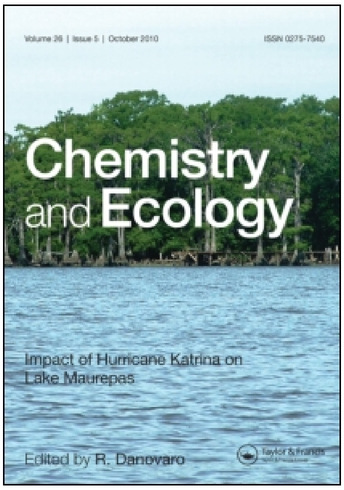

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

Application of Remote Sensing in Detection of Ocean Oil Pollution

J. T. Juang[a]; K. S. Chen[b]; C. F. Chen[b]; L. Y. Chang[b]
[a] Institute of Harbor and Marine Technology, Taichung, Taiwan [b] Center for Space and Remote Sensing Research, National Central University, Chung-Li, Taiwan

To cite this Article Juang, J. T. , Chen, K. S. , Chen, C. F. and Chang, L. Y.(1998) 'Application of Remote Sensing in Detection of Ocean Oil Pollution', Chemistry and Ecology, 14: 3, 279 — 289
To link to this Article: DOI: 10.1080/02757549808037609
URL: http://dx.doi.org/10.1080/02757549808037609

Chemistry and Ecology, 1998, Vol 14, pp. 279–289
Reprints available directly from the publisher
Photocopying permitted by license only

APPLICATION OF REMOTE SENSING IN DETECTION OF OCEAN OIL POLLUTION

J. T. JUANG[a,*], K. S. CHEN[b], C. F. CHEN[b] and L. Y. CHANG[b]

[a] *Institute of Harbor and Marine Technology, Taichung 435, Taiwan;*
[b] *Center for Space and Remote Sensing Research, National Central University, Chung-Li 320, Taiwan*

(Received 12 August 1997; In final form 15 December 1997)

It is well known that the increase of surface tension due to the presence of oil slicks causes the surface wave motion is depressed or even disappeared, thus making the surface electromagnetically smoother. Therefore, the radar backscattered energy is correspondingly decreased. These damping effects is now well understood and such effects enables the oil slicks to be discernible from the radar image. In this paper, we are concerned with the digital technique that effectively delineates the oil slicks pattern from the SAR image. The detected pattern allows us to estimate the coverage of oil spillage. The technique is based on the fact that the oil slicks make a gray value surface in the image which is a concave area with a certain size. In order to identify correctly these oil slicks and suppress the speckle noise and other natural phenomena, an image pyramid with multi-resolution layers is generated sequentially from the original image. Then a top-down approach, which applies both first and second order derivative operators, the Difference of Gaussian (DoG) and the Laplace of Gaussian (LoG), to the image pyramid, is used to detect oil patches. Two ERS-1 SAR images acquired on August 5, 1994 and September 5, 1994, around Taiwan, were used for testing. Results indicate that the proposed method depresses the speckle noise and other sea noise signals, and enhances the oil slicks pattern clearly. The robustness to the empirical parameters introduced in this scheme was also demonstrated.

Keywords: Remote sensing; SAR image; oil pollution

1. INTRODUCTION

An oil slick is a film of oil floating on the surface of water. The presence of the oil films affects the strength of radar backscattering

*Corresponding author.

signal from the sea surfaces. Characterization of the radar image responses to oil slicks has been done in the past (Alpers and Huhnerfuss, 1988). The dependences of polarization, angular and frequency response was investigated in the line of finding the optimum radar system to detection of oil slicks (Singh *et al.*, 1986). Efforts are also devoted to the discrimination between crude oil pollution and natural surfactant films. The formation of the films, usually an inhomogeneity, in relation to atmospheric conditions, such as wind speed and the sea states, and as current vectors, were also studied (Robinson, 1994). The intensity of the radar back-scatter from sea surface is related to the surface height spectrum. At near normal incidence, the signal strength is mainly due to Kirchhoff scatterers, while at the larger incidence angle, the Bragg resonance is the dominant mechanism. As indicated in the paper of Chen *et al.* (1992), the backscatter strength is determined mainly by the surface wind vectors, given a set of radar incident angle, frequency and polarization. Singh *et al.* (1986) used a two frequency scatterometer system to study the influence of surface oil on the radar returned signal. They found that, in general, at low wind state, the surface is electrically smooth which the backscatter signal is weak. But during the strong wind which roughens the sea surface, the backscatter strength increases in response to the increase of roughness. Thus, at low wind speed, the signal-to- noise ratio is too low to detect the oil films, while at considerably higher wind speed, the contrast between the spill area and the background is reduced, making the detection difficult, if not impossible. However, when wind speed was moderate, say up to $10\,ms^{-1}$, C-, X- and Ku-band radar is capable of giving a reliable detected oil spill (Pavlakis, 1995).

This study is concerned with automatic detection of oil spill on the ocean surface. The multi-resolution concept was applied to decompose the original image into a different level of resolution levels from which the potential oil slicks were delineated. A final selection of oil slicks were then determined from such combinations. The detailed methodology will be addressed in next section; the following section will present the experimental results and discussion. Some concluding remarks will be given in the final section.

2. METHOD

Because the presence of oil slicks on sea surface increases the surface tension of sea water, the surface wave is significantly depressed or disappeared. This implies that the roughness of sea surface becomes lower if an oil slick exists. It is now well understood that the radar backscattered energy is highly dependent on surface roughness (Ulaby *et al.*, 1982; Chen *et al.*, 1992). Therefore, the gray value surface of such a radar image will become a concave area if that area is corresponding to an oil slick. In this study, we propose a scheme to detect the concave area on the SAR images and infer that the area is covered by oil slick.

Generally, SAR images are not generated by direct interactions with a ground target. The information about the target on the SAR images comes from some secondary effect. For first order, the major one is variation of surface roughness. The main problem associated with information extraction from SAR images is that the factors affecting the roughness of sea water are too many, for example wind field on sea surface and internal wave of sea water. This problem becomes very severe when the area of interest is large. Another drawback comes from the fact that the SAR system uses coherent polarized wave as a detection source. As a result, the SAR images inherently contain multiplicative "speckle" noise which further complicates the detection of oil slicks.

Because of the reasons mentioned above, the traditional image classification technique is not suitable for this application, especially for some algorithms based on "pixel by pixel" approach. In this study, we propose a top-down scheme to overcome these difficulties. The scheme, basically, includes two major components: (1) reducing original image resolution serially and generating an image pyramid, (2) applying the Laplace of Gaussian and the Difference of Gaussian (Rosenfeld and Kak, 1982) to the multi-layer of the image pyramid to locate the position of oil slicks.

A. The Image Pyramid Generation

Direct use of SAR images to detect the oil slicks, to some extent, is not sufficiently reliable because of the complex process of SAR imaging mechanism and the presence of inherent multiplicative speckle noise. Therefore, in order to reduce the effect of noise and other sea clutter, a unit of 2 by 2 pixels is used to reduce the original image sequentially and generate an image pyramid with a multilayer structure (Fig. 1). Note that the top level of the pyramid is the coarsest image while the bottom of the pyramid is the original image.

B. The Top-down Detection Method

It was mentioned above that the gray values of oil slick on the SAR images are lower than that of background. This means that the gray value surface of the oil slicks on images is a concave area. Hence, we can use a second order derivative operator, the Laplace of Gaussian (LoG) to detect such an area (Rosenfeld and Kak, 1982). A two dimensional LoG operator on a image plane $f(x,y)$ can be expressed as follows:

$$\mathrm{LoG}f(x,y) = \frac{1}{\pi\sigma^4}\left[1 - \frac{x^2+y^2}{2\sigma^2}\right] \cdot \exp\left[-\frac{x^2+y^2}{2\sigma^2}\right]. \tag{1}$$

Equation (1) was repeatedly applied over a "W by W" window on the coarsest image of the image pyramid. In order to avoid the impacts of the deleterious truncation, the window size W should be chosen such that $W \geqq 3C$, where C is the width of the positive main lobe of the LoG function.

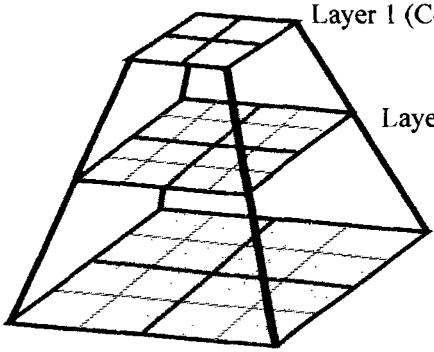

FIGURE 1 The image pyramid.

At this point, we can delineate the concave areas in image gray value surface by convoluting the image with a LoG operator and take the negative portion of resulting image. However, not all of such concave areas are oil slicks coverage, since some natural phenomena, for instance, the variation of wind field, has a similar effect. Nevertheless, oil film and sea water are electromagnetically different. In fact, the gradient of gray value in image on the boundary of oil–water, normally, is greater than that made by nature. Therefore, a first order derivative operator, Difference of Gaussian (DoG), is used to measure the sharpness of the edge on the boundary of the slicks detected by the previous procedure. A two dimensional DoG operator can be expressed as follows:

$$\mathrm{DoG}_x[f(x,y)] = \frac{-x}{\sqrt{2\pi\sigma^3}}\exp\left[-\frac{x^2+y^2}{2\sigma^2}\right] \tag{2}$$

$$\mathrm{DoG}_y[f(x,y)] = \frac{-y}{\sqrt{2\pi\sigma^3}}\exp\left[-\frac{x^2+y^2}{2\sigma^2}\right]. \tag{3}$$

In this paper, the sharpness of the edge on the boundaries of the slicks is defined as:

$$S(x,y) = [\mathrm{DoG}_x \otimes I(x,y)]^2 + [\mathrm{DoG}_y \otimes I(x,y)]^2, \tag{4}$$

where $I(x, y)$ is the image gray value on position (x, y) and $\otimes$ denotes a convolution operator.

To justify whether the detected area is caused by an oil slick or not, two criteria should be chosen empirically. First, a threshold value is selected as $\mu + 1.75\,\sigma$ where μ and σ are mean and standard deviation of sharpness over all image pixels. If the slick boundary pixels whose sharpness is greater than the selected threshold, they are classified as an oil slick boundary pixel. Secondly, if the number of oil slick boundary pixels is greater than the other, *i.e.*, half of slick boundary pixels, we say this slick is qualified to be an oil slick.

Because the oil slicks may vary in size, the window size of the operator has to be adjusted accordingly. In this paper, we apply lower resolution window (larger window size) to detect the oil slicks initially and then to apply higher resolution window (smaller window size) to detect finer oil slicks. This approach effectively reduces the sea clutter and preserves subtle variations of oil slicks. Up to this point, the oil slicks are found only in the coarsest image. The next step is then to use these oil slick pixels as seeds to perform further refinement. First of all, LoG is used again to further delineate small variations of oil slicks on edge portion of the rest layers. In this way, the coarse to fine multilayer approach assures that the pixels detected are the oil slicks, and hence the false alarm rate of detection can be lower. Note that the edge portions in the refinement procedures represent the buffered zone along the edge of oil slicks. Generally, an oil slick is not a completely concave surface on the image. There may be some small convex surfaces and their curvature can be very small; Figure 2 illustrates such a circumstance. The shadow but very small areas will not be detected with LoG plus DoG procedure. A region growing method (Pratt, 1991) then can be used, if necessary, to find out the rest of oil slicks. In all, the overall proposed top-down procedures is sketched in Figure 3.

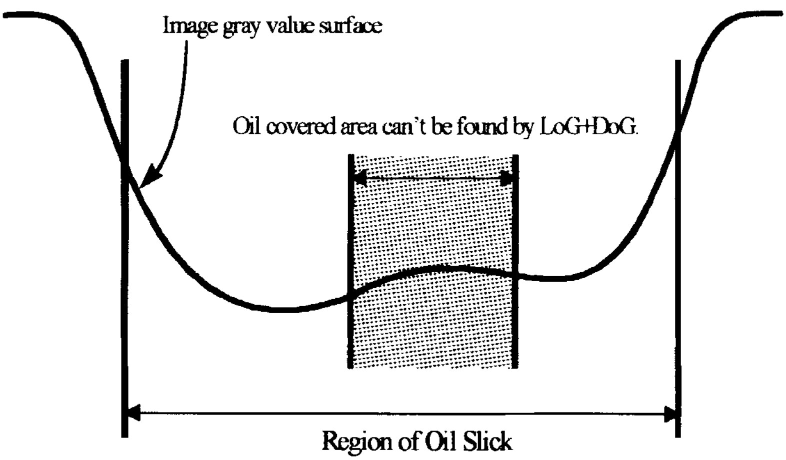

FIGURE 2 Illustration of the case in which the oil slick is not completely a concave surface on image.

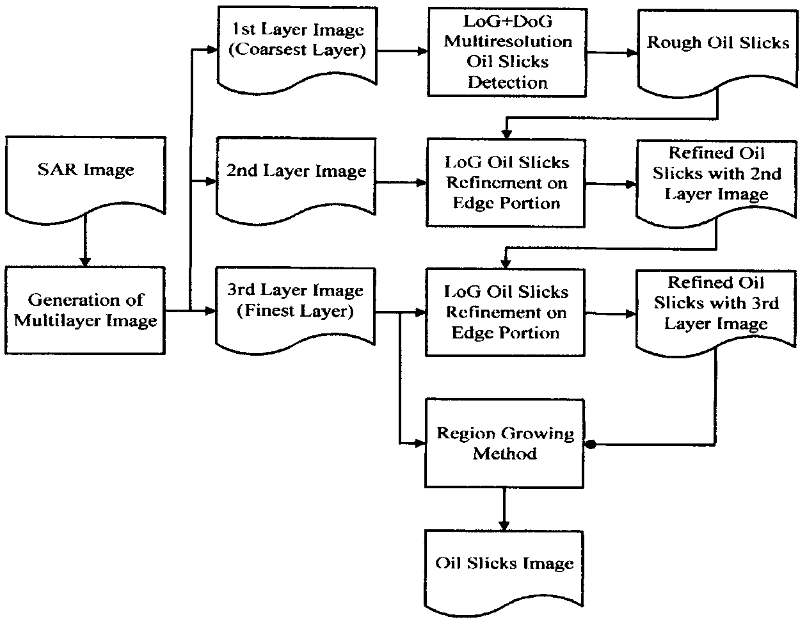

FIGURE 3 The detailed flow chart of proposed top-down detection scheme.

3. EXPERIMENTAL RESULTS

Two ERS-1 SAR images were selected for testing the proposed scheme: Images A and B were acquired on September 5, 1994 and August 5, 1994, respectively. The location of those two test sites was depicted in Figure 4.

Two subscenes were cut from the original full scenes for testing. The image sizes of the subscenes from images A and B are 3000 by 3000 pixels and 2048 by 2048 pixels, respectively. Two full scenes are shown in Figure 5 and the inlet square are the test areas which were shown in Figure 6. The radar signatures of the suspect slicks area was examined. The damping effects that greatly reduces the backscatter signal was evident as shown in Figure 7.

In Figure 8, the white areas in both A and B are the detected oil slicks with proposed scheme and most of oil slicks were found by

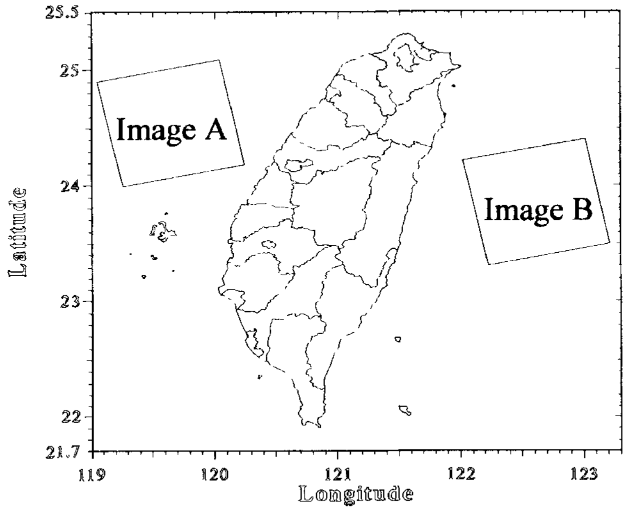

FIGURE 4 The location of test sites (Image A and B).

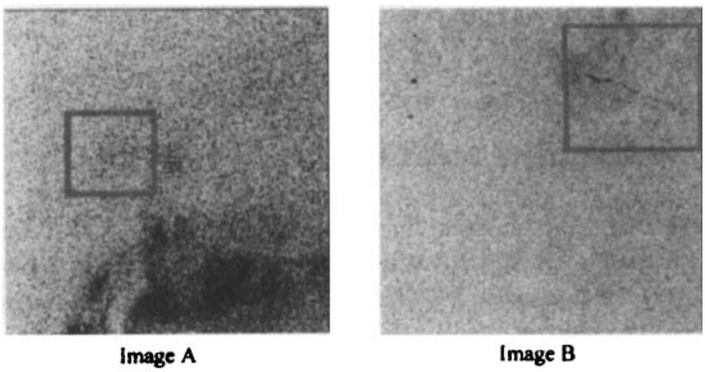

FIGURE 5 Original full scenes. The squares are test areas (ESA, 1994).

visual inspection. (Fig. 9) is part of the enlarged oil slicks where the white lines delineate the detected edge of the oil slicks. It is worth noting that the subtle variations of the edge of the oil slick was clearly detected.

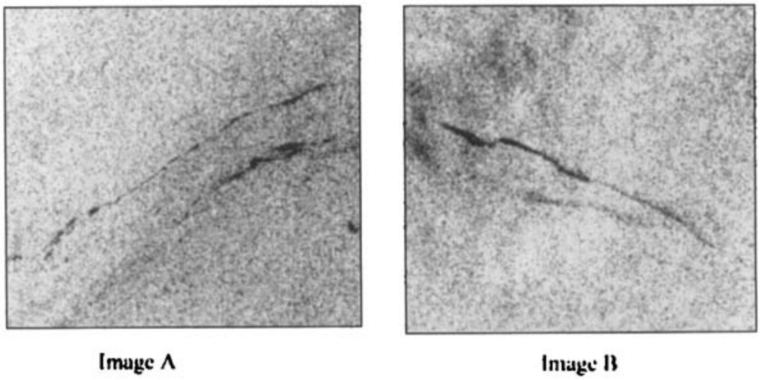

FIGURE 6 Close-up of test area images.

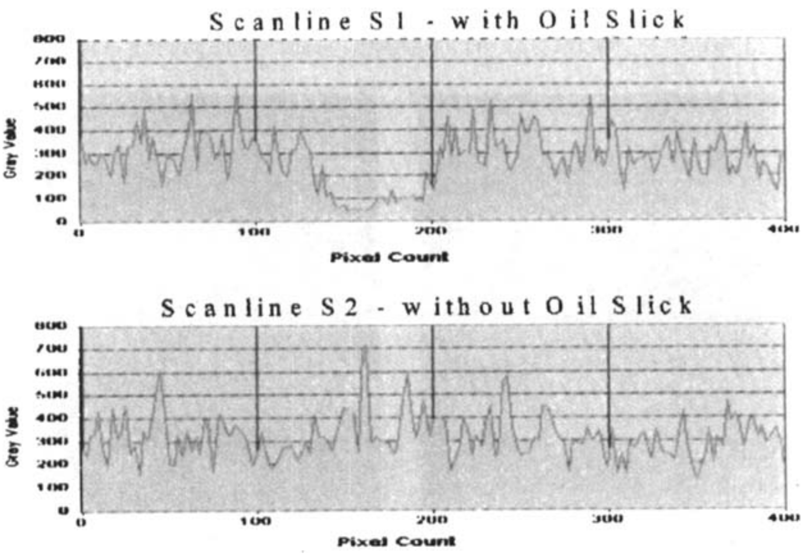

FIGURE 7 Radar signature reduction due to the oil films.

4. CONCLUSION

From the experimental results, it is demonstrated that the proposed scheme is able to suppress the effects of speckle noise and other sea clutter effectively, and significantly enhances the reliability to detect the oil slicks pattern. In spite of the empirical parameters introduced in

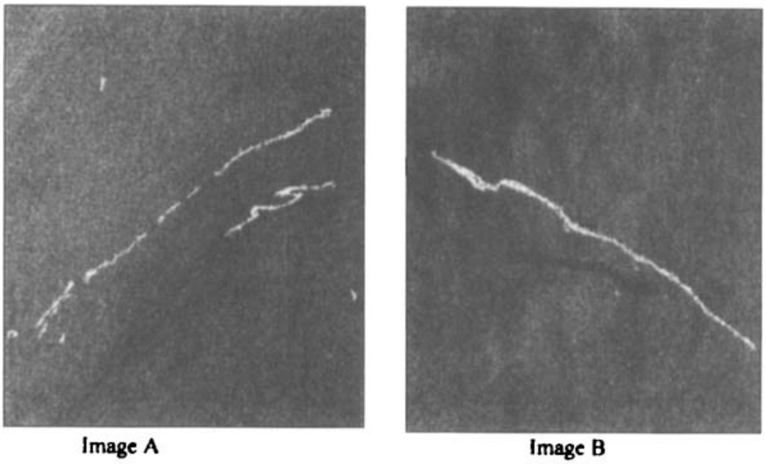

FIGURE 8 The red areas are the detected oil slicks with proposed scheme.

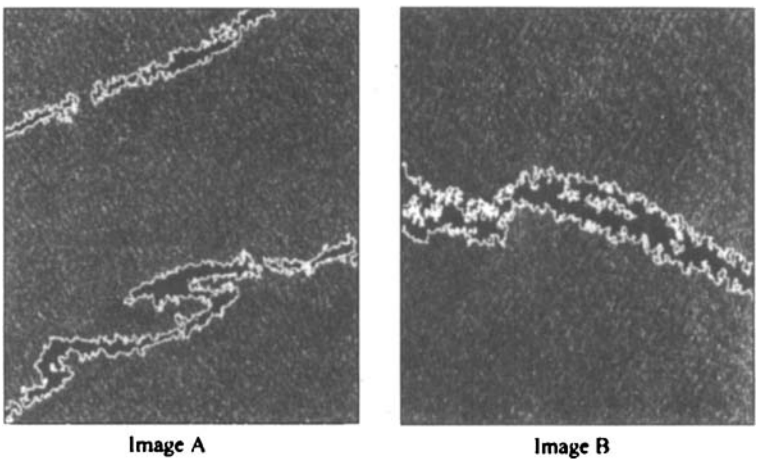

FIGURE 9 Part of enlarged oil slicks where the white lines delineate the edge of oil slicks

the proposed scheme, acceptable result was obtained when the same set of the parameters were applied to different images. Thus, the applicability and robustness of the proposed scheme was demonstrated. Because the field survey of the oil slicks which spilled over the sea is extremely difficult so that we have not sufficient ground truth as an evidence. Nevertheless, the effectiveness of the proposed method was presented and demonstrated. Of course, further validation may now be required.

References

Alpers, W. and Huhnerfuss, H. (1988) Radar signatures of oil films floating the sea surface and the Marangoni effect, *J. Geophys. Res.*, **93**, 3642–3648.

Chen, K. S., Fung, A. K. and Weisman, D. (1992) A backscattering model for ocean surfaces, *IEEE Trans. Geosci. and Remote Sensing*, **30**, 811–817.

Pavlakis, P. (1995) Investigation of the potential of ERS-1/2 SAR for monitoring oil spill on the sea surface, EC JRC/IRST/AT, Rept. EUR 16351 EN, Luxemburg.

Pratt and William, K. (1991) *Digital Image Processing*, 2nd Edition, John Wiley and Sons, London.

Robinson, I. S. (1994) *Satellite Oceanography*, John Wiley and Sons, London.

Rosenfeld, A. and Kak, A. C. (1982) *Digital Picture Processing*, 2nd Edition, Academic Press, Oxford.

Singh, K. P., Gray, A. L., Hawkins, R. K. and O'Neil, R. A. (1986) The influence of surface oil on C- and Ku-band ocean backscatter, *IEEE Trans. Geosci. and Remote Sensing*, **GE-24**, 738–744.

Ulaby, F. T., Moore, R. K. and Fung, A. K. (1982) *Microwave Remote Sensing, Active and Passive*, Vol. II, Addison-Wesley.