Backscattering from A Target Moving along Random Rough Surfaces

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Abstract

This paper is concerned with an analysis of backscattering of electromagnetic waves from a target moving along random rough surfaces (RRSs). We apply the discrete ray tracing method (DRTM) to the backscattering problem in order to investigate the influence of the backscattering from RRSs on the radar cross section.

Key words: backscattering, directivity, random rough surface, DRTM, clutter, radar cross section

1. Introduction

The electromagnetic wave scattering by random rough surfaces (RRSs) has attracted many researchers' interest from a technical view point of radar cross section (RCS) associated with the remote sensing technology [1], [2]. It is well known that the flying objects just above a terrestrial surface are hardly detectable by the radar installed on the surface. This is because that the backscattering of electromagnetic waves emitted from the radar is caused mainly by the reflected waves from the target and the RRSs as well as the interacted reflections between them. The purpose of this paper is to investigate the problem of electromagnetic wave backscattering from a target moving along RRSs from a view point of RCS.

Recently, we have proposed the discrete ray tracing method (DRTM) to deal with large sized RRSs in association with the researches on wireless sensor networks [3]. In this paper, we apply the DRTM to the problem of electromagnetic wave backscattering from a target moving along some types of RRSs [3], and we study how the radar directivity helps to reduce the clutter from RRSs.

2. Numerical Method

The geometry of the problem is shown in Figure 1 where its structure is assumed to be one-dimensional (1D) because it is uniform in z-direction. The radar is located at $(x, y) = (0, h_r)$ and the target is at $(x, y) = (d, h_t)$ where h_r and h_t are constants, and d is the distance between radar and target in the x-direction and variable. Moreover r is the distance from radar to target, and θ is the angle between r and d. It is assumed that the RRS is made of lossy dielectric of which electric property is specified by dielectric constant ϵ_r and conductivity σ, while the target is composed of a perfect conductor. RRSs are numerically generated by the convolution method [3]. In the present simulation, we consider only the Gaussian type of spectrum for the RRSs of which parameters are designated by the height deviation h and the correlation length cl.

2.1 Discrete Ray Tracing Method

In the DRTM we carry out two types of discretizations. The first step of the DRTM is to discretize a 1D RRS in terms of straight lines so that it could be approximated by a piece-wise linear line. Needless to say, the computer memory should be as small as possible for a practical application of the computer simulations. The second step of DRTM is to search rays with respect to the geometry of the problem as

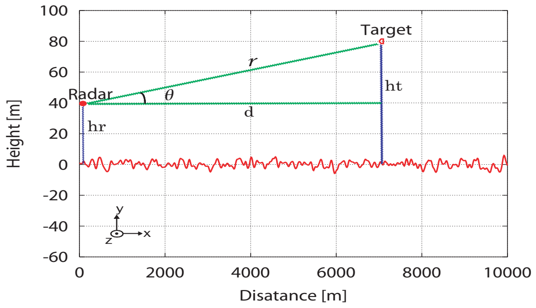


Figure 1: Radar and target above random rough surface.

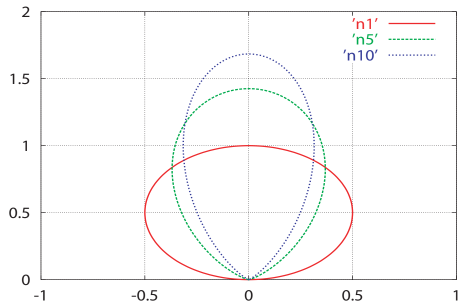


Figure 2: Directivities of employed antennas.

simply as possible to save computation time. The final step is to approximately evaluate electric field dstributions based on the searched rays with an allowable degree of accuracy.

First we divide x-axis into N_x straight lines with length Δ. Then we can discretize any types of rough surfaces in terms of representative points as follows;

$$\begin{gathered} \boldsymbol{r_i} = (x_i, f(x_i)) \\ (i = 0, 1, 2, \cdots, N_x) \end{gathered} \tag{1}$$

where

$$x_i = \Delta i \quad (i = 0, 1, 2, \cdots, N_x) \tag{2}$$

and $f(x)$ is the height function of 1D RRS and Δ is the length of each straight line in the x-direction. The height function of the rough surface is given numerically by the DFT method [3] or the convolution method [3]. It goes without saying that the latter method proposed by Uchida is more flexible and effective to practical applications than the former method [3].

Next we derive the normal vectors of the discretized straight lines by the following relations:

$$\begin{gathered} \boldsymbol{n_i} = (\boldsymbol{u_z} \times \boldsymbol{a_i})/|\boldsymbol{u_z} \times \boldsymbol{a_i}| \\ (i = 0, 1, 2, \cdots, N_x - 1) \end{gathered} \tag{3}$$

where $\boldsymbol{u_z}$ is the unit vector in z-direction. It should be noted that only the position vectors $\boldsymbol{r_i}$ and the normal vectors $\boldsymbol{n_i}$ are enough to numerically search rays. This fact results in saving much computer memory.

The essence of the algorithm for searching rays by the DRTM is summarized in the following. We assume that arbitrary two lines of the discretized RRS are in line of sight (LOS), if a representative point of one straight line is in LOS with that of another line. Otherwise, they are not in line of sight (NLOS). We may select the representative point arbitrarily between $\boldsymbol{r_i}$ and $\boldsymbol{r_{i+1}}$, for example, the central point at $(\boldsymbol{r_i} + \boldsymbol{r_{i+1}})/2$ or the starting point at $\boldsymbol{r_i}$. This algorithm enables us to simplify ray searching greatly resulting in saving much computation time. It is worthy noting that searched rays are approximate, but they can easily be modified to more accurate rays [3].

2.2 Directivity of the Radar Antenna and Field Evaluations

Neglecting the near fields, the electric field radiating from a small dipole antenna is expressed in the following vector form [4].

$$\mathbf{E_0} = \sqrt{30GP_i}[(\mathbf{u_r} \times \mathbf{p}) \times \mathbf{u_r}]\Psi(r) \tag{4}$$

where $\mathbf{r}$ is a position vector from the source to a receiver point and $r = |\mathbf{r}|$. The unit vector $\mathbf{u_r} = \mathbf{r}/r$ is in the direction from the source to the receiver point, and $|\mathbf{u_r} \times \mathbf{p}| = D(\theta) = \sin\theta$ is the directivity of the small dipole antenna.

In this paper we use an artificial antenna based on the small dipole antenna with a more sharp directivity in the form [4]

$$D(n, \theta) = G_n \sin^n \theta \tag{5}$$

where G_n is the gain in comparison with the small dipole antenna. Of course $G_1 = 1$, because $n = 1$ corresponds to the small dipole antenna itself. Actually, a pencil type of radar is often used for searching target, and therefore, we select $n = 10$ in the numerical simulation. Figuer 2 shows the directivities for $n = 1, 5, 10$ with the directivity gains such as $G_1 = 1, G_5 \simeq 1.425, G_{10} \simeq 1.685$, respectively. As a result, the electric field emitted from the artificial antenna with a sharp directivity, $n > 1$, is given by

$$\mathbf{E_0} = \sqrt{45 G_n P_i} D(n-1, \theta)[(\mathbf{u_r} \times \mathbf{p}) \times \mathbf{u_r}]\Psi(r) \; . \tag{6}$$

We have discussed the principle of DRTM algorithm for approximate evaluation of electric field in the previous section. Based on the ray data, the electric field $\boldsymbol{E}$ at the receiver is formally expressed in the following diadic and vector form:

$$\boldsymbol{E} = \sum_{n=1}^{N} \left[\prod_{m=1}^{m=M_n^i} (\boldsymbol{D^i_{nm}}) \cdot \prod_{k=1}^{k=M_n^s} (\boldsymbol{D^s_{nk}}) \cdot \boldsymbol{E_0} \right] \frac{e^{-j\kappa r_n}}{r_n} \tag{7}$$

where $\boldsymbol{E_0}$ is the electric field of the incident wave in Eq.(6) at the first reflection or diffraction point, and κ is the wavenumber in the free space. N is the total number of rays considered, M_n^s is the number of times of its source diffractions [3], and M_n^i is the number of times of its image diffractions [3]. $\boldsymbol{D^i}$ is a diadic form of image diffraction, and $\boldsymbol{D^s}$ is a diadic form of source diffraction. The distance of the n-th ray from source to receiver is given by

$$r_n = \sum_{k=0}^{k=M_n^i+M_n^s} r_{nk} \quad (n = 1, 2, \ldots, N) \tag{8}$$

where r_{nk} is the k-th distance from one reflection or diffraction point to the next one.

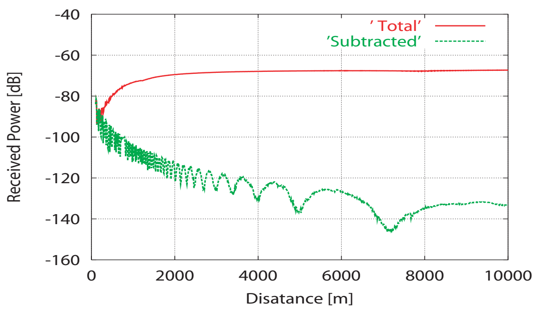
3. Numerical Examples

When we observe the RCS from a target flying above a RRS, the clutter from the RRS dominates and the backscattering from the target is shadowed by the clutter especially for a far-distance target. In this study, we define a subtracted field derived from the well-known two total fields in order to express the effect of target explicitly. One is the total backscattering in case of a target flying above the RRS, and the other is the backscattering in case of no target there. As is evident from this definition, the subtracted field denotes the effect of target in terms of the rays such as a reflection ray directly from the target as well as the reflection rays first from target and next from RRS or vice versa. It should be noted that the subtracted field is influenced by the Doppler shift, but we do not discuss its effect here.

Figures 3, 4 and 5 show numerical examples of the two received powers, corresponding to the total and subtracted backscatterings, versus the distance between the target at the height of $ht = 500[m]$ and the radar at the height of $hr = 40[m]$ with directivities $n = 1, 5, 10$, respectively. Dielectric constant of the RRS is $\epsilon_r = 5.0$ and its conductivity is $\sigma = 0.0023[S/m]$, and the target is assumed to be made of a perfect conductor. The operating frequency of the radar is chosen as $f = 1[GHz]$. It is shown that the backscattering expressing the effect of target is buried in the clutter from the RRS except for the near region of the radar. However, it is demonstrated that the shaper the radar directivity becomes, the longer is the range of the radar detection.

4. Conclusion

In this paper, we have applied the DRTM to numerical analyses of backscattering of electromagnetic waves from a target moving along RRSs. The point of the DRTM is to discretize not only RRS but



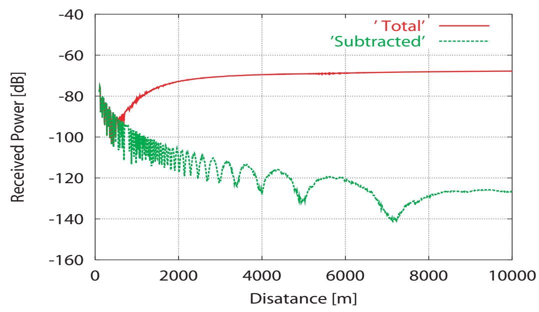


Figure 3: Total and subtracted back scatterings (n=1, h=500 [m]).

Figure 4: Total and subtracted back scatterings (n=5, h=500 [m]).

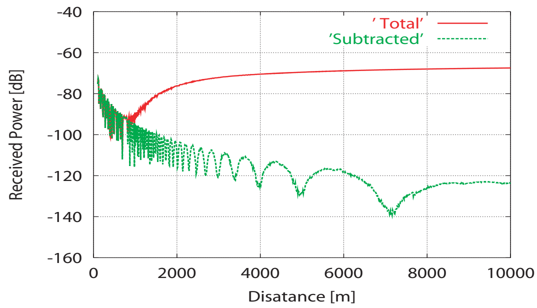


Figure 5: Total and subtracted back scatterings (n=10, h=500 [m]).

also the ray tracing itself, resulting in saving a great deal of computer memory and computation time. Numerical calculations were carried out for backscattering from a target above 1D RRSs. We have introduced the subtracted backscattering together with the total backscattering in order to make clear how the radar directivity helps to reduce clutter from RRSs and to enhance the backscattering from the target relatively. We have not discussed the Doppler shift which directly influences on the subtracted field introduced in this paper.

Modification of the present DRTM to 2D RRSs deserves as a future investigation. Moreover, inclusion of the Doppler shift in the DRTM analyses also deserves as another investigation.

Acknowledgments

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