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Remote Sensing of Oil Films on The Sea Surface

Deniz Yüzeyindeki Petrol Tabakasının Uzaktan Algılanması

Gökhan Kara

Maritime Transport and Management Engineering, Engineering Faculty,
University of Istanbul, 34850, Avcılar, Istanbul, Turkey

Abstract

The calculation of the contrast is investigated between clear and oil covered sea surfaces. The problem is to estimate the contribution of these two effects on the total contrast, so that the substance effect can be calculated. Oil film thickness distribution and wave influence to contrast are also studied. It has been shown that there are sufficient contrasts for optical remote sensing of oil film.

Keywords: oil, optic constant, pollution, remote sensing, sea surface

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Introduction

It is well known that oil pollution is most the important component of sea pollution. At the present time the quantity of oil, spilt to the seas by different causes is estimated as m ta^{-1} (million tons a year). The main ways by which the oil reaches a sea are as follows:

1. *Transportation* that includes tanker accidents, tanker operations, bilge and fuel oil, dry docking and non-tanker accidents,

2. *Fixed installations* that include coastal refineries, offshore production and marine terminals,

3. *Other sources* that include municipal wastes, industrial waste, urban run-off, river run-off, atmospheric fall-out, ocean dumping,

4. *Natural inputs*.

Total quantity of oil spill is about 2.5 m t a^{-1}. The calculations show that this amount of oil is a level, which may cover 5 % areas of the world ocean. It is note negligible amount and it can be influence atmosphere and ocean radiative and thermal interaction, the amount and spectral contents of penetrated radiation. To prevent the oil pollution of the sea. It is necessary to identify on time of oil films on the sea surface. For this aim using of the remote sensing methods has very advantages.

The aim of this work is an investigation of physical basis of the possibility of indication of the oil films on the sea surface by optical remote sensing methods. This investigation is needed to develop optic systems for remote sensing of oil pollution of the seas. It is well known that in order to "see" any object by eyes or optical sensors the following two conditions must be satisfied. First, the contrast, K, between the brightness of the object, $B_{obj,}$ and brightness of the surroundings of the object, B_s, must be greater than sensitive threshold, ε. Second, the quantity of energy from object or its surroundings must be sufficient to run sensor. In the problem of active remote sensing the brightness, B_{obj}, and, B_s, are formed by reflection of the incident radiation. Therefore, to indicate the spectral bands where the conditions showed above satisfied the detail investigation of reflection coefficient for a clear and oil film covered sea surface must be carried out. The contrast between the degrees of reflectivity of oil film covered and pure areas of the sea surface is the result of two effects, namely,

1. The different optic properties of sea water and oil film, the so-called "substance effect",

2. The damping effect of the oil film on sea short waves, causing a change a surface roughness.

The contrast of the oil films on the smooth sea surface and dependence of the contrast on the oil thickness, l, was studied (Osadchy et al., 1998). In the paper it was also considered the random distribution of the thickness, l, which had been taken as a gamma distribution. In the present work we studied the spectral behavior of the contrast K and influence on K of the film thickness, l, the sea surface waves. For the distribution of the film thickness, l, we took logarithmical normal distribution thinking that it ought to be closer to the real situation.

First we considered the contrast of oil films with a constant thickness l for a different wavelength λ. Then we studied the reflection from sea surface covered oil films with thickness are distributed on Log-normal. Finally we calculated the influence of the sea surface waves on contrast K (i.e. "the substance effect").

Materials and Method

Reflectance of oil film with a constant thickness

Let us consider the oil film with a constant thickness l on the smooth sea surface and the light beam of the intensity, I_0, is incident under the angle θ_l see figure 1.

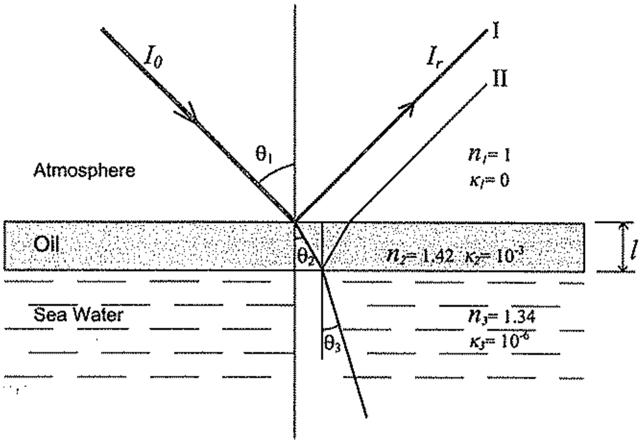


Fig 1. The geometry of problem.

The intensity of the reflected light beam, I_r, is determined by the Fresnel coefficient of reflection of the atmosphere–oil–water system which is defined by (Wolf and Born, 1991).

$$U = \frac{(z_1 + z_2)(z_2 - z_3) + (z_1 - z_2)(z_2 + z_3)e^{-i2\alpha_2 l}}{(z_1 + z_2)(z_2 + z_3) + (z_1 - z_2)(z_2 - 0z_3)e^{-i2\alpha_2 l}} \qquad (1)$$

where

$$z_j^s = \frac{1}{m_j \cos\theta_j} \quad , \qquad z_j^p = \frac{\cos\theta_j}{m_j} \qquad (j = 1,2,3)$$

are the impedance of the j- th medium corresponding to a (s) and (p) polarization; the quantity α_2 is taken as

$$\alpha_2 = \frac{2\pi}{\lambda} m_2 \cos\theta_2$$

here $m_j = n_j - ik_j$, is the complex refractive index of the j-th medium (n and k are the refraction and absorption indices). The angles θ_1, θ_2 and θ_3 are connected with Snell's law.

$$\frac{\sin\theta_3}{\sin\theta_2} = \frac{m_2}{m_3} \qquad\qquad \frac{\sin\theta_2}{\sin\theta_1} = \frac{m_1}{m_2} \qquad (2)$$

the reflection coefficient for the intensity is:

$$R(\theta_1, l, \lambda) = \frac{1}{2}\left[|U_s|^2 + |U_p|^2\right] \quad , \qquad R = \frac{I_0}{I_r} \qquad (3)$$

In particular case, when l=0 from (1) and (3) we obtain the Fresnel coefficient of reflection from the water: $R_{water}(\theta_1, \lambda) = R_{water}(\theta_1, 0, \lambda)$

The formula (1) encloses optical constants n and k for a mediums: atmosphere, oil and sea. For the atmosphere absorption is negligible and m_l=1. The measurements of optical constants n and k of seawater and of oil samples of different oil sources seawater in ultraviolet (UV), visible (VIS) and infrared (IR) bands, has been made in (Alperovich et al., 1978; Zolotarev et al., 1977). There are small variances of the optical constants of seawater due to salinity. The following corrections to optical constants of seawater are recommended: In the VIS and IR bands the corrections to n and k are $\Delta n \approx 6\times10^{-8}$; Δk=0. In the IR band the corrections change: Δn in 2×10^{-3} - 9×10^{-3}; Δk in 0.001 – 0.01. The variance n and k for different oil samples are $\frac{\Delta n}{n} \approx 7.25\%; \frac{\Delta k}{k} = 74.5\%$. The variation in k is greater than the variation of n. It is very important to analyse the possibility of identification of sources of the oil on the reflection.

In the figure 2 the dependence of the Fresnel coefficient R on angle θ_l is showed for a clear and oil film covered surface. The behavior booth curves are identifiable. For a vertical incident light (θ_l=0°) the oil film covered surface reflects two times of clear surfaces. Increasing incident angle θ_l the reflection increases: slowly at the small angles (θ<70°) and critically θ>85°.

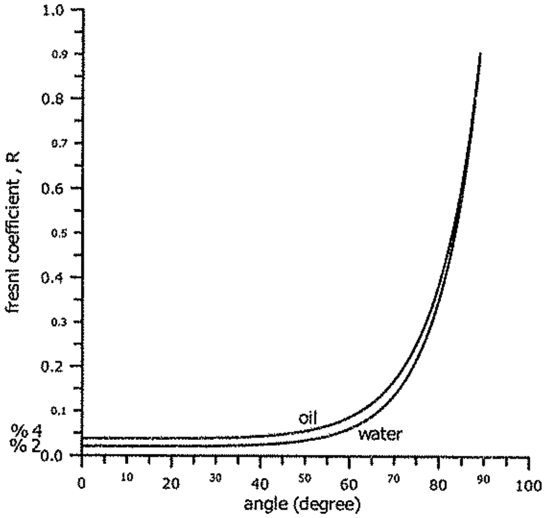


Figure2.The dependence Fresnel coefficient R on incident angle θ_l.

For the different wavelength λ the dependence of the Fresnel coefficient on oil film thickness l has been calculated. In this calculation the non-dimensional thickness $x = \frac{2\pi l}{\lambda} \cdot n_2$ is used. The step Δx is chosen so that no interference oscillation is omitted. We take $\Delta x = \frac{\pi}{4}$ it means that eight points are chosen in the wavelength λ. In the figure 3 the dependence of the Fresnel coefficient on oil film thickness for two wavelengths λ=0.64 μm and λ=3.4 μm, corresponding to minimal and maximal values of absorption index of oil, x_2, are showed. As we see the behavior of the oscillation is essentially different. For λ=3.4 μm the oscillation at $x_a \approx 30$ the value of $R(\lambda)$ differs very little from its asymptotic value R_{asimp}= % 4. However, at $x_a \approx 30$ for λ=0.64 μm the oscillation of

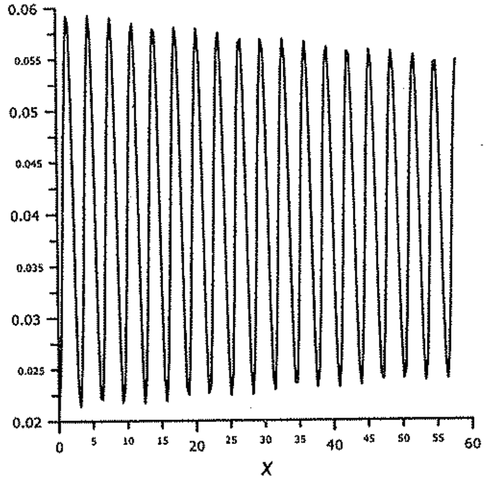


Figure 3. The dependence of Fresnel reflection coefficient R of non-dimensional oil film thickness for λ=0.64 μm.

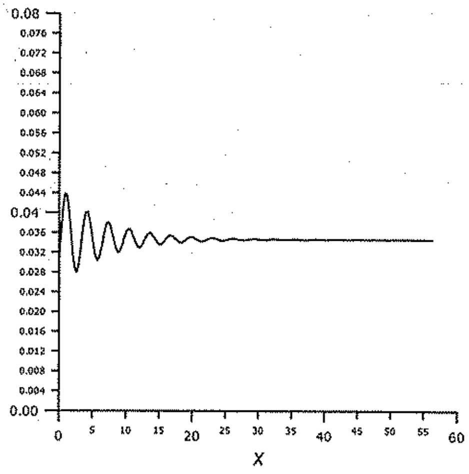


Figure 4. The dependence of Fresnel reflection coefficient R of non-dimensional oil film thickness for λ=3.4 μm.

$R(\lambda)$ is a significant yet. The oscillation is a result of interference of the beams (I and II in fig.1.) reflected from upper and lower sides of oil films. Because at the λ=3.4 μ the absorption index of oil k_2 is a greater than for a λ=0.64 μm the oscillations damp more strongly. If the thickness of the oil films is greater than x_a then the reflection of the system is same as infinitely thickness oil layers. For example, at λ =3.4 μm, x_a=30 and corresponding value of real thickness l_a=11.27 μm and at λ =0.64, μm x_a =1000 and l_a=68 μm. Consequently, for all wavelengths shown in Table 1. oil films with l_a >70 μm will reflect as if from an "oil sea".

Now let us investigate the contrast between clear and oil covered sea surfaces. We consider oil films with a thickness l_a >70 μm and radiation which incidence vertically to sea surface. The contrast between reflectance from the clear surface R_{water}=$R(0, \lambda)$ and from the oil films $R_{oil}(\lambda)$=$R(l_a, \lambda)$ is defined as

$$K(\lambda) = \left| \frac{R_{oil}(\lambda) - R_{water}(\lambda)}{R_{oil}(\lambda) + R_{water}(\lambda)} \right| \tag{4}$$

For the wavelength from Table 1 the curves $R_{water}(\lambda)$ and $R_{oil}(\lambda)$ are shown in figure 4 and the contrast $K(\lambda)$ in figure 5.

Table 1. Optical constant of oil (n_2, κ_2) of sea water (n_3, κ_3) for different wavelength λ, μm (Alperovich at all.,1978 and Zolotarev at all., 1977).

λ	n_2	κ_2	n_1	κ_3
0.60	**1.485**	**0.0029**	**1.340**	**9.6×10^{-9}**
2.50	1.484	0.0040	1.246	1.7×10^{-3}
3.23	1.483	0.0053	1.470	8.8×10^{-2}
3.25	1.474	0.0065	1.471	7.6×10^{-2}
3.27	1.467	0.0071	1.462	6.5×10^{-2}
3.29	1.460	0.0086	1.456	5.5×10^{-2}
3.32	1.451	0.0110	1.447	4.9×10^{-2}
3.34	1.436	0.0160	1.441	4.1×10^{-2}
3.36	1.414	0.0480	1.434	3.5×10^{-2}
3.40	**1.441**	**0.1100**	**1.426**	**2.9×10^{-2}**
3.56	1.526	0.0081	1.394	5.6×10^{-3}
4.44	1.499	0.0071	1.338	1.1×10^{-2}
6.39	**1.489**	**0.0110**	**1.344**	**4.9×10^{-2}**
6.82	1.482	0.0630	1.323	3.2×10^{-2}
7.22	1.498	0.0290	1.314	3.2×10^{-2}
7.60	1.506	0.0170	1.306	3.3×10^{-2}
8.00	1.505	0.0150	1.292	3.5×10^{-2}
8.85	1.504	0.0170	1.264	3.9×10^{-2}
9.52	1.505	0.0180	1.237	4.4×10^{-2}
10.50	**1.505**	**0.0170**	**1.189**	**8.2×10^{-2}**

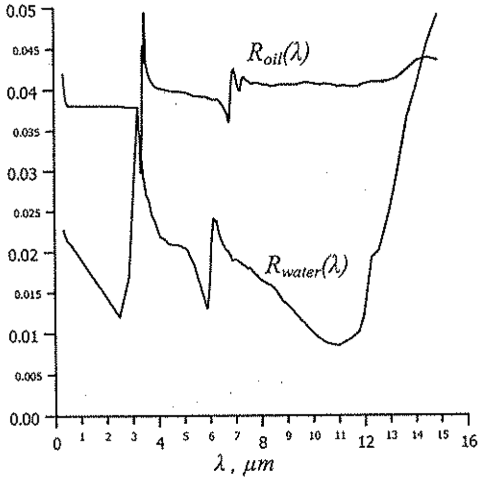


Fig 5. The Fresnel coefficient of reflection R for a clear and oil covered smooth sea surface for a different wavelength at θ_1=0°.

In the spectral band, which is considered, the reflection from the oil film changes very slightly, therefore the changes in $K(\lambda)$ due to changes of $R_{water}(\lambda)$. For example, in the spectral band 8-12 μm where R_{water} is minimum the contrast is maximum and about 80 %. Moreover, in VIS and IR band the contrast is about 50-60 %. Consequently, the contrast is at a high level and by designing an appropriate optical system to sense this contrast the problem of remote sensing of oil films existent on the sea surface can be solved.

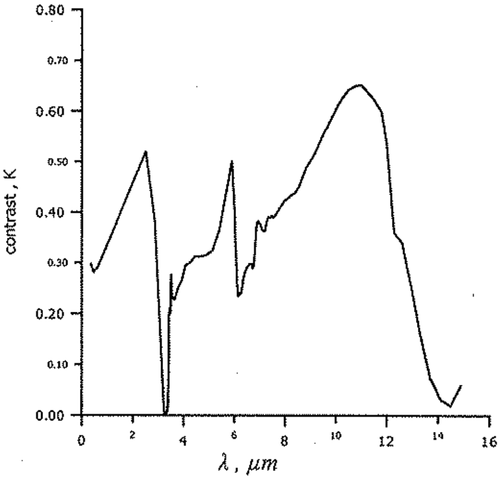


Fig 6. The contrast between a clear and oil covered smooth sea surface for a different wavelength at $\theta_l=0°$.

In the nature the oil film thickness is not constant and changes randomly. Furthermore any optic sensor has a finite band of spectral sensibility. Due to these effects the oscillations in reflectance R are significantly damped. Because the thicknesses of oil films are formed by action of too many parameters, it is reasonable to take the distribution of thickness as a Log-normal one. This distribution has a form:

$$f(l) = \frac{1}{\sqrt{2\pi}\sigma}\frac{1}{l}\exp\left[-\frac{(\ln l - \ln \bar{l})^2}{2\sigma^2}\right] \tag{5}$$

where $\bar{l}$ is a mean value of thickness σ^2 is a dispersion of ln l. The expression (5) when written for dimensionless thickness $x=\frac{2\pi l}{\lambda}\cdot n_2$ is transformed to:

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma}\frac{1}{x}e^{-\frac{\left[\ln\left(\frac{x}{\bar{x}}\right)\right]^2}{2\sigma^2}} \qquad (6)$$

Then the reflection from the oil films which thickness are distributed on (6) is defined:

$$R^*_{oil}(\lambda,x_0)=\int\limits_0^{+\infty}R_{oil}(x,\lambda)f(x)dx$$

In this case, to calculate the contrast $K(\lambda)$ in (4) the R_{oil} must change with $R^*_{oil}(\lambda)$. It is easy to see that the $R^*_{oil}(\lambda)$ depends on average oil films thickness $\bar{l}$ and oil films thickness dispersion σ^2. The result of calculation of $R^*_{oil}(\lambda)$ on the formula (4) for the different average thickness $\bar{l}$ are shown in figures 7,8,9,10. As we can see for different wavelengths λ the general behavior of reflectance $R^*_{oil}(\lambda,x,\sigma)$ is similar. When x increases the oscillation of R^*_{oil} is damped gradually. When the dispersion σ^2 increases the asymptotic value is obtained higher than before. It is reasonable to assume that in nature the value of σ^2 is significant. For greater values of σ^2 the curves have one maximum. These curves are showed in figure 11 separately. As we see when average thickness $\bar{x}$ is less than $\bar{x}_{\max}$ the reflection is proportional to the thickness. This means that the thickness of oil films in interval $(0, x_{max})$ can be indicated from remote sensing measurements of reflectance $R^*_{oil}(\lambda)$.

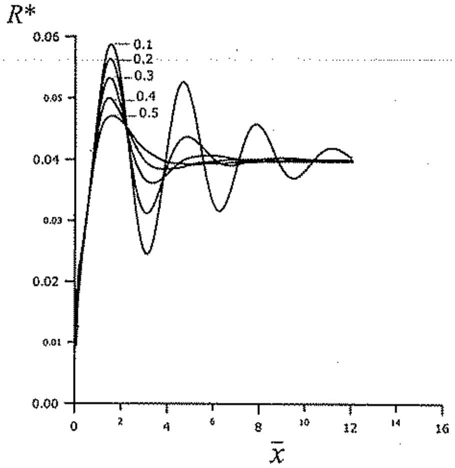
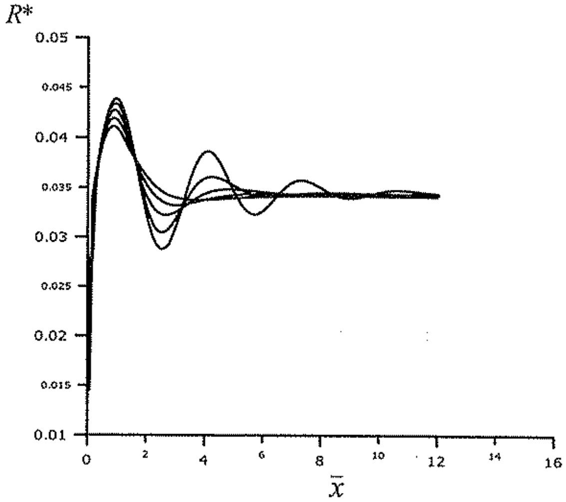


Fig 7. The dependence of reflection R^* on average non-dimensional thickness $\bar{x}$ at the different values of dispersion σ^2 of oil thickness at $\lambda = 0.64\ \mu m$.



$\bar{x}$

Fig 8. The dependence of reflection R^* on average non-dimensional thickness $\bar{x}$ at the different values of dispersion σ^2 of oil thickness at $\lambda = 3.4\ \mu m$.

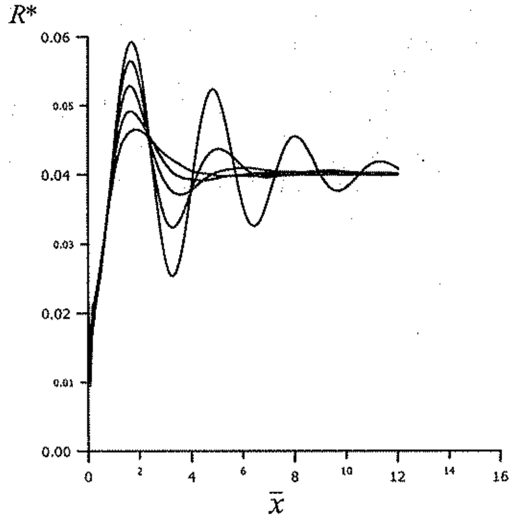


Fig 9. The dependence of reflection R^* on average non-dimensional thickness $\bar{x}$ at the different values of dispersion σ^2 of oil thickness at $\lambda = 6.39\ \mu m$.

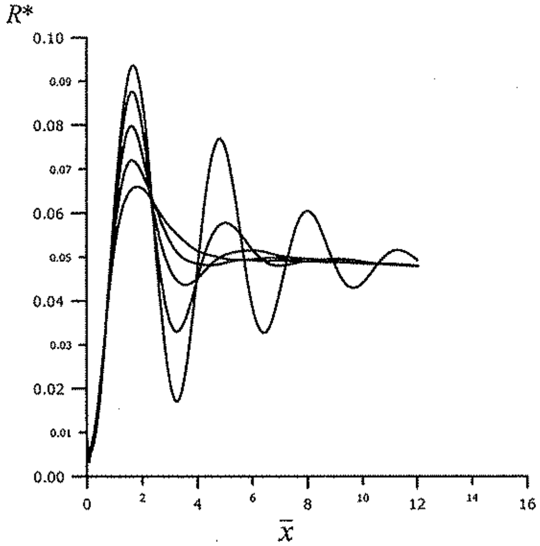


Fig 10. The dependence of reflection R^* on average non-dimensional thickness $\bar{x}$ at the different values of dispersion σ^2 of oil thickness at $\lambda = 10.5\ \mu m$.

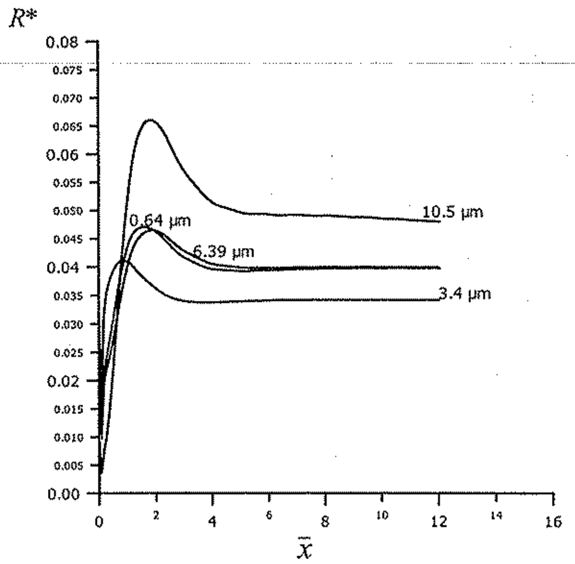


Fig 11. The dependence of reflection R^* on average non-dimensional thickness $\bar{x}$ at the different large values for the dispersion.

In order to estimate the influence of sea waves to contrast we use stochastically distribution facet method (Mullamaa, 1964) to calculate reflectance from the rough surface, clear and oil covered respectively. The distribution of facets is taken as Cox and Munk defined. This distribution is an approximately normal one with the dispersion depends on wind speed *v*. According to Cox and Munk observations the dispersion of oil covered surface slopes three times less than that of clear surfaces. The result of calculations shows that the contrast increases remarkable with wind speed *v*. At v=10 *m/s* the increase of contrast due to surface roughness is about 10 %.

Conclusion

The analysis of contrast between clear and oil covered surfaces for different wavelengths shows that the contrast is at high level and by designing an appropriate optical system the problem of remote sensing of oil films existent on the sea surface can be solved.

Özet

Bu çalışmada temiz ve petrol ile örtülmüş deniz yüzeyi arasındaki kontrastın hesaplanması problemi incelenmiştir. Kontrastı oluşturan nedenler "madde" ve "dalga" etkenleridir. Petrol tabakası kalınlığının dağılımının ve dalga etkisinin kontrastta olan etkisi de ayrıca incelenmiştir. Petrol tabakasının optik olarak uzaktan algılanabilmesi için yeterli kontrastın olduğu gösterilmiştir.

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