Using hyperspectral techniques in quality assessment of water bodies

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Remote sensing techniques provide the possibility of real time monitoring of vast areas. Such methods are very useful especially for quality assessment of aquatic ecosystems. These delicate environments are very sensitive to even the slightest changes in the physical properties and chemical composition of their habitat, therefore only the rapid detection and response to any pollutants introduced into the water body could prevent its deterioration. This paper concentrates mainly on the use of a hyperspectral system to identify water surfaces polluted with petroleum-derived wastes. The described research had been carried out in controlled laboratory conditions, ensuring the precise measurement of the analyzed substances spectral reflectance characteristics. In the event of an oil spill, such information could be retrieved in a short time to help authorities formulate the most effective environmental protection plan, which would reduce damages. Using a hyperspectral sensor, which can more accurately identify different materials, could eliminate the false alarms of features which have the same colour and appearance as oil. Hyperspectral data provides a rich source of information regarding the content and composition of various materials, but often it provides more data than an analyst requires. Therefore finding a method for selecting an optimal set of spectral bands was essential when using hyperspectral imaging to monitor water quality. Based on data acquired and analyzed as part of this study, it has become apparent, that imagery captured in the UV range of the electromagnetic spectrum is most helpful in determining polluted areas of water bodies.

1 Introduction

Oil spill effects are so alarming that it is considered to be a serious environmental catastrophe. The environmental consequences of such accidental episodes are especially severe, when they happen near the shore, in shallow waters, or in areas with slow water circulation. These areas are often hit, as most tanker accidents occur when vessels run aground in shallow waters. According to official data [5], the amount of oil spilled during tanker accidents in 1989 and in 1990 were 114,000 and 45,000 tons, respectively. At the same time, the total volume of oil pollution caused by marine oil transportation was 500,000 tons a year.

The distribution of oil spilled on the sea surface occurs under the influence of gravitation forces - it is controlled by oil viscosity and the surface tension of water. Only ten minutes after a spill of 1 ton of oil, the oil can disperse over a radius of 50 m, forming a slick 10-mm thick [6]. Therefore, if the oil is not contained quickly, it will affect a very large area in a very short time.

Aquatic wildlife and their habitats are affected by oil spills by means of physical contact, ingestion, absorption, and inhalation. The oil spill causes damage to the entire aquatic food chain. Suspended oil on the water contaminates plankton, algae, larvae, and fish eggs, which are consumed by small fish species. This contamination is then passed on to larger fish, bears, aquatic birds, and even humans. The growth and germination of marine plants are affected by oil spills as well. When exposed to oil spills, some species of marine algae and seaweed may even perish [4].

Some of the most common oil spill management techniques are booms, skimmers, sorbents, chemical dispersants, biological agents, and in-situ burning. However, in order for any of these methods to be fully effective, they must be implemented on the entire area of the oil spill. Therefore a method allowing the precise and fast detection of areas affected by an oil spill must be determined.

Water pollution may be analyzed through several broad categories of methods: physical, chemical and biological. Most involve collection of samples, followed by specialized analytical tests. These traditional methods are usually very accurate in determining areas contaminated by oil-based pollutants, however they are very time consuming and impossible to execute on a large area simultaneously. Several methods involving Synthetic Aperture Radars (SAR) have also been proposed. [7] Such techniques give fairly accurate results, but the acquired SAR imagery requires extensive post-processing in order to be easily interpreted. Using optical sensors to determine the extent of harmful pollutants in aquatic bodies would surely simplify this process. Such methods would also quicken the detection of problem areas, enabling a faster response and clean-up operations, decreasing the negative effects of the contaminant on the water ecosystem.

2 Spectral detection of water pollutants

Hyperspectral systems allow for the detection imagery in very narrow spectral bands. Such images enable the automatic generating of spectral reflectance curves of materials and substances registered on the hyperspectral images. As spectral response curves can be compared to a human fingerprint in that they are unique for each substance, it is possible to distinguish between objects by comparing such curves. This methodology is however very time consuming and requires the acquisition of a great number of images – the more images are acquired, the more precise the resultant spectral reflectance curves are [2].

By comparing spectral response curves of chosen objects derived in controlled laboratory conditions, it is possible to determine spectral bands in which these objects will differ from oneanother. Imagery acquired in field conditions in these specific bands will allow for the fast detection of these specific objects. Such a methodology was applied in this study.

2.1 Samples used in study

A series of samples were used during the study. These included pure petrol, pure oil, pure diesel, pure water as well as water samples contaminated with different amounts of petrol, oil and diesel. Pure samples were poured into transparent glass containers covered with either black or white sheeting in order to the amount of light passing through the sides of the containers, influencing the results.

2.2 Acquisition of spectral reflectance curves

Hyperspectral data was acquired by means of a terrestrial hyperspectral set (Fig. 1) consisting of a monochromatic camera and two VariSpec optoelectronically tunable filters – one in the VIS range (400 - 720nm) amd the other in the NIR range (650 – 1100nm). The entire process of image acquisition is controlled by especially created software – “Wiano” [1].

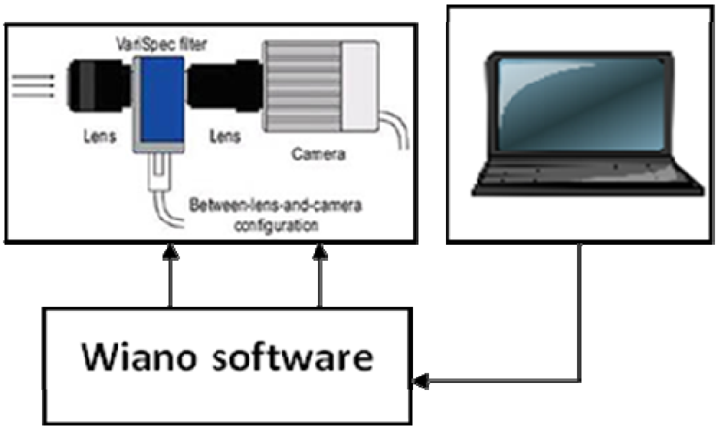

Fig. 1 Hyperspectral set consisting of a monochromatic camera, VariSpec filter and Wiano software.

Additionally, in order to acquire imagery in the UV range or the electromagnetic spectrum, a set of two optical filters was used:

- B+W 58ES 403 8x-20x - this filter lets light in the 320-385nm range through and completely restricts visible wavelengths. It does however let through a small amount of infrared radiation.
- B+W 58 081 2xMRC - this filter is often used in everyday photography to enhance the natural colour of the sky. It is also used to restrict unwanted infrared radiation, which is passes through the B+W 58ES 403 8x-20x filter.

By mounting a B+W 58ES 403 8x-20x filter and a B+W 58 081 2xMRC filter onto the monochromatic camera, it was possible to acquire imagery in the UV range.

For image acquisition, the camera and chosen filter was attached to a boom, locating the sensor 2 meters above the studied samples. Such a configuration allowed us to reduce the effect of the glass containers, in which the samples were held.

The samples were illuminated by three 50Wat ASD Inc ProLamp lamps. Such illumination is stable and spectrally unchangeable in the 320 – 2500nm range.

In order to ensure a correct exposure and repeatability of results, a white reference plate (95%) was used. The exposure time for each frame was set automatically in the Wiano software using a Region of Interest (ROI) set to the white reference plate. As a result, on all registered images, the white plate has a Digital Number (DN) equal or close to 233, which is 95% of all possible DN's on an 8-bit image. By ensuring this, it is possible to calculate the spectral response (%) of any given object on the image.

2.3 Results

The hyperspectral set enabled the acquisition of imagery in the 420-720nm range and the 650-1100nm range. By combining this data, it is possible to derive spectral response curves for chosen objects in the 420-1100nm range. Within this range, the spectral reflectance characteristics of all of the studied samples were very similar. The biggest spectral contrasts exist between pure water and oil (Fig. 3).

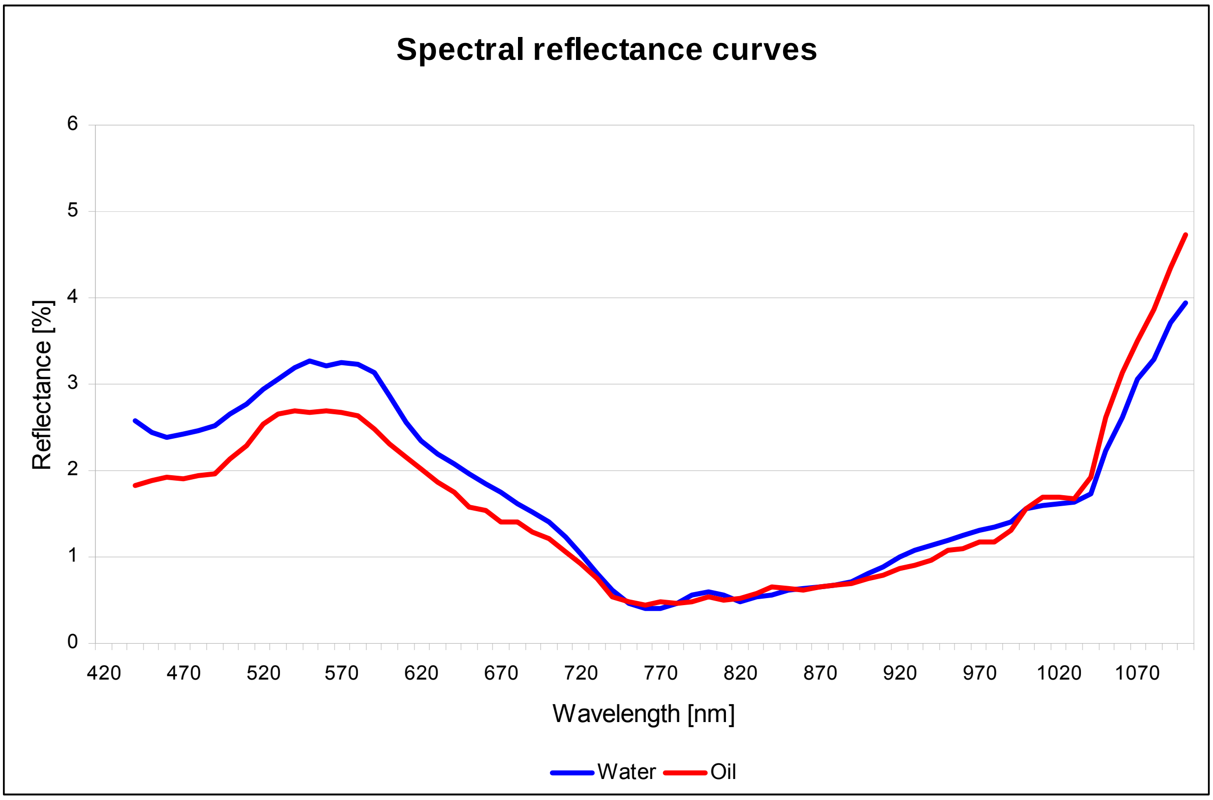

Fig. 3 Spectral reflectance curve of water and oil in the 420 – 1100nm range.

An analysis of the above curve shows a slight spectral contrast (0,5%) between oil and water in the visible range of the electromagnetic spectrum. This can be confirmed by visual analysis of the substances. As can be seen in Fig. 3, the infrared range of the electromagnetic spectrum is of no use in the detection of petroleum products in water.

The following image is an example of data (Fig. 4) collected using the UV optical filter set.

Fig. 4 Image registered in the UV range of the electromagnetic spectrum of samples of (from left) pure oil and pure water. The image also represents a white reference plate.

Based on the acquired image, and the known reflectance of the white reference plate (95%), it was possible to determine the spectral response of the samples. In laboratory conditions, pure water in a glass container covered with white sheeting has a reflectance of roughly 26%, while pure oil in the same conditions reflects only 16% of incident light in the UV range. These results cannot be interpreted as the reflection coefficients of these substances, as the containers and background have a large affect on this result. However, because both substances were in identical containers, it is correct to say, that water reflects roughly 10% more light in the 320 – 385nm range.

3 Conclusion

Based on the acquired imagery and conducted analyses, it can be said that sensors working in the visible and near infrared regions of the electromagnetic spectrum are of little use in the rapid and accurate detection of petroleum-based pollutants in water bodies. The spectral differences between these substances are usually below 1%, which is less than the average error of generating a spectral response curve using the hyperspectral set.

In the 320 - 385nm range of the electromagnetic spectrum these differences are much more visible – roughly 10%. Further work should be conducted using more narrow bands of the ultraviolet range, i.e. acquired by a UV hyperspectral sensor. Analyses of such images and spectral responses could allow for a more precise evaluation of this phenomenon. It would be possible to indicate a single narrow UV band, in which this spectral contrast would be greatest. In the event of a oil spill, a single image could be rapidly acquired using a satellite or airborne sensor and used to accurately determine areas effected by a catastrophe. Such a system would retrieve detailed information in almost real-time, which would help authorities formulate the most effective environmental protection plan, which would reduce damages to the environment.

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