PHYSICAL OPTICS-BASED METHOD FOR RADAR SIGNATURE OF COMPLEX OBJECTS OVER A SEA SURFACE

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ABSTRACT

In this contribution, a methodology based on asymptotic methods is proposed to compute the scattered field from a complex target over a sea surface. The sea surface is generated by using the Elfouhaily directional wave spectrum. The Radar Cross Section (RCS) computation combines the geometrical optics, the physical optics and the equivalent current method. It also takes into account multiple-bounce and shadowing effects. Both the target and the sea surface have been meshed with triangular facets in order to compute the scattered field. Simulated RCS results of objects are presented to show the validity of this model. Then, the radar signature of complex scenes (target+sea) is investigated.

Index Terms— radar cross section, asymptotic method, complex target, sea surface.

1. INTRODUCTION

Electromagnetic scattering from a complex scene has attracted much interest these last years. Indeed, numbers of models have been developed for various applications like radar cross section computation, target detection... There are still many problems to solve as the interaction between the target and the environment or the influence of the rough surface on the target signature.

In the proposed work, the scattering of complex targets in a marine environment (see figure 1), which has an rough aspect and random behavior, is investigated. In order to numerically simulate scattering from this scene (sea+target), different techniques can be used. Taking into account the size of the scene and a high frequency operating system, asymptotic methods seem to be best suitable for an efficient computation (low memory, computational cost...). These last years some developments have been done to model the scattering from a target on (or above) the sea surface [1, 2, 3, 4].

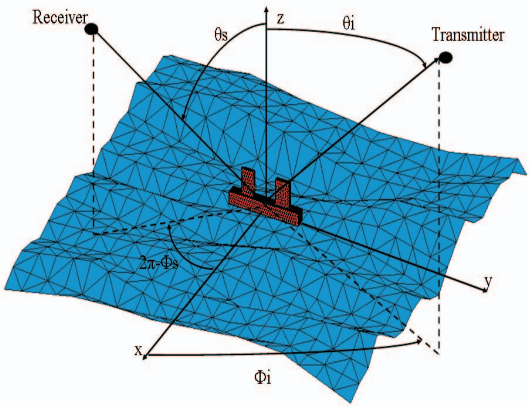


Fig. 1. Setup of a complex target over a sea surface.

The model must takes into account most of the interaction phenomena between the incident wave and the target, a realistic sea surface and the interactions between both elements (sea and target). To generate a realistic sea surface the Elfouhaily directional wave spectrum has been considered. The proposed scattering model integrates the geometrical optics, the physical optics, the equivalent currents method, shadowing effects and multiple-bounce. In what follows, the components of the considered model are shortly reviewed and some numerical results illustrate the validity of (parts of) the model. Finally some first results dealing with a complex scene are shown.

2. SCATTERED FIELD FROM COMPLEX TARGETS

In order to compute the scattered field from a complex target, the combination of Geometrical Optics (GO), Physical optics (PO) and Method of Equivalent Currents (MEC) is used. One also takes into account multiple-bounce (up to the third-order) and shadowing effects. In this section, a short overview of the considered methods to compute the scattered field and the radar cross section of a target is given.

2.1. Asymptotic methods

According to the GO, if the incident field is a plane wave, the reflected field is also a plane wave and contains no information on the size of the surface. For the PO, the incident wave generates equivalent surface currents and the scattered field strengths are calculated as an integral over these currents. To take into account diffraction contributions, the MEC can be considered. The basic idea of this PO-based method is to calculate the currents on the edge and integrate them to obtain the scattered field.

According to the PO, the scattered field is calculated as an integral over the complete surface of the object. However for complex targets this integration is not conceivable. In this case, the solution is to import in our algorithm a meshed target by triangular facets. If the surface is made up of a large number of small facets, the PO surface integral could theoretically be performed by calculating one single ray to each facet (each ray is a representative of a wave front) and adding all contributions. In what follows this solution is considered to construct our model of scattered field.

2.2. Shadowing effects

To compute the scattered field, the shadowing effects must be taken into account. To find the visible facets of the target from a given point, one uses successively two methods. The first one is the back-face culling algorithm. Then, a Z-buffer-based approach is applied.

2.3. Multiple-bounce

The treatment of multiple-bounce is another important topic. Previous works shown that, in the near field, the multiple interactions could be approximated very well by GO methods [5, 6]. Thus, hybrid GO-PO techniques have been developed. The basic idea is that for each propagation path to a receiver the PO calculation is applied only to the last reflection at the surface of the object.

This solution has been considered in our method but with some particular implements. Each triangle of the target reached by a GO-ray is projected onto the space in the specular direction. If this projected-patch cut off another part of the target (i.e. multiple-bounce exists), one defines the new illuminated area (by this ‘beam’). If necessary, an adaptive subdivision of the illuminated part is processed (see figure 2.a) to find the correct intersection with the target.

The scattered field, when no more bounce can be find, is then performed by the GO from a bounce to another and by the PO from a surface to the receiver. In short, the scattered field is computed, for a double-bounce by combining GO+PO and for triple-bounce: GO+GO+PO.

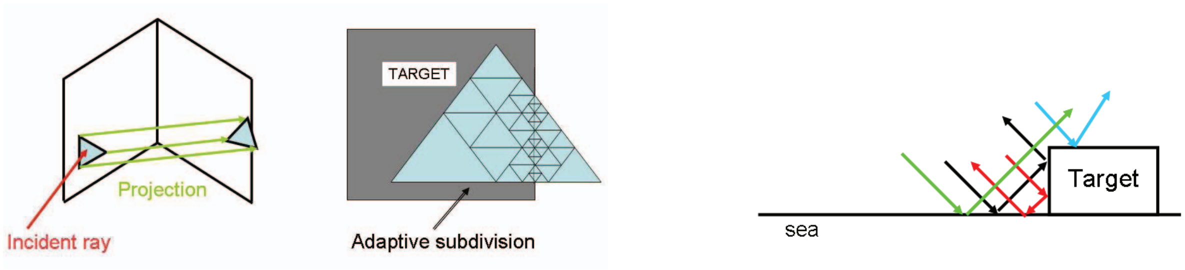
3. SCATTERED FIELD FROM THE SEA SURFACE

3.1. Sea surface generation

To generate a realistic sea surface, the Elfouhaily spectrum [7], which takes into account the wind speed and the direction of the wind, has been used to create the sea surface. The dielectric properties of sea water are defined through the modified Debye equation [8] which in turn depends on the temperature and the salinity. Finally, a meshed version of this sea surface is generated with triangular patches.

3.2. Scattered field computation

From the high frequency point of view, if the rough surface has a large curvature radius, the physical optics approximation (or Kirchhoff approximation) will be obviously very good when the reflection from the rough surface is evaluated. To compute the scattered field, the sea surface is also meshed by triangular facets, and one uses the same PO algorithm as for the targets (both the target and the sea become a unique target). The considered interactions between the target and the sea surface are represented on figure 2.b.



(a) (b)

Fig. 2. (a) Adaptive subdivision for patch projection in multiple-bounce. (b) Multiple interactions between the wave and the complex scene (sea+target).

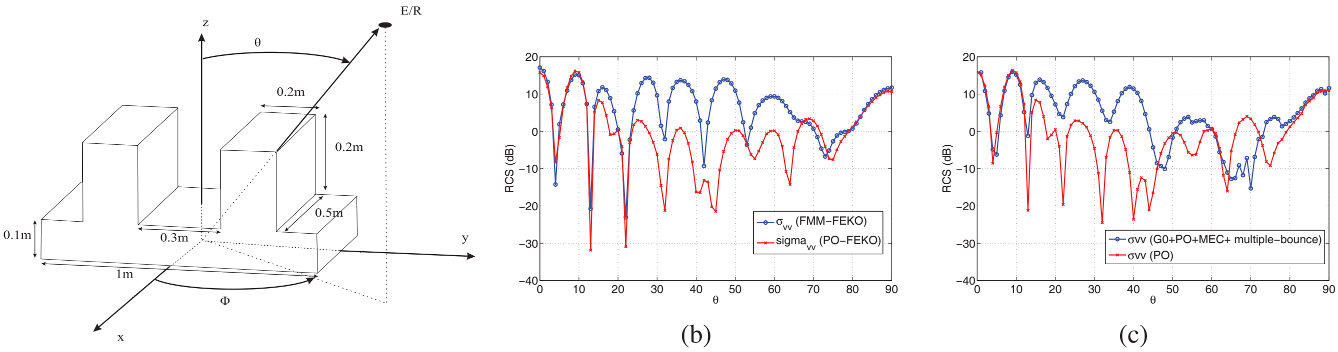
4. NUMERICAL RESULTS

4.1. RCS of an object

To validate our algorithm, the monostatic RCS of a complex object (see figure 3.a) at $f = 2$GHz is computed using the FEKO software and our model.

Firstly, the object is considered as a Perfect Electrical Conductor (PEC). Figure 3 shows the results obtained for the FEKO-PO, Fast Multipole (FMP)-FEKO, our PO model and our 'global' model. The POs' results are very closed and the RCS obtained with our global model tends towards the exact one (FMP-FEKO).

Secondly, the object is made of a PEC and a dielectric part (see Fig 4). As expected, the obtained RCS show some differences with the RCS of the PEC object. Notice that the diffraction by dielectric edges is not taken into account but this does not explained the all differences. Figure 4.c shows a bistatic RCS of this object.

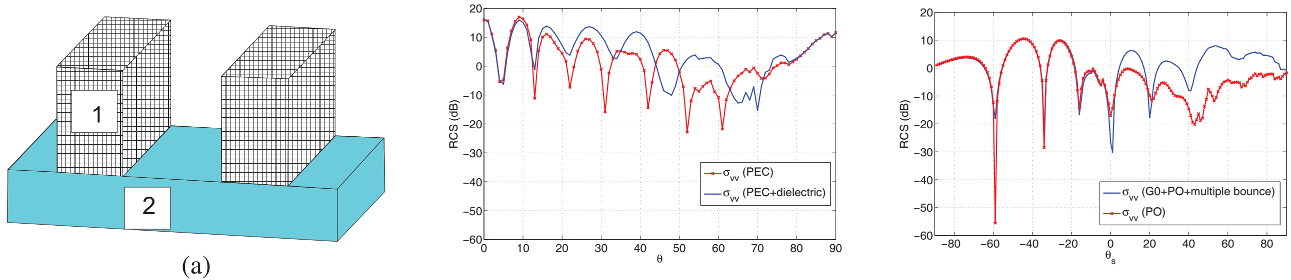


(a) (b) (c)

Fig. 3. (a) Setup for target RCS. (b-c) for a PEC material and a monostatic configuration: $f = 2$GHz, $\Phi = 90°$ and vv-polarization. (b) results obtained by the FEKO software for PO and Fast MuiltiPole methods. (c) results using only the PO and our global model (GO+PO+MEC+multiple-bounce+shadow).

4.2. RCS of an object over a sea surface

In this part, the RCS of the complex scene shown at figure 1 is considered. The object is PEC and the sea parameters are the temperature $t = 20°$C, the salinity $S = 35$ppt and the wind speed $U_{10} = 3$m/s. The sea is a 20×5m surface and the target is centered on it. Figure 5 shows the obtained RCS results to be compared with the ones of the object alone at figure 3.



(a)

(b)

(c)

Fig. 4. (a) Inhomogeneous object. Area 1: wood $\epsilon_r = 1.4$, area 2: PEC. (b) Monostatic RCS: $f = 2$GHz, $\Phi = 90°$ and vv-polarization for the PEC and the inhomogeneous object. (c) Bistatic configuration: $f = 2$GHz, $\Phi_i = 90°$, $\theta_i = 45°$, $\Phi_s = 90°$.

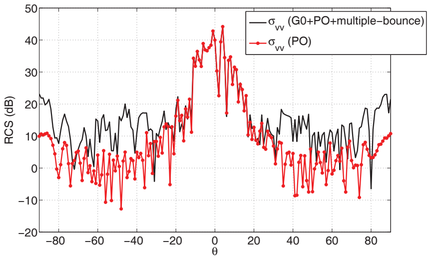


Fig. 5. RCS of a complex scene (target+sea). Monostatic configuration, $f = 2$GHz, $\Phi = 90°$, vv-polarization.

5. CONCLUSION

In this contribution the radar signature of complex objects over a realistic sea surface has been investigated. The proposed approach leads to convenient results (each part of the model has been validated separately). We do not expect at this time a perfect model but an accurate one which will be used in a global bistatic radar radiolink for SAR imaging or detection purpose of target in a maritime environment. Future works on the scattering model will focus on the effect of small roughness of the sea against the RCS of the target.

6. REFERENCES

[1] R. J. Burkholder, P. Janpugdee, and D. Çolak, “Development of computational tools for predicting the radar scattering from targets on a rough sea surface,” The Ohio State University - ElectroScience Lab, Tech. Rep. 735231-3, January 2001.

[2] F. Xu and Y.-Q. Jin, “Bidirectional analytic ray tracing for fast computation of composite scattering from electric-large target over a randomly rough surface,” *IEEE trans. on Antennas and Propagation*, vol. 57, pp. 1495–1505, 2009.

[3] K. Kim, J. Kim, and D. Cho, “radar cross section analysis of marine targets using a combining method of physical optics/geometric optics and a monte-carlo simulation,” *Ocean Engineering*, vol. 36, no. 11, pp. 821–830, 2009.

[4] W. Luo, M. Zhang, Y.-W. Zhao, , and H. Chen, “An efficient hybrid high-frequency solution for the composite scattering of the ship very large two-dimensional sea surface,” *Progress In Electromagnetics Research*, vol. 8, pp. 79–89, 2009.

[5] H. Ling, R.-C. Chou, and S.-W. Lee, “Shooting and bouncing rays: Calculating the rcs of an arbitrarily shaped cavity,” *IEEE trans. on Antennas and Propagation*, vol. 37, p. 194205, 1989.

[6] T. Griesser and C. A. Balanis, “Backscatter analysis of dihedral corner reflectors using physical optics and the physical theory of diffraction,” *IEEE Trans. Antennas and Propagation*, vol. 35, p. 11371147, 1987.

[7] T. Elfouhaily, B. Chapron, K. Katsarsos, and D. Vandemark, “A unified directional spectrum for long and short wind-driven waves,” *Journal of Geophysical Research*, vol. 102, no. C7, pp. 15 781–15 796, 1997.

[8] L. Klein and C. Swift, “An improved model for the dielectric constant of sea water at microwave frequencies,” *IEEE trans. on Antennas and Propagation*, vol. 25, no. 1, pp. 104–111, 1977.