EM Scattering from Dielectric Sea Surface by the Ray-tracing Method

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Abstract

For the EM scattering problem, the multiple scattering plays an important role in accurate RCS calculation, especially when the wind speed upon sea surface is large. Meanwhile, as is known that the ray-tracing method is a highly powerful technique to deal with multiple reflection problems. Therefore, the ray-tracing algorithm described in this paper, is ultilized to tackle with the EM scattering problem from dielectric sea surface. In the ray-tracing method, the Geometrical Optics is used to determine the ray propagation paths, while Physical Optics is applied to calculate the field contribution of each ray hitting an object. We test this method using a simple examples. Our theoretical results are generally in good agreement with the simulation results by the Physical Optics based on FEKO. In the end, the RCS of a dielectric sea surface by ray-tracing method is compared with the MoM by FEKO. Good agreement is found between the analytic solution and ray-tracing method.

1. Introduction

The earth is about seventy percent of the area covered by sea water and it is becoming increasingly important both strategically and economically because of its abundant natural resources[1]. In this paper, the ray-tracing is studied for the EM scattering from sea surface. The ray-tracing method is well known for its more accurate results by considering the scattering due to multiple interactions. Compared with the low-frequency numerical methods, for example, Method of Moment (MoM) [2], Fast Multipole Method (FMM) [3], Finite-Difference Time-Domain (FDTD) [4] et al, the ray-tracing method can be much faster in computing electromagnetic (EM) scattering from large and complex objects. While compared with the Physical Optics (PO) method, which is also a high frequency method, the ray-tracing method takes the multiple intersections problem into consideration, and improve the accuracy. In the ray-tracing method, the Geometrical Optics (GO) is used to determine the ray propagation paths, while PO [5] is applied to calculate the field contribution of each ray hitting an object. In practice, triangular surface mesh is widely used in representation for complex objects. When deal with the EM scattering from sea surface, the sea surface is firstly constructed into a great deal of triangulars, then the scatters are triangular surface meshed. According to the ray-tracing method, the reflected field is calculated according to GO and the PO integral is preformed to obtain the scattered field based on the pre-calculated reflect field. We test the validity of this method using a simple examples. Our results are generally in good agreement with the simulation results by the PO based on FEKO. In addition, the RCS from a dielectric sea surface by ray-tracing method has been compared with the MoM based on FEKO in the end. Good agreement is found between the analytic solution and ray-tracing method.

2. Ray-Tracing Method

In the ray-tracing method, intersection algorithm plays an important role for the estimation precision and calculation time. And the high frequency approximation of radio wave using GO has enabled the development of many site-specific deterministic propagation models [6-8]. Therefore, it is easy to determine the ray propagation path by GO. Then the reflected field is calculated according to GO and the PO integral is preformed to obtain the scattered field based on the pre-calculated reflect field.

The ray-tracing method consists of three main steps, i.e., the ray tracing step, which simply finds the ray paths in the propagation; the field tracking step, which determines the field of the exit ray; and the far-field calculation step, which calculates the scattered field and RCS. The scattered far field from a scatterer is the summation of contributions from many rays that strike the scatterer.

According to the GO theory, the optical rays obey the Snell principle in the process of reflection.

$$\hat{k}_r = \hat{k}_i - 2\left(\hat{k}_r \cdot \hat{n}\right)\hat{n} \tag{1}$$

where $\hat{k}_i$ is the incident direction vector, $\hat{k}_r$ is the reflected direction vector and $\hat{n}$ the normal vector of the reflected

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facet.

The reflected electric field can be expressed as

$$\vec{E}^r = \begin{pmatrix} \vec{E}^r_{\parallel} \\ \vec{E}^r_{\perp} \end{pmatrix} = \begin{pmatrix} \Gamma_{\parallel} & 0 \\ 0 & \Gamma_{\perp} \end{pmatrix} \begin{pmatrix} \vec{E}^i_{\parallel} \\ \vec{E}^i_{\perp} \end{pmatrix} = \overline{\Gamma} \cdot \vec{E}^i \tag{2}$$

where $\Gamma_{\parallel}$ and $\Gamma_{\perp}$ are the reflection coefficient matrix of horizontal and vertical polarization respectively.

According to Stratton-Chu integral equation,

$$\begin{cases} \vec{E}^s = \oint_s \left[-j\omega\mu\left(\hat{n}\times\vec{H}\right) + \left(\hat{n}\times\vec{E}\right)\times\nabla' + \left(\hat{n}\cdot\vec{E}\right)\nabla' \right]\psi dS \\ \vec{H}^s = \oint_s \left[j\omega\varepsilon\left(\hat{n}\times\vec{E}\right) + \left(\hat{n}\times\vec{H}\right)\times\nabla' + \left(\hat{n}\cdot\vec{H}\right)\nabla' \right]\psi dS \end{cases} \tag{3}$$

when deal with the high frequency scattering field, the Stratton-Chu integral equation can be reduced to

$$\begin{cases} \vec{E}_s = jkZ_0 \dfrac{e^{-jkr}}{4\pi r} \int_s \hat{r}\times\left[\hat{r}\times\left(\hat{n}\times\vec{H}\right) - \dfrac{1}{Z_0}\hat{n}\times\vec{E} \right] e^{jk\hat{r}\cdot\vec{r}'} ds \\ \vec{H}_s = -jk \dfrac{e^{-jkr}}{4\pi r} \int_s \hat{r}\times\left[\dfrac{1}{Z_0}\hat{r}\times\left(\hat{n}\times\vec{E}\right) + \hat{n}\times\vec{H} \right] e^{jk\hat{r}\cdot\vec{r}'} ds \end{cases} \tag{4}$$

where $\vec{E}_s(\vec{r})$、$\vec{H}^s(\vec{r})$ is the far scattering field，$\vec{E}$、$\vec{H}$ is the total field of scattering facet，$\hat{n}$ is the normal vector of scattering facet，$\vec{r}$ is the position vector of observation point，$\hat{r}$ the direction of scattered wave vector，$\vec{r}'$ is the position vector of the scattering facets.

Let $\vec{J}$ and $\vec{M}$ be the electric and magnetic equivalent current densities respectively, then

$$\begin{cases} \vec{J} = \hat{n}\times\vec{H} \\ \vec{M} = -\hat{n}\times\vec{E} \end{cases} \tag{5}$$

Then the Stratton-Chu integral equation can be expressed as

$$\begin{cases} \vec{E}_s = jkZ_0 \dfrac{e^{-jkr}}{4\pi r} \int_s \hat{r}\times\left[\hat{r}\times\vec{J} + \dfrac{1}{Z_0}\vec{M} \right] e^{jk\hat{r}\cdot\vec{r}'} ds \\ \vec{H}_s = jk \dfrac{e^{-jkr}}{4\pi r} \int_s \hat{r}\times\left[\dfrac{1}{Z_0}\hat{r}\times\vec{M} - \vec{J} \right] e^{jk\hat{r}\cdot\vec{r}'} ds \end{cases} \tag{6}$$

3. Simulation and Discuss

In order to confirm the validity of the present ray-tracing method, we test the validity of this method using a simple example. First, the RCS of a dielectric plate, with all sides $3\,m$ in length, is calculated with a frequency of 1.0GHz. The relative permittivity is $\varepsilon_r = (73.6087, 54.5816)$. The incident angle θ_i is from 0° to 90°, and the azimuth angle $\phi_i = 0^\circ$.

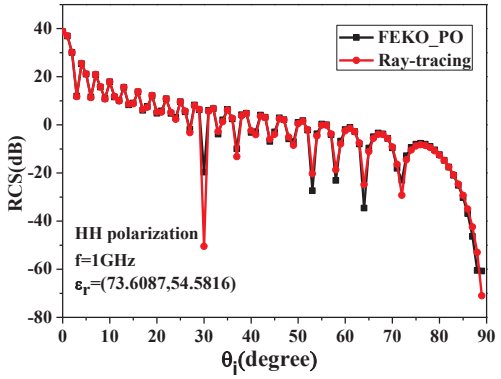


Fig. 1. Comparison of FEKO-PO and Ray-tracing method

In this case, as shown in Figure 1, the comparison shows a good agreement between the FEKO-based PO result and the present ray-tracing result.

The geometry for 2-D rough sea surface is shown in Figure 2. Because the MoM-FEKO need a long computation time, a contaminated sea with ELH spectrum is chosen $3m$ in length and width. Figure 3 shows the backscattering of ray-tracing method and FEKO-based MoM for HH-polarization and VV-polarization. The relative permittivity is $\varepsilon_r = (73.6087, 54.5816)$. The frequency is 1.0 GHz, azimuth angle $\phi_i = 0^\circ$

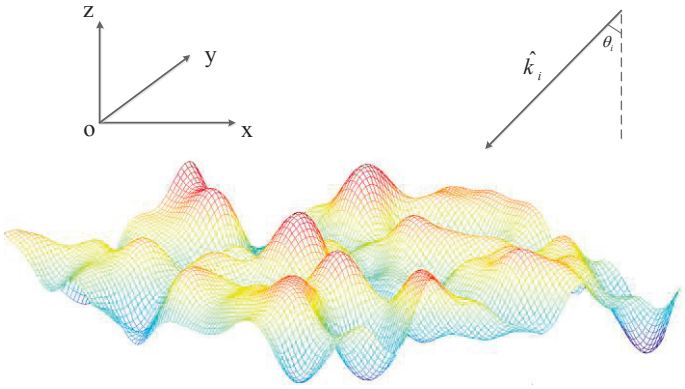
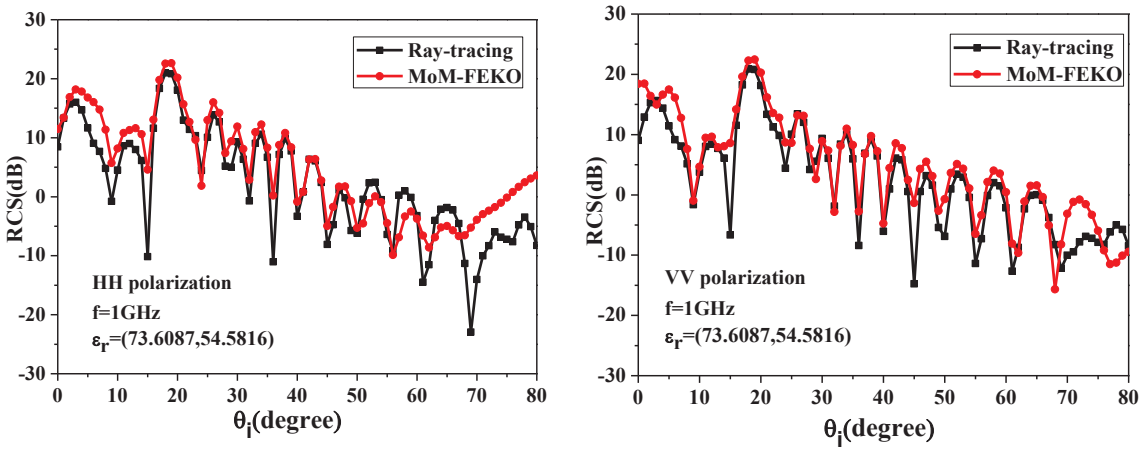


Figure 2 Geometry for 2-D rough sea surface

It is seen in Fig. 3, the comparison shows a good agreement between the FEKO-based MoM result and the present ray-tracing result for HH-polarization and VV-polarization. In addition, there exists a little difference from 70° to 80°. This is because that the ray-tracing method, which is an approximation method, can give a fast RCS prediction of large-scale objects. When deal with a small-scale sea surface, the ray-tracing method may has some difference with MoM, especially for the grazing incidence. In addition, the ray-tracing method described in this paper doesn't take the edge diffraction effects into consideration, which is important for the improvement of prediction accuracy. However, the computation time of the FEKO-based MoM are more than four hours. In contrast to this, the total computation time of all incident angles are 10 seconds in the ray-tracing method.



(a) HH polarization (b) VV polarization

Figure 3 Back scattering of a small sea surface

4. Conclusions

In this paper, a general high frequency method-ray tracing method for calculating radar cross section (RCS) from dielectric sea surface is described. The ray-tracing method which is based on the GO and PO theory, can give more accurate results by considering the scattering due to multiple interactions, while the computational time is much shorter compared with the numerical methods. The computational results using ray tracing method have been compared with the MoM or analytic solution, it is concluded that the ray-tracing method is an effective way for the RCS prediction of large-scale objects.

5. Acknowledgments

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