		50	SAM, HDI

absorption maxima kept their characteristics. Due to the higher fugacity, crude oil became a shade lighter than diesel.

4.6. Combination of detection methods

Previous sections showed that none of the methods performs well for every scenario, detection methods have to be chosen according to the present ground cover of the measurement area. In case of presence of many different ground types, a combination of methods may be practical. Different combinations of HI, HDI, SID and SAM were tested. Most useful combination is HDI and SAM, because both perform very well in their category.

[Fig. 2] shows that HDI and SAM operate complementary. The plastic objects in the scene are no longer erroneously detected. SAM searched for ground spectra of sand contaminated with crude oil (45 ml/kg). Otsu's method states very good separability between sand and the contaminated sand for this combination [Fig. 4]. HDI emphasizes the correct HC detection of SAM. A disadvantage is the necessity of ground spectra of different contaminated ground types for SAM (and SID).

5. CONCLUSION

Findings of this study indicate that oil spill mapping by HS data, acquired by a sensor for airborne application, based on HC detection indices is possible. It is shown, that these methods work even for small amounts of contamination for the two most relevant types of HCs, crude oil and diesel.

Practical classification methods for fast hazard mapping to encounter oil spill events were evaluated. Different significant types of land coverage were taken into account.

Also, separability between HC contaminated and non-contaminated ground, as well as the limiting performance were determined qualitatively.

In future work, these results are to be further evaluated by a flight campaign under realistic conditions. Also, the detection of hydrocarbons on water bodies and vegetation is yet to be further investigated. The methods are to be integrated in a technology demonstrator, like Fraunhofer IOSB's hyperspectral multisensory platform for fast image acquisition and near-realtime data processing [9]. Such a system may be adapted for projects in environmental monitoring, disaster management, pipeline monitoring and hazard mapping.

11. REFERENCES

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