DETECTION OF OIL SPILL POLLUTION USING RADARSAT SAR IMAGERY

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ABSTRACT:

The Straits of Malacca and South China sea are exposed to pollution caused mainly by oil spilled produced from deliberate rinsing of tanks, spillage from oil tanker collision and illegal oily waste disposal. The government and public are concern over oil spills and need to response more effectively so as to minimize their environmental impact. The use of remote sensing technology in managing oil spills has received a considerable attention over the past few years. Many organisations have used remote sensing technology as an effort to monitor oil spill pollution in the sea. The ability of Radarsat Synthetic Aperture Radar (SAR) data in the detection of oil spill pollution was carried out in this study. The digital image processing techniques included radar backscatter calibration, speckle filtering, edge detection filtering, texture analysis, brightness value (dB) analysis, oil spill shape analysis and image classification were used to enhance the spillage area in the Radarsat SAR imagery over the Straits of Malacca. The results showed that oil spill pollution over a wide ocean area could be detected by Radarsat SAR imagery.

1.0 Introduction

Malaysia is surrounded by sea and hence act as a shipping route and sources for petroleum exploration. By being so, it is often highly exposed to pollution. The Straits of Malacca and South China Sea are sensitive to oil spill pollution due to their important role in economical, social and environmental aspects of the country. In conjunction with this, coastal regions near ports, harbour and other terminals are especially prone to environmental hazard resulted from heavy traffic by very large crude-oil carriers and other vessels. Oil pollution cause marine ecological disasters that resulted in great damage to the quality and productivity of marine environment and involved great expenses in clear-up operations.

There are several oil incidents involving oil tankers since 1975-1997 such as Showa Maru (1975), Dieogo Silang (1976), M. V. Fortune (1979), Century Dawn (1988), collision between Nagasaki Spirit and Ocean Blesing (1992), collision between M. T. Evoikos and M. T. Orapin Global (1997) (Department of Environment (DOE), 1997). These incidents have caused serious marine pollution and great damage to coastal resources along the shorelines and offshore of Malaysian coast. This issue has been on our government agenda for many years. In order to solve this problem, the government has continues to give high priority on the conservation of marine and environmental resources.

This effort was further strengthened with the establishment of an airborne surveillance programme by Department of Environment (DOE) in 1996 for combating oil spill and beach clean-up operation which fulfil the requirement of the first National Oil Spill Response Plan, 1996 (DOE, 1996). This programme had been successful in providing useful and speedy surveillance information on oil spill movement, location and distribution of the spillage in the Straits of Malacca and South China Sea. However, an airborne surveillance programme provides limited information on oil spillage due to limited spatial coverage of a large area and limited operational capability. The limitation of air surveillance capability can be solved using microwave remote sensing technology. Remote sensing provides real time information on ground features for a wide area that could not be obtained by other conventional methods.

Radarsat satellite has a capability to penetrate cloud cover in the tropical country, cover a wide area and provide information on sea surface roughness that is very useful in the identification of oil spill feature on the sea surface.

2.0 Materials and Methods

2.1 Study Area

The study area is located in the Straits of Malacca which cover the sea area between Banting and Sepang in Selangor State. It lies between longitude 97^{o} 36' 15.61" E and 98^{o} 09' 45.33" E and latitude 2^{o} 26' 44.61" N and 2^{o} 53' 21.08" N. The Straits of Malacca forms the main seaway for connecting the Indian Ocean with the China Sea and provides the shortest route for tankers trading between Middle-East Asian. Serious accidents always occur in the high traffic density areas as well as in open sea areas with mild traffic condition. Generally, the sea condition at Straits of Malacca is calm but during southwest monsoon season, the wind velocity increases to 50 knots.

2.2 Data

Radarsat Synthetic Aperture Radar (SAR) data of Straits of Malacca dated 20 December, 1999 at 23:03 p.m. was used in the study. Radarsat SAR data used 5.6 cm wavelength, frequency 5.3 Ghz with horizontal-horizontal (HH) polarisation, also known as C band. The type of Radarsat SAR data used in the study was Standard 2 beam mode. Radarsat data has 12.5 m spatial resolution and 110 km x 100 km swath area with an incidence angle between 23.7^{o}–31.0^{o}.

2.3 Methods

The study used PCI EASI/PACE Version 6.3 image processing system to process Radarsat data. Several image processing techniques including radar backscatter calibration, geometric correction, image enhancement, oil spill verification and image classification were carried out in this study for the detection of oil spill.

2.3.1 Image Processing

The study required pre-processing method before further processing techniques can be applied on the Radarsat SAR data. Radar backscatter calibration was applied in this study to generate radiometrically calibrate image which represent the original signal amplitude that would allow the data to be quantitatively related directly with the actual radar backscatter to the physical target (oil spill) on the ground. The Radarsat image then was geometrically corrected and registered to the Rectified Skew Orthomorphic (RSO) projection where the corresponding elements of the same ground area appear in the same place on the registered image (Chen and Lee, 1992).

In order to detect oil spill pollution in the Radarsat SAR image, histogram equalisation enhancement and image multiplication were carried out on the Radarsat image to generate the intensity of radar backscattering. The image then was masked using threshold technique to ignore land surface area. Synthetic Aperture Radar (SAR) imageries including Radarsat SAR data had a major problem that contain speckle noise due to coherent nature of radar backscatter used in the image formation. The effect of speckle caused grainy appearance in the radar image which disrupt visual interpretation. In order to solve this problem, speckle filtering was used to remove speckle in the radar image that would be enhanced oil slick areas in the image (Maged, 1999; Assilzadeh et al., 1999). The study used different types and size of speckle filter included Enhanced Frost, Enhanced Lee, Frost, Gamma Map, Kuan and Lee filters. About 30 filtering processes were applied in this study using window size from 3x3, 5x5, 7x7, 9x9 and 11x11.

2.3.2 Detection of Oil Spill

Most of the previous study found that oil spill appeared as a dark slick or dark spot in SAR image due to the dampening effects of Bragg wave on the sea generated by low backscatter cross-section of the smooth surface of oil spillage. Whereas the surrounding water appeared bright due to the roughness surface gave high backscatter cross-section.

The identification of oil spill in SAR imagery is dependent on being able to distinguish between the possible causes of low backscatter regions. In this study, each of the dark slick in the filtered image were evaluated qualitatively through visual interpretation on the computer screen based on the regions of low backscatter and low values of the digital number in the image. The dark slicks were evaluated quantitatively based on the mean intensity, standard deviation and speckle factor of filtered image (Lira and Frulla,1998).

2.3.3 Oil Spill Verification Using Direct Analysis

Normally, dark slick in the Radarsat SAR image can be identified as an oil spill if its resulted from oil spillage or can be identified as a look-alikes if its caused by natural phenomena such as natural seepage, internal waves, sea current or rain cell on sea surface. In the radar image, natural phenomena also appeared as a dark slick due to low backscatter cross-section effected by the smooth surface of these phenomena. Direct analysis such as edge filter, brightness evaluation, texture analysis and shape analysis were used to verify oil spill from their look-alikes.

Edge detection filters from 3x3 up to 11x11 window sizes were applied on the very good filtered image to distinguish oil spill from their look-alikes. The average value of radar intensity for oil spill was extracted using radar brightness values on every pixel within the dark slick boundaries. The average radar intensity values for the identified oil spill and the surrounding area then were converted to average radar backscatter coefficient (σ^o) value using the following equation:-

$$\text{Backscatter coefficient}, \ \sigma^o = 10 \log_{10} < \hat{I} > \quad \ldots\ldots\ldots\ldots (1)$$

Where,

$< \hat{I} >$ is a mean intensity of the distributed area.

The dark slick texture then was analysed using texture analysis namely homogeneity, contrast and dissimilarity from 3x3 up to 11x11 window sizes.

According to Solberg and Volden (1997), oil shape analysis was very important in the differentiation between oil spill and their look-alikes because of weather was greatly affected on the shape of oil spill that released from a stationary object or from a moving ship. The combination of oil shape analysis that had been done by Lu et al. (1999) and also by Espedal and Wahl (1999) was applied in the study to strengthen the differentiation between oil spill and their look-alikes. Normally, the moving ship produced long linear slicks which were categorized as linear, curved and patchy (Lu et al., 1999) whereas the other shape can be categorized into straight, bent or curve, wide or rounded and angular shapes (Espedal and Wahl, 1999).

2.3.4 Oil Spill Verification Using Contextual Information

The other parameters in the study area such as shape and location of the suspected oil spill, meteorological data, sea currents, wind speed and wind direction, bathymetry, oil platform and ship lane location could be used as the contextual information to help in distinguishing between oil spill and their look-alikes in order to avoid false detection of oil spill. The previous study used shapes and location of the suspected oil slick (Liew et al., 1998) and also bright object which known as ship (Solberg and Volden, 1997) as the contextual information to differentiate between oil spill and their look-alikes.

The study used ship lane as the contextual information to verify oil spill from their look-alikes due to the lack of other contextual information in the study area like meteorological data (wind speed and wind direction) and oceanographic data (sea current, wave, tidal, bathymetry, sea surface temperature). In addition, the study area was located in the busiest ship lane in the Straits of Malacca which connects south-east Asia countries between Malaysia, Singapore, Indonesia and Thailand.

2.3.5 Image Classification

In order to delineate oil spill from their look-alikes and the surrounding area, the dark slicks in the Radarsat image were classified using unsupervised classification technique.

3.0 Results and Discussion

The result of calibrated radar backscatter in 32 bit real format shown that sea area in the image appeared dark where an oil spill could not be seen clearly in the image (Figure 1). It could be seen clearly when the calibrated radar backscatter image was enhanced using histogram equalization enhancement and multiply operation (Figure 2). The results of the study showed that speckle in the Radarsat image can be removed using Enhanced Frost, Enhanced Lee, Frost, Gamma Map, Lee and Kuan filters. However, the quality of the resultant images is dependent on the filter types and window size.

From the qualitative and quantitative evaluation, the study found that Lee filter (7x7) was the best filter to detect dark slick in the Radarsat image because it removed speckle and preserve edge and texture of the dark slick very well, thus the dark slick appeared sharp and the shape remain unchanged (Figure 3). While the dark slick in the other filtered image appeared blurred and the shape was changed because it had smoothed out the speckle in the surrounding area together with the dark slick edges and texture. The study also found that Kuan filter (11x11) is the suitable filter to enhance ships in the Radarsat image which shown as a bright spots in the image (Figure 4).

Figure 1: Calibrated radar backscatter image in 32 bit real format

Figure 2: Calibrated radar backscatter image after enhanced using histogram equalization and multiply operation

From the visual interpretation analysis, several patches and linear dark slick located at the centre of Straits of Malacca and wide dark slicks located near the coast and at the centre of Straits of Malacca were found clearly in the Lee (7x7) filtered image as shown in the Figures 5(a), 5(b), 5(c) and 5(d).

The study used edge of the dark slicks as an outline to delineate oil spill from their look-alikes because high viscosity of oil had formed a steep slope surface which appeared sharpen and brightness in the image. Whereas low viscosity of their look-alikes had formed a small slope surface that appeared blurred in the image. The study found that patchy and linear dark slicks at the centre of Straits of Malacca had high probability as an oil spill due to their edges appeared sharpen and brightness in the image whereas the wide and bent dark slicks had high probability as look-alikes because of their edges could not been seen clearly in the image.

The dark slick could be identified as an oil spill or look-alikes depend on the radar backscattering coefficient, σ^o value in the Radarsat image. The results of the study showed that the average of radar backscatter coefficient for the identified dark slick was –13.01 dB which lower than the values of their look-alikes and the surrounding area. The study found that the radar backscatter coefficient value of the identified oil spill was similar with the value by Jones and Jacob (1998) which varied from –9 dB to –14 dB in the north-west and from –26 dB to –20 dB along the south coast from St. Anne Head to Caldey Island. The earlier study done by Guinard and Purves (1970) also showed the difference value of radar backscatter coefficient for oil spill from 6 to 20 dB with using horizontal polarisation of Four Frequency Radar image and even smaller for the cross-polarised component. This situation showed that radar backscatter coefficient value for oil spill was not always similar due to several factors may affect the radar backscattering of oil spill such as oil spill types, oil spill thickness, types of remote sensing data and others.

Figure 3: Radarsat image filtered by Lee filter (7 x 7)

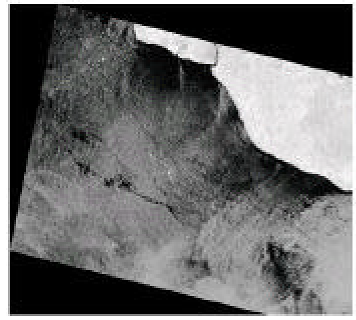
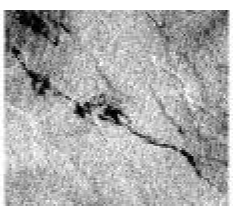


Figure 4: Radarsat image filtered by Kuan filter (11 x 11)



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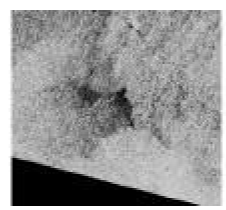

(5a) (5b) (5c) (5d)

Based on the study done by Solberg and Volden (1997), the dark slick texture such as homogeneity, contrast and dissimilarity were used to delineate boundary of oil spill from their look-alikes and the surrounding area. The characteristics that considered in the study were (i) the probability of oil spill is increased if the surrounding areas are homogeneous while the probability of look-alikes is increased if the surrounding areas are heterogeneous; (ii) the probability of oil spill is increased if the contrast between the slick and the neighbouring region is high while the probability of look-alikes is increased if the contrast between the slick and the neighbouring region is low and (iii) the probability of oil spill is increased when the dissimilarity between the dark slick and the surrounding area is high while the probability of look-alikes is increased when the dissimilarity between the dark slick and the surrounding area is low.

The results of the study showed that homogeneity (11x11), contrast (7x7) and dissimilarity (11x11) analysis produced very good image to differentiate the texture of oil spill, look-alikes and the surrounding area. The patchy and linear dark slicks at the centre of Straits of Malacca had high probability as an oil spill due to the texture of the surrounding areas were homogeneous, very high contrast texture between the dark slicks and the surrounding areas. Whereas, wide and bent dark slicks had high probability as a look-alikes due to the texture of the surrounding areas were heterogeneous, low contrast texture between the dark slicks and the surrounding areas, and low dissimilarity texture between the dark slicks and the surrounding areas.

In this study, an oil spill shape analysis was used to strengthen the probability of the dark slicks in the Radarsat image as an oil spill (Espedal and Wahl ,1999; Lu et al., 1999). The effects of the moving ships in the ship lane area could be related closely with the type of the dark slicks or oil spill shape that found in the image. Mostly the formation of oil spill shape was influenced by the ship speed and direction (Espedal and Wahl, 1999). Generally, it produced a linear dark slick but the changes of ship direction would change linear slick to bent slick. From the observation, most of the ships were found along the ship lane area in the Straits of Malacca but located far from the detected large dark slicks near the coast and wide dark slicks at the centre of Straits of Malacca (Figure 4). However, the ship was found not far from the patchy and linear dark slicks at the centre of Straits of Malacca which appeared as white spot in the image (Solberg and Volden, 1997). Figure 6 shown the ship in the highlighted circle was the point source of the identified oil spill at Straits of Malacca. According to Solberg and Volden (1997), the probability of oil spill is increased if a slick is closed to a bright object.

Based on the results from oil spill verification using direct analysis and contextual information analysis, the study concluded that the patchy and linear dark slicks at the centre of Straits of Malacca had high probability as an oil spill whereas the other dark slicks had high probability as look-alikes. The discrimination of oil spill fom their look-alikes and the surrounding area was done using unsupervised classification to ensure that the dark slick in the image was the true oil spillage. The result of unsupervised classification shown that the identified dark slicks was successfully delineated from their look-alikes and the surrounding area (Figure 7).

Further more, the information of oil spillage such as location and distribution also could be determined in the Radarsat imagery. The results of the study shown that the oil spill incident in the Straits of Malacca dated on 20 December 1999 was located between longitude 97^{o} 40' 56.78" E and 97^{o} 52' 00.69" E and between latitude 2^{o} 41' 49.60 N and 2^{o} 35' 06.42" N. This oil spill incident occurred in the ship lane location or navigational route at Straits of Malacca between Banting and Sepang in the Selangor State and it was distributed from north-west to the south-east of the Straits of Malacca. This information was very useful to the oil spill beach clean-up strategy groups for immediate action in order to fulfil the requirement of the National Oil Spill Response Plan (1996) for combating oil pollution in the Malaysian seas.

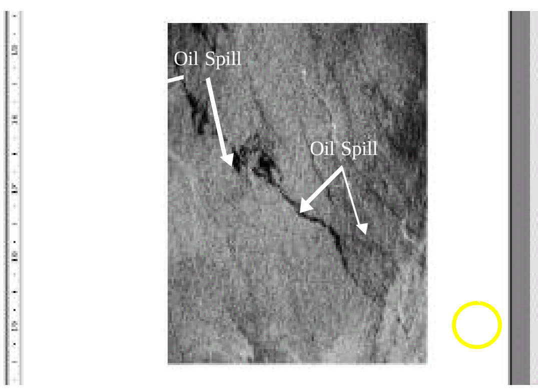

Figure 6: The zoom image shown that the ship was found not far from the detected of oil spill.

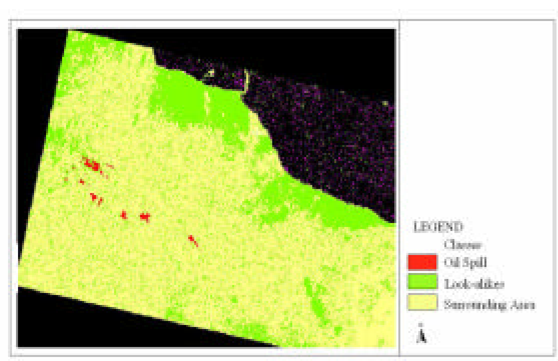

Figure 7: Unsupervised classification image shown the delineated oil spill from their look-alikes and the surrounding area.

4.0 Conclusion

The study concluded that remote sensing imagery from Radarsat satellite had been detected oil spill pollution in the ocean successfully due to their capability to operate day and night, penetrate cloud cover, and provide real time information on oil spill features, location, distribution and also could be detected the ship that being as the point source of the identified oil spillage in the ocean. The spatial distribution of oil spill in the Radarsat SAR imagery showed that oil spill pollution occurred at the major ship routes in the Straits of Malacca.

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