A Forward Scattering Model for Foliage Camouflaged Complex Targets

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1 INTRODUCTION

DETECTION and identification of hard targets inside vegetation canopies are among challenging problems in Remote Sensing. The challenges of this problem can be decomposed into two parts. The first part of the problem is related to the computation of the field propagation through and scattering from foliage, and the second part of the problem pertains to the characterization of the scattering from the target illuminated by the attenuated incident field and scattered field from foliage. An accurate hybrid method is proposed to characterize the effects of scatterings from forest components and their near field interactions with the hard target. Electromagnetic (EM) scattering from vegetation canopies can be simplified in terms of problems of scattering from individual dielectric cylinders and thin dielectric disks, modeling branches and leaves, arranged in a semi-deterministic fashion. This also includes the interaction of the scattered fields with a half space dielectric layer, representing the ground. An advanced method has been developed [1], where the forest stand is modeled with realistic look tree of arbitrary kind and the scattering from all tree components, when illuminated by the mean field, is calculated in a uniform fashion, valid from near-field to far-field regions. The coherent summation of all the scattering contributions is considered in order to accurately compute the total field at a given point with in the forest canopy. The total field is composed of the mean field and scattered field and the mean field is derived, using Foldy's approximation, which accounts for the phase change as well as extinction due to the scattering and absorption of the tree particles. The total field is used as the excitation to illuminate the hard target which may have complex geometry and material properties. In order to have some level of accuracy and computational efficiency, Physical Optics (PO) approximation, is proposed as a solution for the problem of scattering from electrically large objects. It is shown that reciprocity theorem can be effectively applied to derive the back scattered field from the induced PO currents on the target. By this, the interactions of target and foliage on both illumination and scattering are taken in to account. The very challenging step in this process is to determine the lit and shadowed points on the target, considering the very complex geometry of the target and very large number of the scatterers around the target which act as a source of illumination for the target. In this paper, a powerful technique is proposed to accurately and effectively calculate the induced current on the target including the effects of shadowing. This model has been applied to a simple geometry of PEC box and the reciprocity theorem is used to estimate the back scattered field from the object.

2 FORMULATION

PO approach is widely used to estimate the scattering from the large objects. To treat an irregularly shaped object with PO approximation, the object is first decomposed into many flat elementary patches, which have a simple geometry such as rectangular or triangular. Then, using tangent plane approximation, the current on the lit region of the scatterer is approximated as [3],

$$\vec{J} \approx 2\ \hat{n}\times\vec{H} = -2i\frac{Y_o}{k_o}\hat{n}\times(\nabla\times\vec{E}) \tag{1}$$

where $\vec{E}$ and $\vec{H}$ are the incident electric and magnetic fields on the object, respectively, and $\hat{n}$ is a normal unit vector, as shown in Fig. 1. Using the reciprocity theorem, it can be shown that the backscattered field from an arbitrary object can be expressed in terms of incident electric field and the induced electric currents on the object. The backscattered field, in the far field region at the radar location $\vec{r}_R$, is given by [2]

$$\vec{E}^s_{pq} \approx \pm\frac{ik_o\eta}{4\pi}\frac{e^{ik_o r_R}}{r_R}\iint_{surface}\vec{E}_q\cdot\vec{J}_p ds \tag{2}$$

where p and q are h or v. $\vec{E}_q$ is the q-polarized total incident electric field, including the direct and reflected fields from the ground plane, and $\vec{J}_p$ is the induced electric current on the object, generated by p-polarized incident fields. For simple objects, Geometrical Optics (GO) approach can be used to treat the shadowing effects of the object, which is referred to as GOPO approach. However, this is not computationally efficient to determine the shadowed area for complex targets particularly when we consider the large number of illuminating sources around the target. In order to effectively calculate the electric current on the surface of the target, and at the same time capture higher order near-field multiple scattering on the target a POPO approach is proposed. In this approach, the PO approximation of (1) is first used to calculate the electric currents every where on the surface of the target. Then the scattered field from these primary induced currents is calculated again on the surface of the object from which the second order PO currents are computed, using (1). In this way the shadowing effect is precisely treated without the need for complex ray tracing for the myriads of source points around the target. The scattered magnetic field of $\vec{H}^s_{12}$ from primary PO currents of $\vec{J}_1$ can be written as [4],

$$\vec{H}^s_{12} = \int (\vec{r}-\vec{r}\,')\times\vec{J}_1(\vec{r}\,')(ik_o - \frac{1}{|\vec{r}-\vec{r}\,'|}) \frac{e^{ik_o|\vec{r}-\vec{r}\,'|}}{4\pi|\vec{r}-\vec{r}\,'|^2} d\vec{r}\,' \tag{3}$$

Finally the scattered field can be estimated by (2), using the induced electric currents including the primary and secondary PO currents. As an example a simple PEC box with dimensions of a, b, and c respectively along the x, y, and z directions is considered in free space, see (Fig. 1.). For azimuthal angle of $\phi = 0$ the backscattered field from the box as a function of elevation angle is calculated. In applying a second order PO, care must be taken for not including spurious responses. For example, surfaces which are in the y-z plane and x-y plane from a dihedral will generate an erroneous strong backscattering. In reality internal fields inside the box can not be generated. To rectify this problem, the plane sitting on the x-y plane that does not contribute to the back scattered field should be removed. For targets placed on the ground, the effect of ground reflection from the area just below the lower surface of the target should also be excluded.

2.1 HYBRID GOPOPO METHOD

In order to investigate the backscattering from hard targets with complex structures such as tanks, (see Fig 5 (a)), another step should be taken. In this step, the electromagnetic interaction among the object components is very important and must be accounted for. To demonstrate this point, two simple objects such as two boxes are considered (see Fig. 4 (a)). The original POPO approach, proposed in Section 2, contains the interaction between all the points on the target. However, there are interactions which erroneously generate strong backscattering. Therefore a hybrid GOPOPO approach is defined. In this approach, for calculation of the first order PO currents, induced on the target, first we need to find the geometric optics shadow boundary, defined as,

$$\hat{k}_i . \hat{n} = 0 \tag{4}$$

where $\hat{k}_i$ is the direction of the incident field and $\hat{n}$ is a normal unit vector to a given facet. That is, the first order PO currents on facets where $\hat{k}_i . \hat{n} > 0$, are zero. For computation of the second order PO currents, same approach is followed. Therefore, in computation of (3), only the contribution of the points where

$$(\vec{r}-\vec{r}\,')\cdot\hat{n} < 0 \tag{5}$$

are considered. By this, all the double-bounce scattering mechanisms are correctly accounted for, in the numerical simulations.

3 SIMULATION

In order to show the validity of the proposed POPO approach in treating the shadowing effects, a PEC box with dimensions of 2λ along the x and z axes, and 5λ along the y axis, is considered in free space. For calculating the integral in (2), each surface is meshed into $\lambda/8\times\lambda/8$ square elementary patches. In this approximation, for each elementary patch, the electric field and the electric current are considered constant and equal to their values at the center point of that elementary patch. Fig. 2. shows a comparison between the exact MoM solution and POPO approach for calculating the RCS pattern as a function of incident elevation angles. As can be seen, the POPO formulation generates a very accurate result compared to the MoM. Another simulation was done to verify the validity of the POPO solution when the object is placed above the ground plane. For this simulation, a PEC box with dimensions of 6λ along x,y, and z directions is placed on the ground plane with relative permittivity of $\varepsilon_r = 5.6 + i\ 0.8$ and the frequency is chosen to be $f = 2GHz$. Fig. 3. shows a comparison between the RCS, calculated by GOPO and POPO approaches for horizontal and vertical polarizations of incident field. As can be seen, there is a very good agreement between the GOPO and POPO solution in presence of the ground plane. To verify the proposed hybrid GOPOPO method a PEC box with dimensions of 3λ along the x, and z directions and 10λ along the y direction, placed on top of another box with dimensions of 6λ along the x, and z directions and 10λ along the y direction, is considered. Fig 4. shows the RCS comparison between the hybrid GOPOPO method and the exact EFIE method, for horizontal polarization of the incident field. For meshing the structure in this simulation the spacing between the points is less than $\lambda/2$. As shown in Fig. 4(b), there is a very good agreement between the exact numerical method and the hybrid GOPOPO approach. The same procedure is applied to a tank and the current distribution over the hull is shown in Fig. 5. The shadowed area on the top is generated by the turret roof and the gun which has been successfully captured by hybrid GOPOPO.

4 REFERENCES

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[2] Mojtaba Dehmollaian, Il-Suek Koh, and Kamal sarabandi, " Simulation of Radar Scattering from Electrically Large Objects under Tree Canopies", submitted to AP conference 2004.

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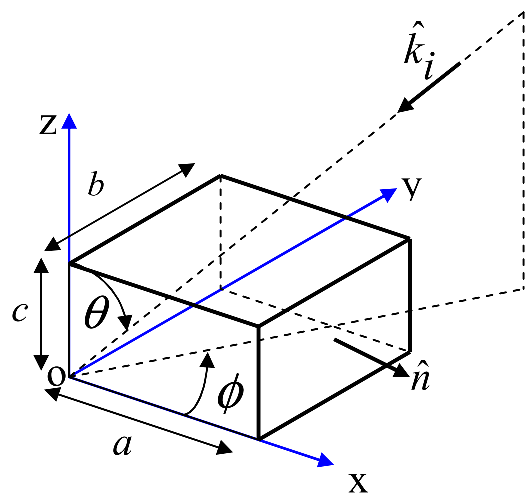
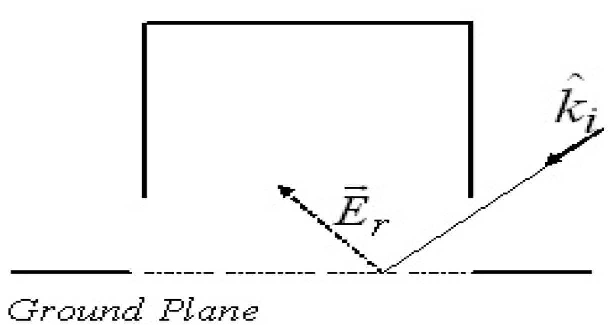
[4] Kamal Sarabandi and Tsen-Chieh Chiu, "Optimum Corner Reflectors for Calibration of Imaging Radars," *IEEE Trans. Antennas and Propagation*., Vol. 44, No. 10, October 1996.



(a)



(b)

Figure 1. (a) A box with arbitrary dimensions of a, b, and c in x, y, and z directions, respectively. (b) Hole approach for treating the reflected waves from the ground plane, coming into the box.

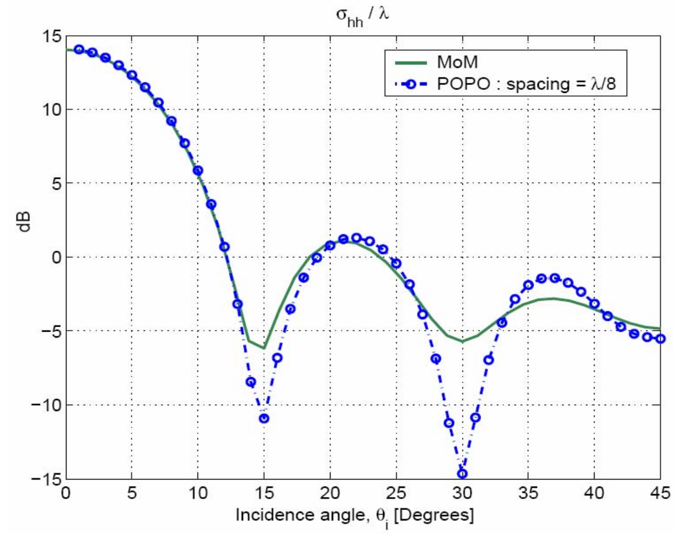
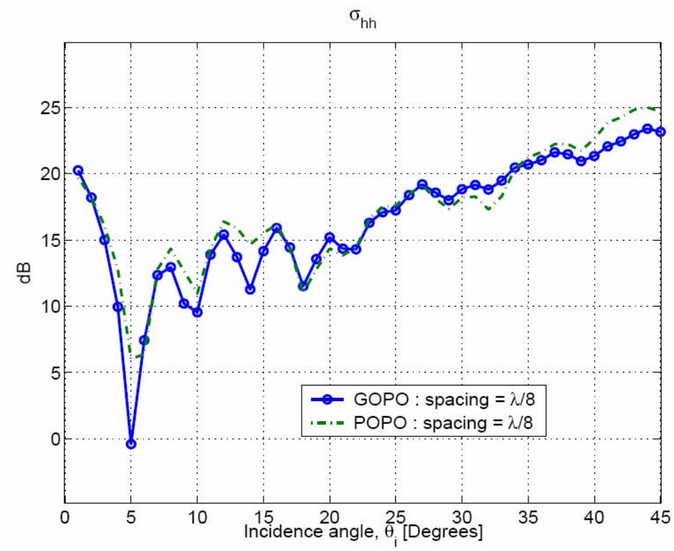


Figure 2. 2D-RCS comparison of a PEC box, in free space, with dimensions of 2λ along x and z directions and 5λ along the y direction, calculated with MoM, and POPO solutions as a function of incident elevation angle at $\phi = 0$ for H-Pol.



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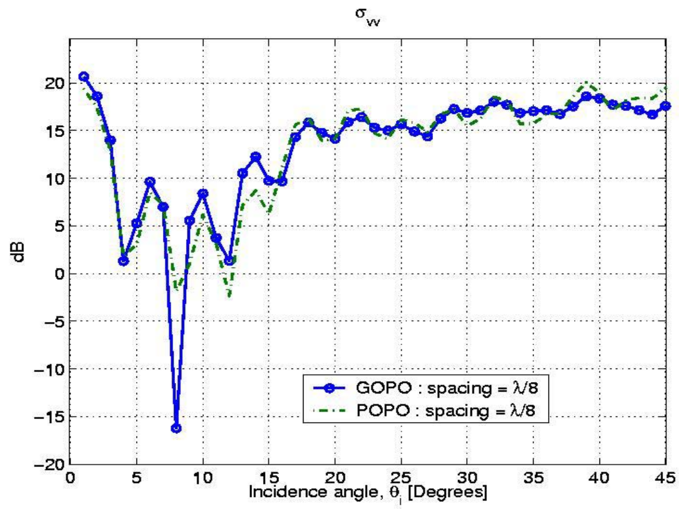
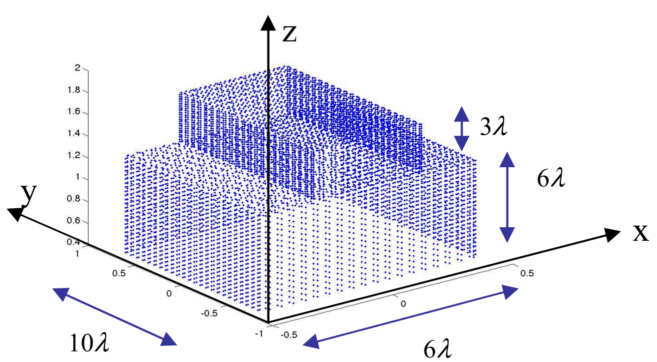
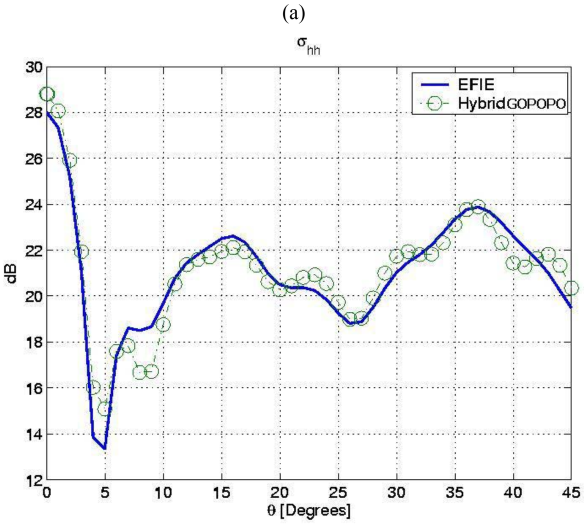


(b)

Figure 3. RCS comparison of a PEC box with dimensions of 6λ along x,y, and z directions, located on the ground plane, calculated by GOPO and POPO approaches as functions of elevation angle at $\phi = 0$ for (a) H and (b) V polarizations.

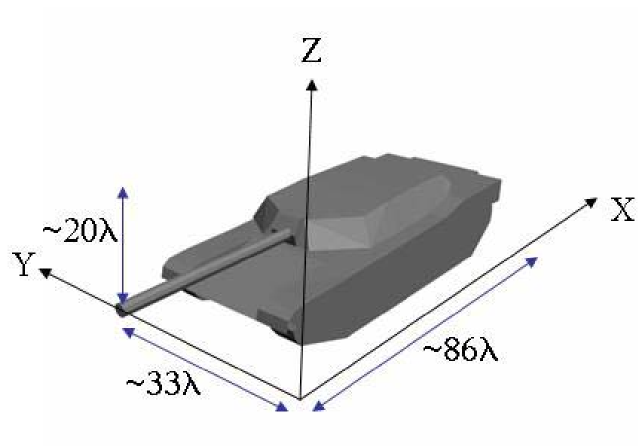


(a)

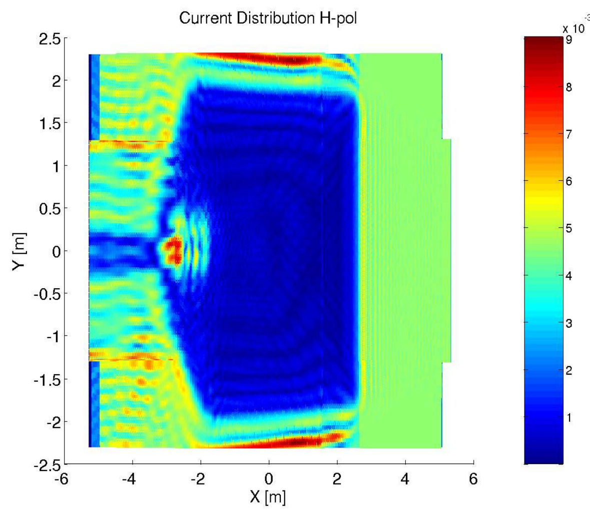


(b)

Figure 4. (a) The box with dimensions of 3λ along the x, and z directions and 10λ along the y direction, placed on top of another box with dimensions of 6λ along the x, and z directions and 10λ along the y direction. (b) Comparison of the 2D-RCS calculated by exact EFIE method and the hybrid GOPOPO method for H-polarization of the incidence field.



(a)



(b)

Figure 5. (a) Structure and approximate dimensions of a simplified tank, used for simulation at $f = 2\,GHz$. (b) Electric current distribution, induced on the hull of the tank when the incident wave is in the direction of $\theta = 30^o$ and $\phi = 0^o$.