HYPERSPECTRAL IMAGE ANALYSIS FOR OIL SPILL DETECTION

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1. Introduction

During the last several decades, the Chesapeake Bay has suffered from several large oil spill events have threatened coastal habitats and species. Chesapeake Bay's marine resources remain vulnerable as they share the coastal areas with major interstate commerce routes, underground pipelines, extensive development, large industrial facilities, and heavy shipping traffic to the ports of Norfolk and Baltimore. In order to effectively protect communities and species in jeopardy, fast and accurate determination of oil spill hazard areas is needed, particularly if monitoring large quantities of oil spilled. Where oil-handling infrastructure is aging, this need is amplified. This research addresses remote sensing, especially hyperspectral image analysis applicable to the Chesapeake Bay.

This case study is a prototype of oil spill leaks in Patuxent River in Maryland (Darrell and Brebbia, 1996) and the associated image analysis for detecting oil spills using hyperspectral imagery and the effect of oil contaminants on soil, water quality, wetland, and vegetation. Hyperspectral airborne images, as an effective survey tool, are a main source for getting real-time data. In the event of an oil spill, this information can be retrieved in a short time to help authorities plan the quickest route to the spill and formulate an effective environmental protection plan that could be a way to reduce damages. Hyperspectral sensor affords the potential for detailed identification of materials and better estimates of their abundance. This can eliminate the false alarms of features that have the same color and appearance of oil, such as large algae blooms or jellyfish. These phenomena may be identified by visual interpretation as a suspected oil spill using some conventional sensors. Some other types of light fuel, such as gasoline and diesel, cannot be identified visually because of their changing appearance with time.

Hyperspectral sensing can record over 200 selected wavelengths of reflected and emitted energy. With this spectral information one can exploit the spectral signature of oil and also distinguish between different concentrations of crude oil dispersant. HSI observations with high spectral and spatial resolution can be used to detect oil using the spectral signature matching to identify oil spectra based on chemical composition. Oil signatures can be extracted for deferent oil concentration to identify the level of oil contamination of polluted areas, which is necessary for determining proper cleaning processes.

In this research, some of the problems of the conventional techniques can be minimized, when using more advanced methodology to identify oil spill based on the spectral signature matching not by visual interpretation of the image. New techniques such as HSI should be used in order to make the proper distinctions between oil spills and to properly identify natural phenomena. Preliminary results of this research show that with HSI spectral information, the signature of oil can be used to detect minute concentrations of hydrocarbon (crude oil) on the sea and it can distinguish between different levels of oil dispersant on water. The first part of this study also includes the monitoring of oil slicks movements, dispersion in water, and identifying spills on the shoreline. The second part will emphasize the oil contaminates in wetland, soil, vegetation, and grass in the Patuxent River basin in Chesapeake Bay due to oil pollution.

A number of remote sensing systems are available (e.g., side-looking airborne radar, laser fluorescence, microwave radiometer, infrared-ultraviolet line scanner, SAR, ERS 1, 2 and LANDSAT satellite systems). However, problems associated with each of these systems preclude their exclusive use during oil spills. Although remote sensing data can be a valuable tool in the response effort, results from different sensors can vary widely (Fingas, 1991). This problem is particularly apparent during major spills, when many interpretative analyses for satellite images are based on oil color or oil film appearance on water. Many of these analysis techniques have many problems identifying and quantifying oil floating on the sea. As the spill progressing, a surprising number of false positive sightings may be seen. Ice, internal waves, kelp beds, natural organics, pollen, plankton blooms, cloud shadows, jellyfish, algae, and guano washing off rocks all appear as oil (Pavia and Payton, 1983) (McFarland et al., 1993). Weather conditions are one of the limitations when using some sensors such as radar imagery, wind speed and high waves usually cause difficulties inherent in estimating area of coverage (Payne et. al., 1984). Waves will increase natural dispersion during the early parts of the spill, break the surface tension that causes the oil to look "slick," and mix some of the oil into the surface layer temporarily. Observers should note that as the wind speed increases, the ability to detect the oil decreases (Ministry of Transport 1992). Visual observation of submerged oil is extremely difficult unless the water is very clear and shallow. Spill characteristics appear differently under low light conditions and under strong winds conditions (Fingas, 1991). Observations in an up-sun direction are typically difficult to interpret. Glare due to very low sun angles and sunlight directly overhead can make observations particularly difficult due to poor contrast between the oil sheen and water. After oil spends even a short time floating on the ocean surface, it starts to change its physical characteristics due to various physical, biological, and chemical processes (Schriel, 1987). The false reports obscure knowledge of the actual location and description of the spill. In additional to other factors that make some conventional remote sensing techniques unreliable.

One of these conventional methods was used for tracking oil spill movements by using space shuttle photography, the images was taken in sequential order in the same time of the oil spill even, The visual interpretation of the four images was based on the shape and the size of the oil spill, and the oil color. The enlargement of the spill with the time indicated the oil dispersant rate and the spill movement direction towards the shoreline. Also the oil type can be identified as a crude oil based on the slick color and shape.

1.1 Space Shuttle Photography

The four Space Shuttle images (from mission STS- 41C) were selected for the Saudi Arabia shoreline. The images were taken consecutively in a short period of time for the different stages of an oil slick. The oil spill appears black in the images; any slick in the image is significantly darker (> 2dB difference) than the surrounding sea surface water. The Space Shuttle photography has the advantage of taking images, with direct human visualization, which is not possible with other satellite techniques (Figure (1) a,b).

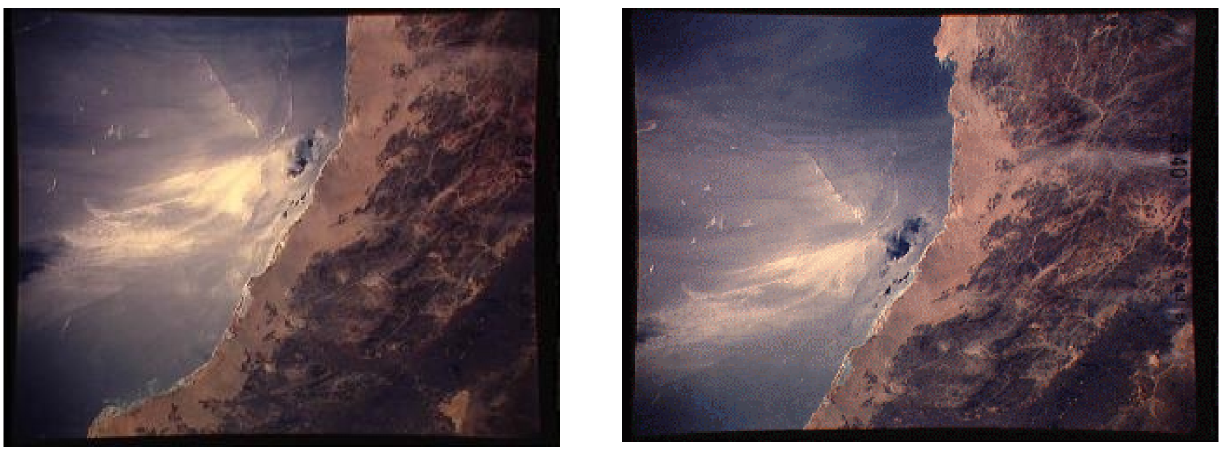


Figure (1) a, b

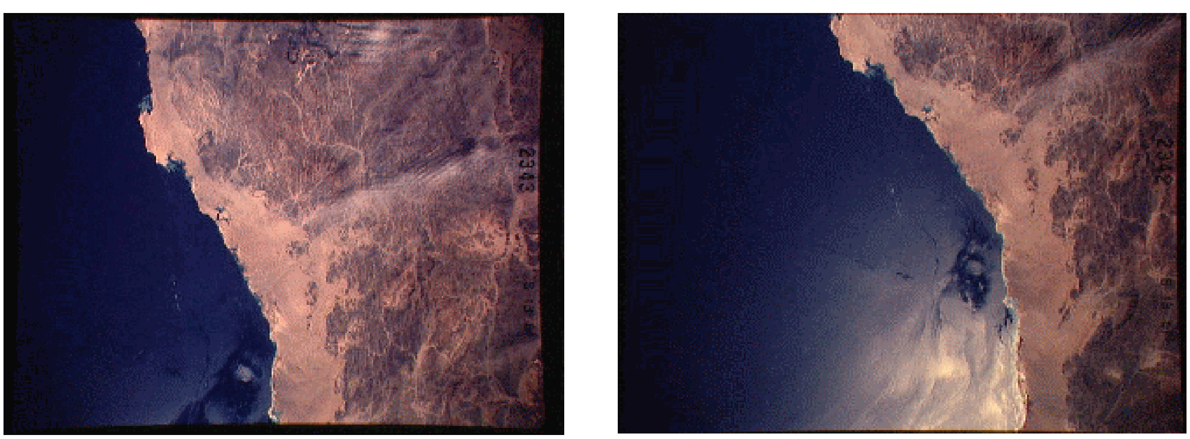


Figure (2) a, b

The four Space Shuttle images (numbers 2340, 2341, 2342, 2343) were taken consecutively of the same oil spill from different angles and locations, show extensive oil slick, in the shallow water surface, close to the shore. The first image shows the initial stage of the spill. The oil slick appeared larger in each image as it is spreading with respect to time. The dark heavy oil spill seems to be sufficiently thick, which can be identified as crude oil, as there was no significant gapes exist in the main slick (Figure (2) a,b).

Winds and current forces pushed three small oil slicks to the shore. The sea wave patterns show that the wave's direction in curved lines paralleled to the shore boundaries and two long oil streaks appear related to wave direction. The upper right line, appears perpendicular on the waves direction, which seams to be traces of a ship track moving away from the spill, the line seems sharper toward the slick direction and thinner as it go further away from the spill location. The wave patterns grow and persist for a long time after a ship passes (Figures 1,2).

1.2 AISA Hyperspectral Sensor

The AISA Airborne Imaging Spectrometer is a push-broom style, hyperspectral system measuring up to 288 bands of continues visible to IR wavelengths. 25 bands were selected for our image processing. The data was derived from the Pipco oil company project for pollution protection for Patuxent River in Maryland (Figure 3). For high spatial and spectral resolution requirements, the Airborne Imaging Spectro-radiometer for Applications (AISA) sensor system gets more information out of each pixel of data -more detail, finer imagery and faster turnaround than from other multi-spectral systems or traditional methods of monitoring. The use of AISA data for identifying spectral signatures for oil spill and oil contaminated areas, can be more successful than traditional methods. Time sequence images of the oil can guide efforts in real-time by providing relative concentrations and accurate locations (Galt, 1994). Environmentally sensitive sites such as wetland can be quickly and accurately mapped, measured, and characterized. AISA can be used to build a spectral library for oil spill on water and land for areas, which contaminated by oil. The Spectral signature can be used for identifying shoreline features specially areas which are environmentally sensitive, and determine the level of oil contamination (heavy or moderate) areas onshore. This can be useful for focusing cleanup processes.

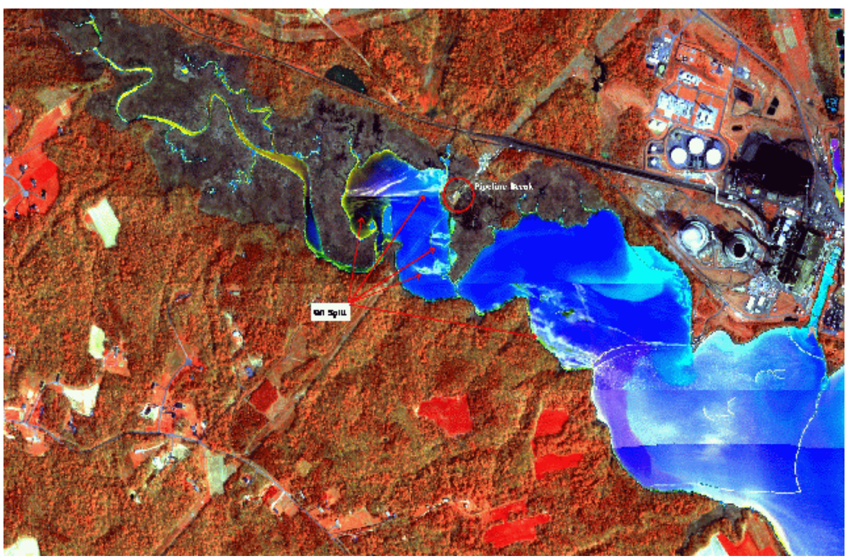


Figure (3) shows an AISA hyperspectral image in Patuxent River for an oil spill due to a petroleum pipeline break, and also the contaminated offshore areas (Maryland April 2000)

1.3 Hyperspectral Data

Hyperspectral sensors such as the Airborne Imaging Spectroradiometer for Applications (AISA) enabled the construction of an effective, continuous reflectance spectrum for every pixel in the scene. These systems can be used to discriminate among earth surface features. Hyperspectral sensors afford the potential for detailed identification of materials and better estimates of their abundance. This can eliminate the false alarms of features, which may be identified by mistake as a suspected oil spill with other conventional sensors (McFarland et. al.,1993). Hyperspectral sensing can record over 200 selected wavelengths of reflected and emitted energy. With this spectral information one can exploit the spectral signature of oil to detect minute concentrations of hydrocarbon on the sea surface, and also to distinguish between different crude oil concentrations. Applications of the hyperspectral sensing include determination of contaminated soil wetlands, shallow water, sand beaches, and shoreline that enables the identification of features with high spatial and spectral resolution. HSI can provide high quality data for analyzing the complex variability of landscape surface cover in different global environments. However, The application of traditional multispectral data analysis tools to hyperspectral data has not yielded satisfactory results because of mathematical and practical limitations.

2. Methodology

The Hyperspectral images are used to detect oil spill and determine characteristics of the substance spilled, and to make predictions of the spread or mitigation success. The tasks involved are:

1. **Predict oil spill spread direction and flow rate characteristics:** Hyperspectral image analysis for oil spills must be fast and timely for operational environmental monitoring. The airborne HSI temporal image process predicts how oil spills disseminate within a particular body of water, under current environmental conditions, and where it might affect sensitive sites, such as coastal wetlands.

2. **Identify shoreline features and the severity of oil spills:** With its high spectral and spatial resolution, HSI can be used to identify shoreline features, and areas damaged due to spilled oil. Areas impacted are environmentally sensitive, e.g., wetlands with shallow water, sea-grass, salt marshes, tidal-flats, waterways, or sandy beaches with significant biodiversity therein.

3. **Determine the pollutant type**: The oil characteristics (e.g., oil types and concentration) are important to help the cleanup crews identify the best cleanup method, the environmental impacts of burning oil, and the modeling techniques (to predict the flow path, dispersion rates, and time before the slick hits the shoreline) (Jordan and Payne, 1980). For example, an oil type can be crude or light oil and the evaporation rate of the light fuel is faster than crude oil, but it could be more toxic for the marine species (Massin, 1998).

2.1 Spectral Angle Mapper (SAM) Method

The Spectral Angle Mapper (SAM) is a signature matching method is used for identifying oil spills and oil dispersant in water and shoreline. Real time analysis of the images allows field checks in the rapidly changing water conditions due to wind, current and tides. HSI is used to extract specific spectral signatures in order to build a spectral library for different oil types on water, wetland, and vegetation contaminated by oil spills. It can also be used to determine the level of oil contamination onshore (Figure 4). Spectral Angle Mapper (SAM) classification is a physically based spectral classification that uses the N-dimensional angle to match pixels to reference spectra. The algorithm determines the spectral similarity of two spectra by calculating the angle between them. The advanced image processing software, ENVI, is used for image analysis.

2.2 Information Extraction of Hyperspectral Data

The basic approach has been to seek a more fundamental understanding of high dimensional signal spaces in the context of multispectral remote sensing, and then to use this knowledge to extend the methods of conventional multispectral analysis to the hyperspectral domain in an optimal or near optimal fashion. The introduction of hyperspectral sensors that produce much more detailed spectral data than those previously provide much enhanced abilities to extract useful information from the data stream that they produce. In theory, it is possible to discriminate successfully between any specified set of classes of data by increasing the dimensionality of the data far enough. In fact, current hyperspectral data, which may have from a few 10’s to several hundreds of bands, essentially make this possible (Landgrebe, 1998). However, it is also the case that this more detailed data requires more sophisticated data analysis procedures if their full potential is to be achieved. Much of what has been learned about the necessary procedures is not particularly intuitive, and indeed, in many cases is counter-intuitive. In this paper, we shall attempt not only to illuminate some of these counter-intuitive aspects, but also to point the direction for practical methods to make optimal analysis procedures possible.

Extracting Oil Spectrum

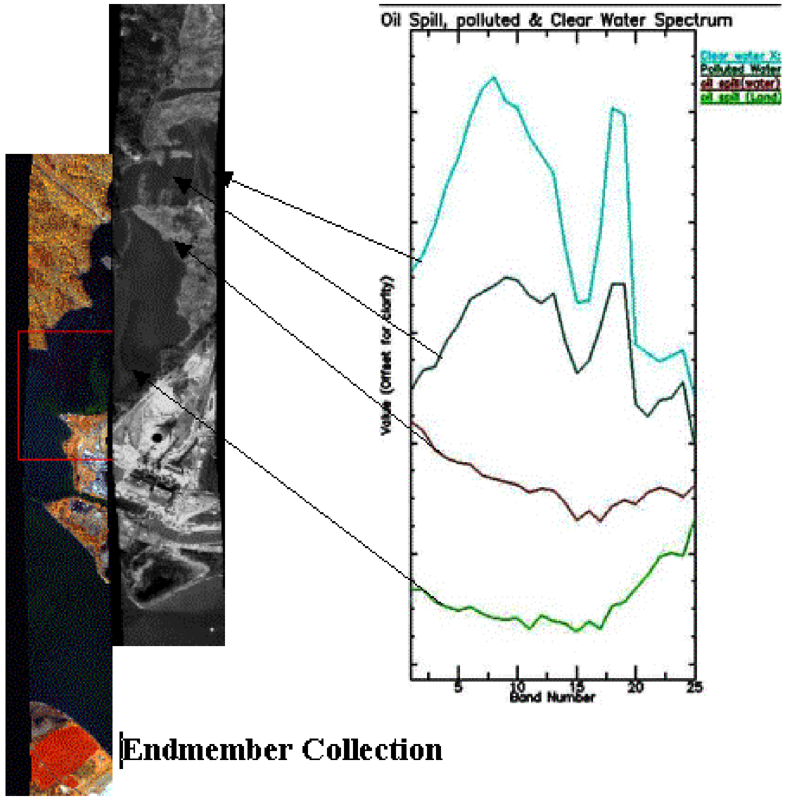


Figure (4) shows the oil on water spectra in red, oil on land spectra in green, polluted water spectra in gray and clear water spectra in cyan. The oil and water spectra extracted from the image create the spectral library; the spectra are used as an endmember collection to train the Spectral Angle Mapper classifier.

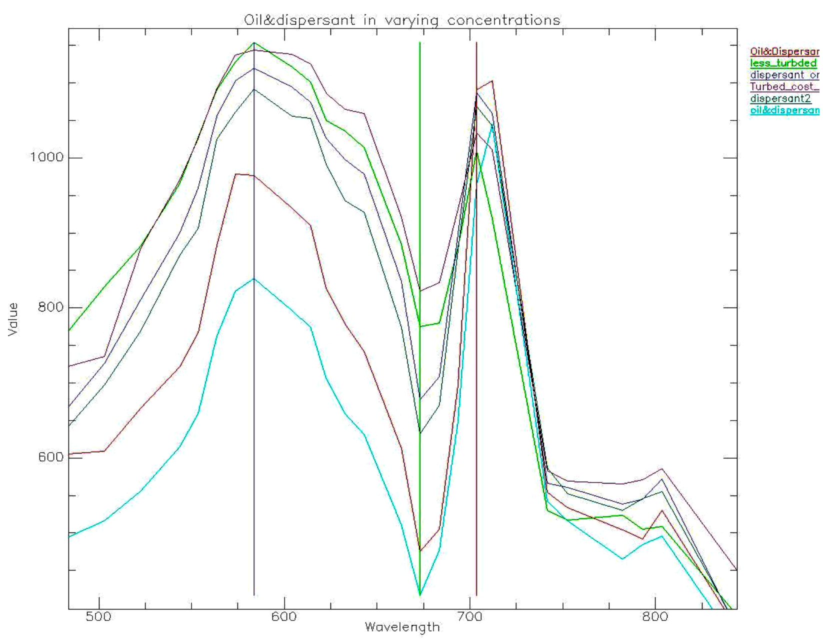


Figure (5) Oil dispersant spectra appeared in red, cyan and green shows that high absorption at 670 nm indicated high oil concentrations compared with the turbid water spectra (appeared in brown, light green, and blue) which shows high reflectance at 580 nm.

As shown in Figure (5) that high oil concentration increases the absorption of light and decrease the reflectance in the visible bands. In the opposite of turbid water have higher reflectance in the visible bands and less absorption in the near IR bands. The water reflectance range is between the two other types.

2.3 Ground Truth

Photography of locations of all zones of sampling and measurement from the air, were used to familiarize the analyst with the materials that exist within the imaged boundaries. In order to successfully identify classes from unsupervised classification results or to create appropriate representative classes (or training sites). Such efforts also allow us to narrow the processing, and analysis focus to a smaller region of the imagery. For extracting the endmembers signatures, the identification and distribution of materials in the field is suggested. In addition, ground truth information that corresponds with the day of data acquisition allows the developing of quantitative relationships between materials on the ground and that which is measured by the remote sensing instrument. These relationships may allow for actual estimates of material densities and amounts.

2.4 Oil Spectra Features Analysis

There are a number of interesting features in the oil spectral which will enable algorithms to be formed for this oil type (Salisbury, 1993). There is a specific peak at 580 – 600 mμ represent the absorption of the dispersant oil, increasing concentration of oil causes a linear dip in the peak at 675-685 mμ (Figure 5). At increasing the concentration of oil on water the dip levels out so that it will be used a good marker for high and low concentration of oil. The dispersant oil give very strong reflectance at 580 mμ and 700 mμ in the visible and near IR . In the blue band there is a reflectance for water at 800 mμ and there is the water absorption at 670 mμ which provides information about the total concentration of oil and water turbidity near shore line.

3. Results

It was demonstrated from our results that by using Spectral Angle Mapper classification technique, the signatures for different concentrations of crude oil and oil dispersant can be matched as long as the sample has high concentration of hydrocarbons as shown in Figure (6) and may not match for light oils such as diesel or gasoline. The model is reliable for distinguishing between different concentrations of crude oil based on the oil spectra for each type of oil spills as shown in Figure (7). Using oil spectra on land allows us to identify the contaminated areas with oil spill on the shoreline (Figure 8). The classified image also indicated that features similar to oil was appeared in areas used for storing coal inside the Maryland Power station, the results confirmed that materials which have the same chemical composition such as coal (carbon), have the same signature as oil (hydrocarbons). Finally, ground truth information (Figure 9) provides the basis for post-processing accuracy assessments.

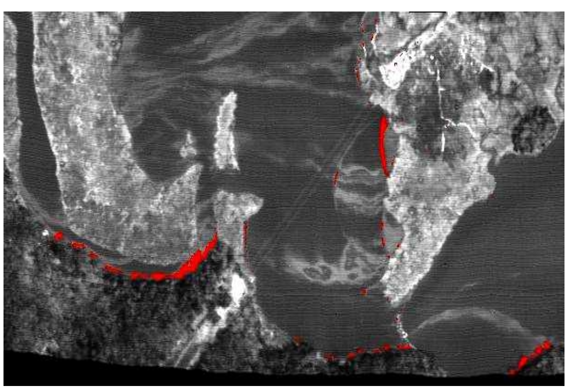


Figure (6) The class image shows heavy oil slicks appeared in red color on the river and the small streams

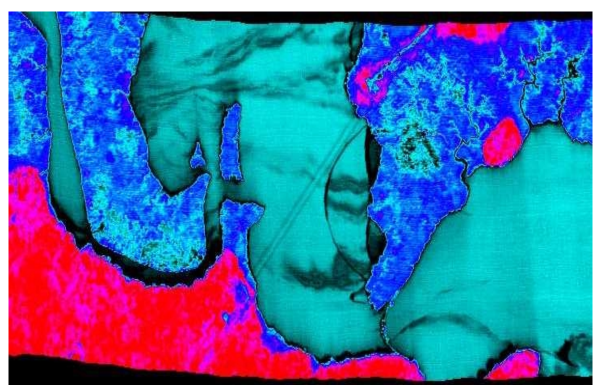
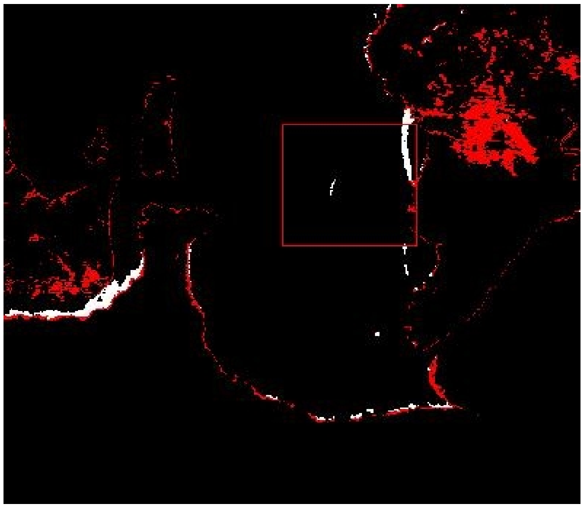


Figure (7) One of the rule images shows dispersed oil and polluted water appeared in black



Class Image Figure (8) Figure (9)

Figure (8) shows two classes, white indicted heavy oil slicks on water, it appear close to the shore outline, and red color represents oil spills on land and on the river edges due to the pipeline break.

Figure (9) shows picture was taken on the same time of oil spill event is used as ground truth for comparing results.

4. Summary and Conclusions

1. Using hyperspectral imagery as an advanced remote sensing technology is more reliable to minimize the limitations of conventional remote sensing techniques for detecting oil spill.
2. The visual interpretation of the space shuttle images shows many limitations such as changing in oil appearance with time, image glare due to sun angle, and other natural phenomena would result in the same appearance as oil spill due to weather difficulties.
3. The results of this research show that the signature matching method is more accurate than the conventional techniques, which base on the visual interpretation of oil color and the appearance in the space shuttle images.
4. HSI spectral information is used to distinguish between different concentrations of oil dispersant for different levels of oil pollution. The signature of oil is used to detect minute concentrations of hydrocarbon (crude oil).
5. For oil spill image analysis, Spectral Angle Mapper classification is more accurate than other supervised classification techniques. When the training samples are selected from the image based on the pixels color, the classification may be misled. Signatures matching technique can distinguish between materials based on its chemical composition not by visual appearance. This allows more confidence in the classification results.
6. Hyperspectral imagery is fast and timely for operational environmental monitoring for oil compared with space-borne systems. The airborne HSI temporal image processes predicts how oil spills disseminate within a particular body of water, under current environmental conditions, and where it might affect sensitive sites, such as coastal wetlands.

5. Future work

1- Accuracy assessment will be applied on the classification results for several techniques, and evaluation for each classification performance will show the accuracy level for each method.

2- The linear un-mixing signature method will be used to identify contaminated coastal features, to distinguish between mixed signatures for different materials such as grass, water, and soil contaminated with oil.

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