# COMPARATIVE DETECTIONS OF OIL SPILL USING MULTIMODE RADARSAT-1 SYNTHETIC APERTURE RADAR SATELLITE DATA

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**To Colonel Muammar Abu Minyar Al Gaddafi**

**The brotherly leader of of the Socialist People's Libyan Arab Jamahiriya**

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# ABSTRACT

Oil spill or leakage into waterways and ocean spreads very rapidly due to the action of wind and currents. The study of the behavior and movement of these oil spills in sea had become imperative in describing a suitable management plan for mitigating the adverse impacts arising from such accidents. But the inherent difficulty of discriminating between oil spills and look-alikes is a main challenge with Synthetic Aperture Radar (SAR) satellite data and this is a drawback, which makes it difficult to develop a fully automated algorithm for detection of oil spill. As such, an automatic algorithm with a reliable confidence estimator of oil spill would be highly desirable. The main objective of this work is to develop comparative automatic detection procedures for oil spill pixels in multimode (Standard beam S2, Wide beam W1 and fine beam F1) RADARSAT-1 SAR satellite data that were acquired in the Malacca Straits using three algorithms namely, textures using co-occurrence matrix, post supervised classification, and neural network (NN) for oil spill detection with window size 7 x 7. The results show that the mean textures from co-occurrence matrix is the best indicator for oil spill detection as it can discriminate oil spill from its surrounding such as look-alikes, sea surface and land. The entropy and contrast textures can be mainly used for look-like detections. The receiver operator characteristic (ROC) was used to determine the accuracy of oil spill detection from RADARSAT-1 SAR data. The results show that oil spills, look-alikes, and sea surface roughness are perfectly discriminated with an area difference of 20% for oil spill, 35% look–alikes, 15% land and 30% for the sea roughness. The NN shows higher performance in automatic detection of oil spill in RADARSAT-1 SAR data as compared to other algorithms with standard deviation of 0.12. It can therefore be concluded that NN algorithm is an appropriate algorithm for oil spill automatic detection and W1 beam mode is appropriate for oil spill and look-alikes discrimination and detection.

# ABSTRAK

Tumpahan atau kebocoran minyak di saluran air dan lautan kebiasaanya merebak dengan cepat disebabkan oleh tindakan angin dan arus. Kajian tentang perilaku dan pergerakan tumpahan minyak adalah penting untuk mengurangkan kesan negatif kemalangan tumpahan minyak melalui rancangan pengurusan yang sesuai. Namun, kesulitan dalam membezakan antara tumpahan minyak dan tampak kesamaan sering menjadi cabaran dan kekurangan apabila berurusan dengan data Radar Bukaan Sintetik (SAR), ia menyukarkan pembinaan pengesanan tumpahan minyak secara automatik. Algoritma pengesanan tumpahan minyak secara automatik yang dilengkapkan dengan tahap keyakinan anggaran yang tinggi amat diperlukan. Tujuan utama kajian adalah untuk membina prosedur pengesanan automatik piksel tumpahan minyak dalam pelbagai mod (alur piawai *S2,* alur lebar *W1* dan alur halusF1) data satelit RADARSAT-1 dengan menggunakan tiga algoritma pengesanan tumpahan minyak iaitu tekstur mengunakan matrik saling keberulangan, pasca pengkelasan berpenyelia dan jaringan neural (NN) bagi kawasan Selat Melaka dengan saiz tetingkap 7x7. Keputusan kajian menunjukkan tekstur menggunakan purata dari matrik saling keberulangan adalah penunjuk yang paling bagus untuk pengesanan tumpahan minyak kerana ia dapat membezakan tumpahan minyak daripada tampak kesamaan, permukaan laut dan darat. Tekstur entropi dan kontra adalah sesuai untuk pengesanan tampak kesamaan. Ciri penerimaan operator (ROC) digunakan untuk menentukan ketepatan pengesanan tumpahan minyak untuk data satelit RADARSAT-1. Keputusan kajian juga menunjukkan bahawa tumpahan minyak, tampak kesamaan dan kekasaran permukaan laut dapat dibezakan 20% untuk tumpahan minyak, 35% untuk tampak kesamaan, 15% untuk darat dan 30% untuk kekasaran permukaan laut. NN menunjukkan prestasi yang lebih baik dengan sisihan piawai 0.12 untuk pengesanan tumpahan minyak secara automatik. Pada kesimpulannya, NN adalah satu algoritma yang sesuai untuk pengesanan tumpahan minyak secara automatik dan mod W1 adalah paling sesuai untuk membezakan dan mengesan tumpahan minyak serta tampak kesamaan.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AVHRR | - | Advanced Very High Resolution Radiometer |
| HH | - | Refers to horizontally transmitted |
| VV | - | Refers to vertically transmitted |
| MODIS | - | Moderate- Resolution Imaging Spectro radiometer |
| ANN | - | Artificial Neural Network |
| SSA | - | Static Security Assessment |
| NN | - | Neural Network |
| MLP | - | Multilayered Perception |
| SOM | - | Self Organizing Map |
| NASA | - | The National Aeronautics and Space Administration |
| NOAA | - | National Ocean and Atmospheric Administration |
| MWR | - | Microwave Radiometer |
| OSTM | - | Ocean Surface Topography Mission |
| SAR | - | Synthetic Aperture Radar |
| SLAR | - | Side-Looking Airborne Radar |
| SeaWiFS | - | Sea-viewing Wide Field-of-view Sensor |

| | | |
|---|---|---|
| ERS | - | European Remote Sensing Satellite |
| HMC | - | Hidden Markov Chain |
| NRCS | - | Normalized Radar Cross Section |
| APC | - | Antenna Pattern Correction |
| SNR | - | Single to Noise Ratio |
| GLDM | - | Grey Level Dependency Matrix |
| GLDV | - | Grey Level Difference Vector |
| Ref | - | Reference Pixel |
| Nbr | - | Neighbor Pixel |
| HOM | - | Homogeneity |
| CON | - | Contrast |
| Dis | - | Dissimilarity |
| Ent | - | Entropy |
| ASM | - | Angular Second Moment |
| Cor | - | Correlation |
| BP | - | Back-propagation |
| SSA | - | Static Security Assessment |
| ANFIS | - | Adaptive Neuro-Fuzzy Inference System |
| IEEE | - | Institute of Electrical and Electronic Engineering |
| IR | | Infrared radiation |
| UV | | Ultraviolet radiation |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| C | - | Velocity of light |
| f | - | Frequency |
| λ | - | Wavelength |
| $\Theta$ | - | Incident angle |
| σ° | - | The backscatter coefficient |
| dB | - | Decibel unit of measurement frequency |
| $\lambda_B$ | - | Wavelength of the ocean wave |
| $\lambda_r$ | - | SAR wavelength |
| $\delta_{Ocean}$ | - | reflection of the signal occurs over the ocean |
| SCN | - | Scan SAR Narrow |
| WSM | - | Wide Swath Mode |
| SCW | - | Scan SAR Wide |
| μ | - | Mean |
| Σ | - | Standard deviation |
| LoG | - | Laplace of Gaussian |
| DoG | - | Difference of Gaussian |
| *D* | - | The fractal dimension |

| | | |
|---|---|---|
| C-OCC | - | Co-occurrence matrix |
| M1 | - | Class 1 |
| M2 | - | Class 2 |
| $w_{jk}$ | - | The weight connected between node $j^{th}$ and $k^{th}$ |
| $\theta_j$ | - | The bias of node $j^{th}$ |
| $\theta_k$ | - | The bias of node $k^{th}$ |
| $_j$, $i,k$ | - | Nodes at input, hidden and output layers(nodes) |
| $O_j$ | - | The output of node $j^{th}$ |
| $O_i$ | - | The output of node $i^{th}$ |
| $O_k$ | - | The output of node $k^{th}$ |
| $w_{ij}$ | - | The weight connected between node $i^{th}$ and $j^{th}$ |
| $w_{jk}$ | - | The weight connected between node $j^{th}$ and $k^{th}$ |
| $\theta_j$ | - | The bias of node $j^{th}$ |
| $\theta_k$ | - | The bias of node $k^{th}$ |
| $d_{ij}$ | - | The $j^{th}$ desired output for the $i^{th}$ training pattern |
| $y_{ij}$ | - | The corresponding actual output |
| $x_i^{(2)}$ | - | The input of neuron $i^{th}$ in Layer2 |
| $y_i^{(2)}$ | - | The output of neuron $i^{th}$ in Layer2 |

| | | |
|---|---|---|
| $a_i, b_i$ and $c_i$ | - | Parameters that control, respectively, the centre, width and slope of the bell activation function of neuron $i^{th}$. |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Oil spill pollution has a substantial role in damaging marine ecosystem. Oil spill that floats on top of water, as well as decreasing the fauna populations, affects the food chain in the marine ecosystem (Dunnet et al., 1982). In fact, oil spill is reducing the sunlight penetrates the water, limiting the photosynthesis of marine plants and phytoplankton. Moreover, marine mammals for instance, disclosed to oil spills their insulating capacities are reducing, and so making them more vulnerable to temperature variations and much less buoyant in the seawater. Dunnet et al. (1982) stated that oil coats the fur of sea otters and seals, reducing its insulation abilities and leading to body temperature fluctuations where the body temperature is much lower than normal (hypothermia). Ingestion of the oil causes dehydration and impaired digestions (Fingas, 2001 and Zeynalova et al., 2009).

Oil spill pollution causes political and scientific concerns because they have serious effects on feeble maritime and coastal ecologies. Significant parameters in evaluating seawater quality are the amounts of pollutant discharges and associated effects on the marine environment (Topouzelis, 2008). There are many sources of oil pollution and spillage, which may be as a result of exploitation, extraction, transportation, and/or disposal activities. In the case oil pollution occurrence in marine environment, the first undertaken task is determination of priorities for protection against pollution (Shattri and Pourvakhshouri, 2003). According to Roslinah and Shattri (2000); Fingas (2001), more than 75 % of sea pollution is manmade (Roslinah and Shattri, 2000; Fingas, 2001; Brekke and Solberg, 2005). Each year, around 48 % of oil pollution in the oceans is from fuels, 29 % is from crude oil, while tanker accidents contribute only 5 % (Zeynalova et al., 2009).

Remote sensing technology is a valuable source of environmental marine pollution detection and surveying that improves oil spill detection by various approaches. The different tools to detect and observe oil spills are vessels, airplanes, and satellites (Brekke and Solberg, 2005). Vessels can detect oil spills at sea, covering restricted areas, say for example, (2500 m x 2500 m), when they are equipped with navigation radars. On the other hand, airplanes and satellites are the main tools that are used to record sea-based oil pollution (Topouzelis, 2008).

Recently, scientists and researchers have reported the fluorescent Lidar as a promising technique for oil spill detection, because of its high capability to perform actively and can positively distinguish oil from biological substances and surrounding sea environment. According to Holt (2004), most organic multi-party compounds have individuality of the fluorescence production spectrum. Hence, fluorescence emission is a strong indication of the presence of oil. On the other hand, most huge systems installed on large airplanes are seldom use as tool for oil pollution cleanup (Hengsterman and Reuter, 1990; Balick et al., 1997; Brown et al., 2000).

Further Brekke and Solberg, (2005) reported that the most applicable space-borne sensor for oil spill detection is synthetic-aperture radar (SAR). SAR sensors perform in all-weather conditions and provide all-day detection coverage. Again, SAR satellite data can penetrate the cloud covers because of its independence on sun radiation (Trivero et al., 2001), and also can operate at wind speeds of up to 12–14 m/s depending on oil type and age. Sensors operating in wide strip modes with a resolution of 50–150 m are found to be satisfactory and efficient in covering large ocean areas (Topouzelis et al., 2008).

Most scientists have shown great interest in the huge maritime environmental damage due to oil slicks, which have increase pollution effects greatly. Space-borne RADARSAT-1 SAR images are used to monitor and control oil slicks, however, the main challenges lies in the difficulties inherent in discriminating between oil spills and look–alikes. According to Maged and Hashim (2005) both appears as a dark spot in SAR data.  Also according to Alpers and Hühnerfuss (1988); Trivero et al., (1998), the existence of an oil layer on the sea surface damps the small waves which increase the thickness of the top film and this significantly decreases the measured backscattering energy resulting in darker areas in SAR imagery. The European remote sensing satellite (ERS) task is an example of SAR.

However, Frate et al., (2000), argued that careful analysis is required since the dark areas might also be generated by local low winds or by normal sea slicks. Researchers such as Solberg et al., (1999); Brekke and Solberg, (2005); Topouzelis, (2008), agreed that well tuned classification algorithms can be employed to avoid false alarms. Oil spills show a larger discontinuity effect on the environment, mainly because of its thickness. A possible procedure could be formulated based on the selection of an area in an image containing dark pixels; computation of physical and geometrical features characterizing an object; classification of the object into oil spill or look-alike, based on the dark spot texture (Brekke and Solberg, 2005;Topouzelis et al., 2008).

## 1.2 Significance of the Study

Standard procedures are required for oil spill detection from multi SAR data to ensure the coastal zone clean up. These procedures can be of benefit to international oil companies like Brega Marketing Company in Libya (Middle East) and Petronas (Malaysia). Rapid information on pollutant substances that exist on the sea is necessary for coastal management to avoid damage to marine ecosystem. In addition, the improvement of coastal tourism requires the involvement of many parties such as local inhabitants, policy makers, and the scientific community (Siry, 2007). Policy makers play an important role by issuing regulations and policies that guide the design of sites for tourist and support facilities like hotels and recreational areas. In designing such sites, designers need accurate information which could be supplied by microwave radar data (Assilzadeh and Shattri, 2001). According to Marghany (2004), policy makers are required to make the decision more comprehensible by involving scientists.

Furthermore, the role played by the scientific community becomes more crucial due to its potential in contributing to logical ideas through research and developmental activities. Environmentalists and Engineers, as part of the scientific communities are responsible for finding new applications that could improve the quality of human life within coastal areas that are prone to pollutions from oil spills, industrial and household wastes problems encountered by many different countries, including Malaysia, which causes great damages along these coastal zones. In this context, these problems can influence the tourist sector, as it is one of the main sources of income (Carlo et al., 2008).

As humans are one of the agents causing environmental problems, more concerns need to be focused on human activities. Mohamed et al., (2006) stated that the destruction of an island’s ecological environment could also be as a result of unregulated development of extensive infrastructure such as jetties, resorts, and airports. The Malaysian authorities are required to embark on educating inhabitants of the coastal area by providing them with enabling regulations that may enhance clean environmental policies that could promote tourism, since tourism is one of the main sources of Malaysian income (Mohamed et al., 1999; Assilzadeh and Shattri, 2001; Hashim et al., 2006).

## 1.3 Research Objectives

The main objective of this work is to develop comparative detection procedure of oil spills using multimode RADARSAT-1 SAR satellite data. This objective is divided into the following sub-objectives:

i. To examine various algorithms such as co-occurrence texture, Mahalanobis classifier, and artificial intelligence techniques for oil spill automatic detection in multimode RADRASAT-1 SAR data.

ii. To determine an appropriate algorithm for oil spill automatic detection in multimode RADRASAT-1 SAR data that is based on algorithm's accuracy (Solberg et al., 1999).

iii. To develop detection techniques for oil spill based on pixel classifier tools (Neural Network, Mahalanobis Distance, and Texture Algorithm).

iv. To determine the detectability of Radarsat-1 SAR scale image (mode) for oil spill detection from surroundings pixel.

## 1.4 Problem Statement

Oil spill or leakage into waterways and ocean spreads very rapidly due to the action of wind and currents. There is really no part of a marine and coastal environment that is not in some way greatly affected by an oil spill incidence. The closer this spill occurs to the shoreline, the more devastated the damage will be because of the fact that coastal zones are home to a great number of diverse populations of marine, bird and animal life than far into the sea. It is worthy of note that a single gallon of oil can create an oil slick up quite a number of acres in size. The study of the behavior and movement of these oil spills in sea had become imperative in describing a suitable management plan for mitigating the adverse impacts arising from such accidents. But the inherent difficulty of discriminating between oil spills and look-alikes is a main challenge with SAR satellite data and this is a drawback, which makes it difficult to develop a fully automated detection of oil spill. As such, an automatic algorithm with a reliable confidence estimator of oil spill would be highly desirable. The needs for automatic algorithms rely mostly on the number of images to be analyzed, but, for monitoring large ocean areas, it is a cost-effective alternative when compared to manual inspection. Automatic detection algorithms of oil spill are normally divided into three steps: dark spot detection; dark spot feature extraction; and dark spot classification (Brekke and Solberg, 2005; Topouzelis, 2008; Marghany et al., 2009a).

One of the main problems faced in combating and managing oil slick is in forecasting the behavior (i.e. movement and spreading) of oil slicks. Generally, the main idea of predicting the behavior of oil slicks is to determine the time-evolving shape of the slick under different weather patterns in water, where currents exist (Marghany et al., 2009a). Wind direction and speed are the most important climate parameters that can impact the oil spill imagery in SAR data. Models for oil slick behavior are important in environmental engineering and are used as a decision support tool in environmental emergency responses. These models are used to help ships avoid oil slicks (Adam, 1995). Although great progress had been made in detecting and surveying oil slicks, a general model for oil slick movement and spreading has not yet been devised (Marghany et al., 2009a). They also reported that past progresses in modeling the extent of oil in the ocean are not always tested against authentic spills neither does the models are regularly developed with real databases, but rely instead on theoretical scenarios.

According to Verma et al., (2008), some spill-threat scenarios have not been based on real oil movement data at all yet there are frequent demands to provide just such models with credible precision. Consequently, it is important to study the behavior and movement of spilled oil in the sea in order to describe a suitable management plan for mitigating adverse impacts arising from such accidents. Simulation of oil spills using mathematical models form an important basis for subsequent studies collectively, with the information on position of weak resources in time and space (Reed et al., 2004). The simulation outcome may develop a basis for evaluating the damage potential from an eventual oil spills. This may help the regulatory authorities to take direct preventive measures (Marghany, 2004).

In addition, most of the studies that have been conducted in the coastal waters of Malaysia using single radar image, which is inadequate to ensure accurate detection of oil spills. Some of the work involved the implementation of non-appropriate techniques for oil spill automatic detection. For instance, Mohamed et al., (2006) have used data fusion techniques in a single RADARSAT-1 SAR image, with different co-occurrence texture algorithms. However, the data fusion techniques apply to two or more different sensors for example, ERS-1 and LANDSAT. According to Solberg and Solberg (1996), using principal component analysis (PCA) analysis is not considered an appropriate method for data fusion. Data fusion technique involves several methods such as high pass filtering technique, IHS intensity–hue–saturation transformation method, Brovey method, and à Trous wavelet method (Brekke and Solberg, 2005).

## 1.5 Research Questions

In line with exploring the different issues and aspects of this research study, the following research questions are presented. These questions were answered in the process of the research methodology:

i. How can we discriminate between oil spills and look-alikes?

ii. Are the achieved SAR algorithms used in oil spill detection applied to real situations?

iii. Is the oil spill detection on the Malaysian coast using single SAR data per day adequate?

## 1.6 Research Scopes

In order to achieve the research objectives, the scope of the study is focused on the following aspects:

i. Examining Multimode-SAR data of for oil spill detection.

ii. Comparing the results of different algorithms namely- the co-occurrence texture, Mahalanobis classifier, and artificial intelligence techniques, to determine among the three the appropriate detection algorithm for oil spill.

iii. Using Back Propagation Algorithm an Artificial Intelligence technique as a classification tool for oil spill detection.

## 1.7 Contributions of the Research

The contributions of the research are as follows:

(i) The study utilizes multimode RADRASAT-1 SAR data and compare them with previous studies conducted by Mohamed et al., (1999); Roslinah and Shattri (2000); Assilzadeh and Shattri (2001); Marghany (2001); Marghany and Hashim (2005).

(ii) To develop an automatic detection tool based on Artificial Neural Network (ANN), previous studies according to Mohamed et al., (1999); Assilzadeh and Shattri, (2001); Roslinah and Shattri, (2001); Mohamed, (2006), imposed semi automatic tools for single SAR data.

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