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Marine oil spill monitoring based on SAR technology

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Abstract: *Because of the devastating damage of oil spills to the marine ecosystem, it is necessary to monitor the sea surface round-the-clock and round-the-clock, however, the current oil spill monitoring system has some disadvantages, such as small monitoring range, limited monitoring time and high cost. In this paper, an oil spill monitoring system based on synthetic aperture radar is constructed. The principle of oil film imaging, image interpretation and the performance of the system are studied, the system can not only monitor the sea surface all day and all day, but also distinguish oil film types and estimate oil film characteristics. The maximum detection rate can reach about 91%.*

Keywords: *Marine oil spill, SAR, Remote sensing technique, Monitoring*

1. Introduction

In today's rapid economic development, oil is an indispensablestrategic resource for all countries in the world. The rapid growthof oil demand has led to the development of marine transportindustry, offshore oil exploration and exploitation industry andrelated industries, followed by the occurrence of marine accidents, especially the occurrence of offshore oil spill has become a frequent event, which has been widely concerned by all countries.

The failure of the oil exploitation platform, the collision of transportvessels, and the mistakes in the loading and unloading processmay all lead to the occurrence ofoffshore oil spill. In the event ofan oil spill, oil will spread rapidly under the action of waves and wind, which will not only bring huge economic losses, but alsocause devastating damage to the marine ecosystem and then atural environment near the coast. Oil spill at sea is unpredictable. Once oil spill occurs, the relevant departments needto obtain the relevant information of the accident place in a shortperiod of time, so as to take effective measures to minimize theimpact on the marine ecological environment. Therefore, it is particularly important to monitor the sea surface all day and all weather.

Sea surface oil spill monitoring can be mainly divided into two categories: close-range monitoring [1-3] and remote sensing monitoring [4-5]. Close-range monitoring methods include fixed monitoring, tracking by sea buoys and using ships to carry monitoring equipment. These methods are suitable for areas close to ports and wharfs, but the monitoring range is small and cannot meet the needs of large-area oil spill monitoring. With the development of remote sensing technology, remote sensing monitoring technology using aircraft carrying sensors to monitor alarge area of sea is the main stream method used at present. Laser radar has the advantages of high energy, good directivity, range detection, and wide spectral range of white light source, so it hasa good application prospect in three-dimensional spectral imaging of stereo scopic targets and recognition of weak reflectivity targets[6]. Therefore, based on synthetic aperture radar (SAR), a monitoring system for sea surface oil spill is established in this paper, and its working principle and monitoring effect are studied.

2. Principle of SAR

If the radar antenna is fixed in a certain position, it can only collect part of the signal reflected back from the ground or sea. On the contrary, if the antenna is always in a moving state, it can collect the electro magnetic wave signal scattered from the groundor sea back to all directions, and the information obtained will be greatly increased. According to this principle, if a small antenna is continuously moved, a virtual large-aperture antenna can beobtained, so as to obtain the same effect as the actual large-aperture antenna, which is SAR [7].

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The specific working principle of SAR is shown in Figure 1. The antenna moves at a constant speed in the direction perpendicular to the platform, and observes the target at the lower angle in this process, every once in a while, SAR will send pulse signals to the ground or sea surface, and receive, record and store the signals returned by the target at different positions, including the strength and time delay of the echo signal, and then synthesize the signals received at these different positions to generate SAR data [8].

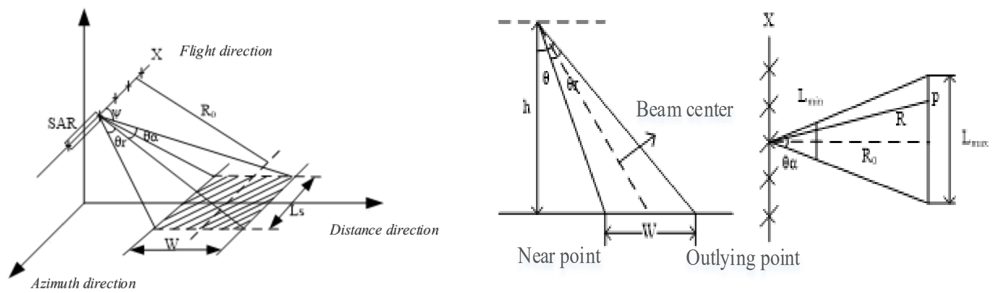

Figure 1: Schematic diagram of SAR working principle

SAR flies at a constant speed v_a in a straight line in the direction X atan altitude of h. θ_r represents the vertical beam angle, θ_α is the heading beam angle, W is the mapping band width, $L_{\max}$ and $L_{\min}$ represents the maximum synthetic aperture length and minimum synthetic aperturelength respectively. The measured target can be regarded as anideal point p, R_0 is the vertical oblique distance between p and the course X.

Assume that SAR is located at the origin of coordinates $t=0$, at acertain time t, the position is $x_a = v_a t$, the coordinate of the point target p at this time is (x_p, R_0), this coordinate is fixed, according to the pythagorean theorem can be obtained at the time t, the oblique distance R between the radar and p:

$$R = \sqrt{{R_0}^2 + (x_a - x_p)^2} \tag{1}$$

Since the ratio of the distance of the target to the distance of the antenna moving horizontally is large, the Taylor series expansion can be used to approximate it,

$$R = \sqrt{{R_0}^2 + (x_a - x_p)^2} \cong R_0 + \frac{(x_a - x_p)^2}{2R_0} \tag{2}$$

The mapping band width can be calculated according to the following formula:

$$W = R_f - R_n \tag{3}$$

Where, R_f is distant point distance, R_n is near point distance.

$$R_f = h \cdot \tan(\theta + \frac{\theta_r}{2}) \tag{4}$$

$$R_n = h \cdot \tan(\theta - \frac{\theta_r}{2}) \tag{5}$$

The azimuth resolution $\delta_x = \frac{R_0 \lambda}{2X_D \sin\psi}$ of synthetic aperture radar is generated by the Doppler effect, X_D is the distance that the satellite moves during the entire sampling time, λ is the wave length of the electro magnetic wave emitted by the radar, R_0 is the distance from the radar to the detection point (oblique distance), and ψ is the azimuth angle (the Angle between the radar beam and the direction offlight of the satellite). The azimuth resolution of the real aperture radar is $\delta = \frac{\lambda R_0}{D}$, D is the aperture length of the real aperture radar.

And the range resolution $\delta_y = \frac{c\tau}{2\sin\theta}$ is determined by the pulse duration τ or equivalent pulse width $c\tau$, θ is the incidence angle, τ is the pulseduration, c is the electro magnetic wave propagation speed, $c\tau = \Delta r$ is the radar pulse width, for the real aperture radar and synthetic caperture radar, the range resolution of the two is the same.

As an active microwave sensor, SAR is not limited by light and climate conditions, it can work all weather, all day and even through the surface or vegetation to obtain information. Therefore, SAR has been widely used in terrain mapping and geological research agriculture and forestry, military, disaster reduction and prevention marine research and monitoring and other fields.

3. The design of sea surface oil spill monitoring based on SAR

Radar remote sensing technology is an active detection technology. This technique is to irradiate the target through the electro magnetic wave emitted by the radar, and receive its echo, and analyze the echo to achieve the purpose of detecting the target.

3.1. Oil film thickness and area estimation and drift model

In order to deal with oil spill events more effectively, it is necessary to estimate the oil film thickness and oil film area ofthe oil spill point in the process of oil spill monitoring, so as to make a more accurate judgment of oil film diffusion. In this paper, the following oil film thickness estimation model [9] is adopted:

$$h = \frac{\rho_{oT}}{(\rho_w - \rho_{oT})s}\left(\frac{-179W^{4/3}t + \sqrt{(179W^{4/3}t)^2} + 30940t^{1/2}S}{15470t^{1/2}}\right)^3 \tag{6}$$

Where, h isthe oil film thickness, S is the oil spill area, t is the oil spill time, W is the sea wind speed, ρ_w is the sea water density, ρ_{oT} is the oil film density when the temperature is *T*.

The oil film area can be calculated using the following formula:

$$S_{os} \approx N_{os} \times R^2 \tag{7}$$

Where, S_{os} is the area of the oil spill area on the sea surface, N_{os} is the number of pixels in the oil spill area, and R is the resolution of the satellite [10].

After oil spill occurs, the oil film will quickly drift and spread along with sea waves and sea breeze. This process is random and affected by many factors. So far, there is no ideal mathematical model of drift. In this paper, the following methods are used toestablish the drift model:

Assuming that the drift velocity of the oil film is $\mathbf{V}$ and the starting center position of the oil film is $\mathbf{O}_o$,then there is $\mathbf{V} = \mathbf{V_t} + K_w\mathbf{V}_w$, After time t, the central position of the oil film is $\mathbf{O} = \mathbf{O}_o + \mathbf{V}t$. Combining the above two formulas, it gives:

$$\mathbf{O} = \mathbf{O}_o + (\mathbf{V}_t + K_w\mathbf{V}_w)t \tag{8}$$

Where, $\mathbf{V}_t$ represents the ocean current speed vector, $\mathbf{V}_w$ represents the sea wind speed vector, K_w represents the ocean current drift coefficient.

3.2. Oil film imaging

According to the working principle of SAR above, the signal returned by the target is a back scattered signal, which SAR receives as the basis for observation, and the strength of the signal is mainly affected by the roughness of the sea surface. Because the existence of capillary waves on the surface of seawater increases the roughness of the sea surface, the radar echo signal is strong, and the corresponding sea surface area will show bright characteristics in the SAR image [11].

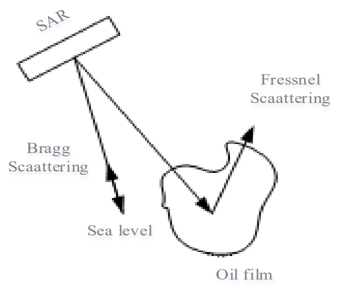

Figure 2: Schematic diagram of oil film imaging principle

As shown in Figure 2, whenthe oil spill accident occurs, the oilfilm covers the surface of the sea water, and the surface tension of the sea water changes, damping the sea surface capillary waves and short gravity waves generated by Bragg scattering, making the sea surface roughness become smaller, the back scattering echo decreases, and the signal strength becomes weak. When presented in SAR images, the brightness of the oil film image is lower than that of the surrounding sea surface, and the sea surface covered by the oil film is shown as dark patches in SAR images [12].

3.3. Image Processing

Commonly used noise filtering algorithms include Lee filtering, improved Lee filtering, enhanced Lee filtering, Frost filtering, enhanced Frost filtering, Gamma filtering, etc [13]. Each filtering method has diferent characteristics. In this paper, the smoothing index SI ($SI = \frac{MEAN}{STD}$) is used to judge the effect of each filter. MEAN is the gray mean of the pixel in the homogeneous region formed by the distributed target echo, and STD is the standard deviation. The larger the SI value, the better the smoothing effect. The SI comparison effect of several filtering methods is shown in Figure 3.

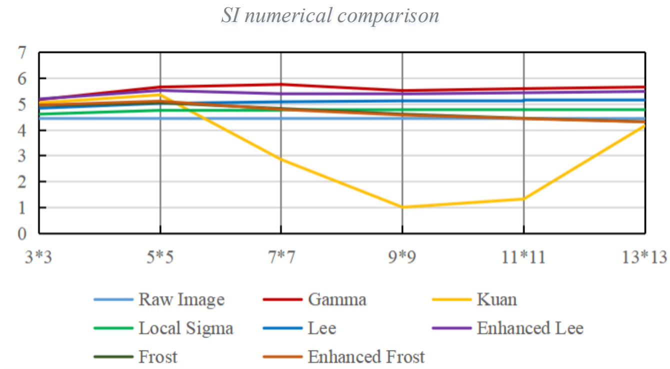

Figure 3: Comparison of filter smoothness index SI

As can be seen from the figure, Enhanced Lee and Gamma have similar smoothness index when the window size isthe same, which has obvious advantages over other filters. Both of these two filters can be used for speckle filtering in oil spill monitoring. So, Gamma filter is selected in paper.

In order to identify and distinguish the difficult dark areas in the image, the feature vector in the gray co-occurrence matrix is usedto analyze the texture of oil film, sea water film and non-oil film. At the same time, there are many interfering factors on the sea surface, such as plankton in the ocean, the stern track formed by ship traveling, and the natural surface in the sea will change theroughness of the sea surface, thus affecting the radar signal. Therefore, this kind of "non-oil film" should be identified and classified in the monitoring process.

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3.4. Design of oil spill monitoring system based on SAR

Based on spaceborne SAR, this paper constructs a sea surface oil spill monitoring system. The system diagram is shown in Figure 4. The whole oil spill monitoring system is mainly composed of three modules: radar signal processing, image processing and target interpretation. The radar signal processing module mainly processes the echo signal reflected by the radar and outputs the original SAR image; Image processing module corrects the input SAR image, filters, de-noising, features extraction, etc, and obtainsthe image of the target area, which is convenient for subsequent processing.

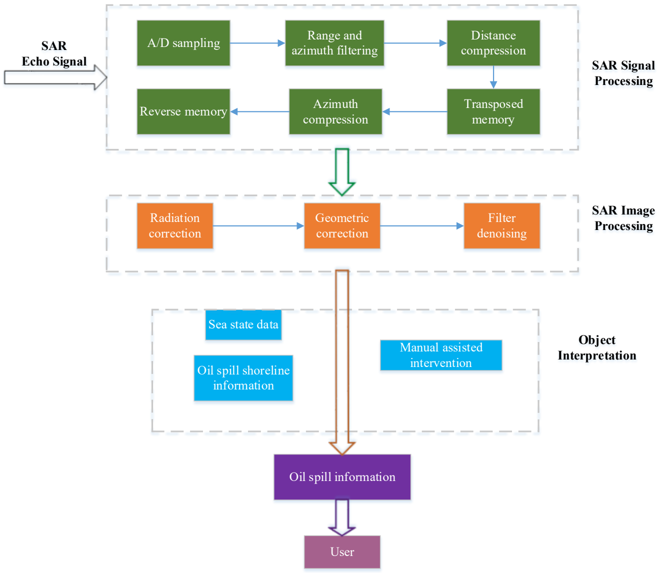

Figure 4: Schematic diagram of oil spill monitoring system based on SAR

The target interpretation module carries out information extraction for the processed image. In this process, not only the image itself should be interpreted, but also the relevant coastal information ofthe oil spill location and the sea state information at that time should be combined, and the image should be interpreted manually to obtain the oil spill information.

The oil spill information includes the location of the oil spill pointthe size of the oil film area, the thickness of the oil film, the distance of the oil film from the shore line, etc. According to the information and the sea situation at that time (wave, wind speed, etc.), the user can take effective treatment measures, and predict the spread of the oil spot, providing an effective and accurate basis for the subsequent processing of the event.

4. Example verification

Based on the above established sea surface oil spill monitoring system, strip oil film and block oil film in the experimental area are tested, and the results are shown in Figure 5.

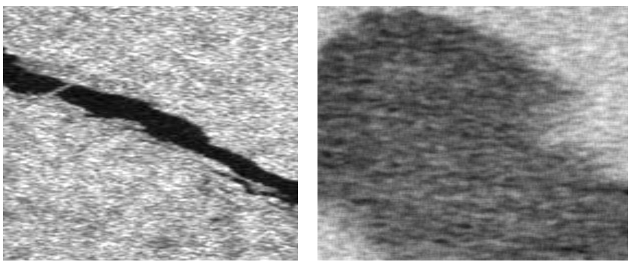

Figure 5: SAR oil spill monitoring system output image

In Figure 5, strip oil film is shown on the left, and block oil film is shown on the right. It can be seen from the image that the brightness of the oil film area is lower than that of the surrounding non-oil film area. Meanwhile, the non-oil film area can be clearly distinguished, and only the oil spill area can be identified, thus achieving the effect of oil spill monitoring.

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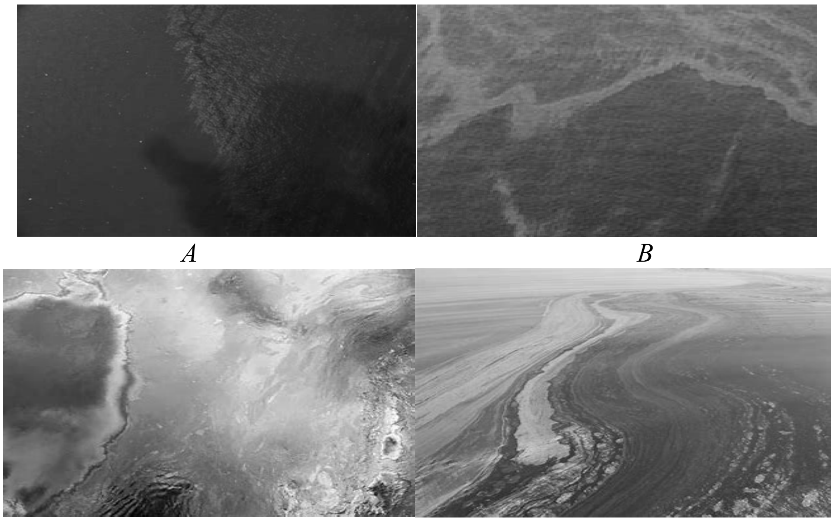
In order to further analyze the monitoring performance,the experimental and comparative study on the oil spill area is also carried out. As shown in Figure 6, detectability experiments were carried out on four monitoring areas with different areas (A, B, C and D), in which the relationship between area size is A<B<C<D. It is obtained the results shown in Figure 7 from the experimental that the smaller the area of the monitoring area, the higher the detection rate, the highest can reach about 91%; on the contrary, the larger the area, the lower the detection rate. At the same time, the detection rate increases with the increase of detection time. For the area with the largest area, the detection rate increases from about 20% to about 72% with the detection time increasing from 0.5h to 6h.



A *B* *C* *D*

Figure 6: Four monitoring areas of different sizes

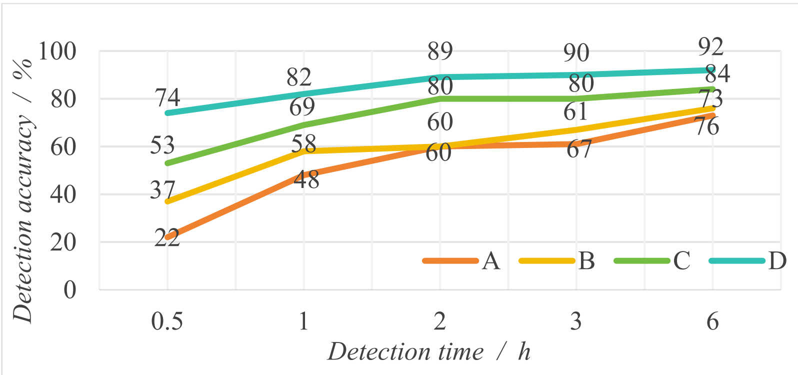


Figure 7: Oil spill monitoring detection rate

5. Conclusions

The sea surface oil spill monitoring system based on synthetic aperture radar can monitor the sea surface all day and all weather, and can effectively identify the types of oil film, distinguish non-oil film areas, and estimate the thickness and area of oil film, providing reliable data for effectively dealing with sea surface oil spill accidents. Due to the complexity of offshore conditions, the system can be optimized and improved in the later research, so that the system can be applied to the monitoring of offshore oil spills in various complex environments.

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