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Utilization of a genetic algorithm for the automatic detection of oil spill from RADARSAT-2 SAR satellite data

Maged Marghany

Institute of Geospatial Science and Technology (INSTeG), Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor Bahru, Malaysia

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ABSTRACT

In this work, a genetic algorithm is applied for the automatic detection of oil spills. The procedure is implemented using sequences from RADARSAT-2 SAR ScanSAR Narrow single-beam data acquired in the Gulf of Mexico. The study demonstrates that the implementation of crossover allows for the generation of an accurate oil spill pattern. This conclusion is confirmed by the receiver-operating characteristic (ROC) curve. The ROC curve indicates that the existence of oil slick footprints can be identified using the area between the ROC curve and the no-discrimination line of 90%, which is greater than that of other surrounding environmental features. In conclusion, the genetic algorithm can be used as a tool for the automatic detection of oil spills, and the ScanSAR Narrow single-beam mode serves as an excellent sensor for oil spill detection and survey.

1. Introduction

Oil spill pollution can cause tremendous destruction in marine ecosystems. In addition to decreasing the fauna population, an oil spill that floats on top of the water affects the food chain in the ecosystem (Alpers, 2002; Brekke and Solberg, 2005; Garcia-Pineda et al., 2013; Xu et al., 2014). In fact, oil spills reduce the amount of sunlight that penetrates through the water, thereby limiting the photosynthesis of marine plants and phytoplankton. Moreover, if marine mammals are exposed to an oil spill, their insulating capacities are reduced, thus making them more vulnerable to temperature variations and much less buoyant in seawater. The oil coats the fur of sea otters and seals, reducing the fur's insulation capacity and leading to body temperature variations and hypothermia, and the ingestion of oil causes dehydration and damage to the digestive system (Fiscella et al., 2000).

In recent years, there has been an explosive increase in the scope of incidents of marine pollution. The Deepwater Horizon oil spill in 2010, for example, is the worst marine pollution disaster that has occurred in the history of the petroleum industry (Fig. 1). This disaster produced three months of oil flows in the coastal waters of the Gulf of Mexico. The Deepwater Horizon oil spill has had serious effects on feeble maritime species, wildlife habitats, fishing activities in the Gulf', coastal ecology, and the tourism industry. Moreover, the oil spill and its cleanup have caused a variety of health problems. The Deepwater Horizon spilled nearly five million barrels of oil, making it the world's largest accidental marine oil spill. Oil spills are difficult to bring under control because of the influence of coastal hydrodynamics such as waves, currents, and tides. Therefore, advanced technologies are needed to achieve accurate surveying and control of marine oil pollution.

Numerous dissimilar types of sensors are conventionally used to detect and monitor oil spills in the ocean and were used during the Deepwater Horizon spill. These sensors are either mounted on satellite platforms or are airborne, i.e., synthetic aperture radar (SAR), microwave radiometer, ultraviolet radiometer and visible and near infrared radiometers that are mounted on the satellite platform. Therefore, airborne remote sensing platforms are also important and include multi-spectral expert systems, hyper-spectral airborne sensors, and airborne thermal infrared spectrometers. Each sensor exploits different physical properties of an oil spill and its surrounding sea environment conditions (Cococcioni et al., 2012; Zhang et al., 2014).

The Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Terra (2000-present) and Aqua (2002-present) satellites provides global coverage twice daily in near real time and is equipped with two 250-m and five 500-m resolution bands. The MODIS 250-m resolution data were used to detect oil spills in the Gulf of Mexico and indicated a dark contrast against the bright background. In the presence of sun glint, which is strongly dependent upon solar geometry and wave fields, the oil-impacted areas are well visualized with high contrast compared with the oil-free areas. In the absence of sun glint, the contrast between the oil slick and background depends on their different spectral characteristics.

E-mail addresses: maged@utm.my, magedupm@hotmail.com

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Therefore, optically and remotely sensed data such as MODIS and AVIRIS could be used to estimate oil slick thickness. Oil slicks with different thickness showed different visual characteristics and led to different spectral reflectance within the visible light wavelength (Zhao et al., 2014). Therefore, oil slick thickness and oil-to-water emulsion ratios are key spill response parameters for containment/cleanup. Furthermore, the near infrared spectral library of AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) data can be used to quantitatively derive the characteristics for thick (>0.1 mm) slicks. Consequently, a multi-spectral expert system based on MODIS and AVIRIS applied a neural network to provide rapid response oil spill thickness class maps using a neural network technique (Zhao et al., 2014).

Nevertheless, MODIS data are not able to detect small areas of oil spills due to its limited resolution. Additional, heavy cloud cover does not allow for the precise detection of oil spills in MODIS data. Similarly, oil spill detection algorithms based on thermal signatures will not efficiently succeed in isolating oil spill pixels, which can be easily mistaken for cloud edges. Under these circumstances, Grimaldi et al. (2011) developed a new algorithm based on the general robust satellite technique (RST) approach for automatic near-real-time oil spill detection and continuous monitoring (i.e., in both daytime and night time) using MODIS satellite data. This group found that the RST algorithm was able to overcome possible false-positive problems related to poorly recognized cloud edges and sea-surface local cooling effects that often reduce the reliability of the retrieval.

Consistent with the work of Marghany and Hashim (2011), synthetic aperture radar (SAR) allows for the improvement of oil spill detection using various approaches. The SAR tools for the detection and survey of oil spills include boats, airplanes, and satellites (Zhang et al., 2012). Vessels can detect oil spills at sea by covering relatively limited areas of approximately 2500 m × 2500 m if they are equipped with navigation radar (Zhang et al., 2011). Because they can probe broader areas, airplanes and satellites are the primary tools used to investigate sea-based oil pollution (Skrunes et al., 2012). Several SAR sensors have been deployed for oil spill detection and survey. Such data were collected by ERS-1/2 (Brekke and Solberg, 2005), ENVISAT (Marghany, 2013), ALOS (Zhang et al., 2012), RADARSAT-1/2 (Zhang et al., 2012; Xu et al., 2014), and TerraSAR-X (Velotto et al., 2011); these data have been used on a global scale to identify and monitor the Deepwater Horizon oil spill. Furthermore, airborne SAR sensors such as the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR, operated by JPL, L-band), which has a 22-km-wide ground swath at incidence angles of 22–65° (Zhang et al., 2012), and E-SAR (operated by DLR, multi-band) have also proven their excellent potential for monitoring coastal zone oil pollution. Recently, multi-polarimetric high-resolution SAR data have become a field of intensive research for oil spill detection (Skrunes et al., 2012; Shirvany et al., 2012).

Fig. 1. Oil spill disaster in Gulf of Mexico.

The SAR sensors are used to image an oil spill based on Bragg scattering theory. Bragg scattering is a significant concept for understanding radar signal interaction with the ocean surface. Briefly, the presence of a capillary wave will produce backscatter that assists radar in imaging the sea surface. Short gravity and capillary waves created by the oil spill are damped by the dynamic elasticity of the water surface, i.e., by changes in surface tension that occur when the surface is stretched or compressed (Alpers, 2002; Marghany et al., 2009; Zhang et al., 2014). As stated by Caruso et al. (2013), the imaging of oil on the sea surface using SAR relies on the damping influence of the oil on the Bragg waves. However, the reduced radar backscatter on the sea surface is not unique to oil. Gade et al. (1998) stated that low winds, biogenic films, wind sheltering by land or oceanic structures, grease ice, internal waves, ship wakes, and convergence zones also generate zones of reduced SAR backscatter (Fiscella et al., 2000). Moreover, thunderstorms, rain, and atmospheric and oceanic fronts can mask surface roughness or produce so-called "lookalike" features (Caruso et al., 2013).

Ocean surface wind patterns play a highly important role in oil spill imaging with SAR data. If the ocean surface is calm due to low wind speed, surface gravity waves disappear, the returned radar backscatter is low, and the ocean surface appears featureless and uniformly dark across the image (Alpers, 2002; Brekke and Solberg, 2005; Zhang et al., 2014). As the winds increase to approximately 3 m s^{-1}, biogenic slicks begin to appear. Biogenic surface slicks such as those produced by plants and animals in the ocean can also dampen the radar return and cause look-alike false alarms for oil detection. At the lower end of this range, biogenic slicks blend in with the low wind zones of the SAR image (Gade et al., 1998). As the winds reach 2–3 m s^{-1}, these slicks start to highlight the oceanic convergence zones along the fronts and eddies. At these speeds, it is often difficult to distinguish biogenic slicks from anthropogenic oil or natural seeps (Fiscella et al., 2000). Once the winds exceed 3 m s^{-1}, biogenic slicks begin to disappear, and the contrast between oil and the sea surface is notably strong (Alpers, 2002). As the winds continue to increase, the short surface waves produce stronger radar backscatter. If wind speed is greater than approximately 8–10 m s^{-1}, mixing via strong wind and/or wave action inhibits the formation of a surfactant layer, resulting in uniformly strong backscatter in all areas of an image such that oil cannot be detected (Brekke and Solberg, 2005; Caruso et al., 2013).

The detectability of oil with SAR is also a function of the sensor configuration. For C-band SAR, the detectability relies on polarization, incidence angle, spatial resolution, and noise equivalent sigma zero (Cheng et al., 2011). For single polarization images, VV-polarization produces better results than HH-polarization. The backscatter intensity decreases with increased incidence angle; therefore, small spills cannot be discriminated with lower-resolution beam modes. Although the NESZ (a measure of the sensitivity of the SAR system) potentially limits the effectiveness at high incidence angles, the effects of wind speed are more important (Cheng et al., 2011).

Consequently, the highly accurate detectability of oil with SAR is expected to aid in the identification of oil spill parameters. However, the detailed parameters of an oil spill are challenging to identify because of complicated sea surface states and the smoothing interaction of an oil spill with the SAR signal. In general,