A Fast Algorithm for Calculating Complex Targets Near-field EM Scattering Characteristics

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Abstract— In order to meet the requirements of fuse's digital simulation and hard-ware-in-the-loop simulation, a fast algorithm based on the electromagnetic scattering modeling techniques of complex targets in the near field is proposed to calculate the echo power of fuse. The main research work in this paper involves the followings: (1) Considering the influence of antenna pattern and distance as well as spherical wave irradiation, a method established by the PO and PTD and GO methods is presented for electromagnetic scattering modeling of complex targets in the near field. (2) In the filed of EM scattering theory of complex targets for missile-target encounter, the EM scattering model of complex targets is introduced to missile-target encounter model. The relative system of coordinates is established to describe missile-target encounter with parallel track. The system of coordinates of a rocket and the system of coordinates of a target are established to describe polarization and antenna pattern located on the rocket. The system of coordinates of the elementary reflector coordinates is established to calculate EM scattering of the elementary reflector in the near field. The system of coordinates of the target is established to calculate EM scattering after transforming the movement parameter and electromagnetic parameter which are in others system of coordinates into the system of coordinates of the target. (3) A fast algorithm is put forward to calculate the echo power of fuse in the near-field. Numerical results prove its high efficiency and preciseness. The goal of this paper is to calculate EM scattering in any missile-target encounter conditions for fuse's digital simulation and hard-ware-in-the-loop simulation and the proposed method would be especially valuable in engineering application.

1. INTRODUCTION

The near-field characteristics of target echo of fuse are very important for fuse's digital simulation. Nowadays, domains of current domestic and overseas researchers have focused on the study of the near-field target characteristic of the fuse, including the study on measurement and algorithm for calculating echo power of fuse. The simulation algorithms are based on PO and PTD method to calculate the echo power of the geometrical elements which are illuminated by radar beam during missile target encounter [1]. But the methods mentioned above cost a lot of time for calculating just one trajectory of the target. However, we often need hundreds of simulation results of echo power under different trajectories for fuse's digital simulation. Inevitably there are serious specific problem. Therefore use of principles, methods should be improved to enhance the numeration efficiency.

This article investigates a new method by dividing the target into several independent cubes and using the PO and PTD and GO methods to calculate the RCS of each cube. Then calculate the echo power of fuse by integrating those of the geometrical elements which are illuminated by radar beam during missile target encounter. Because the RCS of the cubes can be calculated beforehand and store in the database, it would dramatically reduced the time expenses. At the same time, the RCS store in the database can be used in various of conditions of missile target encounter. And the emulation results show that the general time of calculation of echo power of fuse from fast algorithm on all trajectory of the target is less than 1 sec. And the proposed method would be especially valuable in engineering application.

2. METHOD OF MODELING OF NEAR-FIELD ELECTROMAGNETIC SCATTERING

We will introduce the basic principles of method of modeling of near-field electromagnetic scattering before the introduction of fast algorithm. The scattering field of facets and wedges is computed by Physical Optics (PO) and Physical Theory of Diffraction (PTD) and multi-scattering of facets and facets is calculated by Geometrical Optics (GO) and PO.

2.1. Calculation of the Scattering Field of Facets

At first we should divide the surface of the target into small plane triangular elements and make sure the maximal dimension should according to qualification of the PO method [2, 3] ($L_{\max} \le \lambda/5$) and the criterion of a far zone [4] ($L_{\max} \le \sqrt{R/2}\lambda$), where λ represents length of wave, $L_{\max}$ represents the maximal dimension of triangular elements, R represents limiting distance between object and radar.

Referring to the methods of literature [5], the electric field of irradiating wave can be represented as

$$\mathbf{E}_i = \frac{\exp\left(i[\omega t + k\left(R_{im} + \rho \cdot \hat{\mathbf{r}}_i\right)]\right)}{R_{im}} \hat{\mathbf{e}}_i \tag{1}$$

where $k = 2\pi/\lambda$ — wave number, ρ — vector which has been directed from the beginning of coordinates of triangular element in one points on a surface of a triangle, R_{im} — distance from the beginning of system of coordinates of triangle up to the phase center of the transmitting antenna.

The electric field of scattering wave can be represented as:

$$\mathbf{E}_{po} = \frac{ik}{4\pi} \int_S \mathbf{T} \frac{\exp\left(ik\left(R_{im} + R_{sm} - \mathbf{q} \cdot \rho\right)\right)}{R_{im} R_{sm}} dS \tag{2}$$

where $\mathbf{T} = (\hat{\mathbf{n}} \times \mathbf{H}_{\sum}) - [(\hat{\mathbf{n}} \times \mathbf{E}_{\sum}) \times \hat{\mathbf{r}}_{\mathbf{s}}]$, $\mathbf{E}_{\sum} = \mathbf{E}_i + \mathbf{E}_s$ represents sum of the electric field, $H_{\sum} = H_i + H_s$ represents sum of the magnetic field, $\mathbf{q} = \hat{\mathbf{r}}_{\mathbf{s}} - \hat{\mathbf{r}}_i$ represents incremental directed vector, ρ — vector directed from the beginning of coordinate system of triangle to point of surface of triangle, R_{sm} — distance from the beginning of system of coordinates of triangle up to the phase center of the receiving antenna, r_i represents the directing vector of the irradiating wave, r_s represents the directing vector of the reflection wave.

2.2. Calculation of the Scattering Field of Wedges

According to Physical Theory of Diffraction (PTD) [6], the scattering field of wedges can be represented as:

$$\mathbf{E}_d = \frac{\mathrm{j}k}{4\pi} \oint_l \left\{ \left[\hat{\mathbf{r}}_s \times \left(\hat{\mathbf{r}}_s \times \mathbf{J}_e\right)\right] + ik(\hat{\mathbf{r}}_s \times \mathbf{J}_m) \right\} \varphi(\hat{\mathbf{r}}_s) \, \mathrm{d}l \tag{3}$$

$\mathbf{r}_s$ represents the directing vector of the reflection wave. $\mathbf{J}_e$, $\mathbf{J}_m$ are defined from the following formulas:

$$\mathbf{J}_e = -\frac{2F}{ik} \frac{\left(\mathbf{E}_i \cdot \hat{\mathbf{t}}\right) \cdot \hat{\mathbf{t}}}{\sin\gamma_i \sin\gamma_s}, \quad \mathbf{J}_m = -\frac{2G}{ik} \frac{\left(\mathbf{H}_i \cdot \hat{\mathbf{t}}\right) \cdot \hat{\mathbf{t}}}{\sin\gamma_i \sin\gamma_s} \tag{4}$$

where F, G — coefficients of diffraction of Ufimtsev, γ_i and γ_s, — spatial angle between directing vectors r_i and r_s and a vector $t = \{0, 0, 1\}$.

2.3. Calculation of the Multi-scattering Field of Facets and Facets

The problem of an estimation of contributions double reflections between triangles is solved on the basis of technology of the "Shooting and bouncing rays" (SBR). The physical sense of the theory consists that the field falling on some triangular element of a surface, does not scattering in surrounding space, but reflected by laws of GO in a direction of other triangular element and induced on it secondary electromagnetic waves. Thus reflection of waves between triangles is considered on the basis of plane equivalent apertures. As the aperture the plane triangle projected on a plane, orthogonal to mirror reflected ray is considered. The primary goal is definition of amplitude and polarization of an electromagnetic wave reflected from the first triangular element to the second. The integral of physical optics is calculated on the area of the second triangle accepting reflected wave, the multi-scattering field can be represented as:

$$\sigma = 4\pi R_{sm}^2 \frac{\left|\mathbf{E}_s\right|^2}{\left|\mathbf{E}_i\right|^2} \tag{5}$$

where σ represents RCS of multi-scattering field and $\mathbf{E}_i$ represents the transmitting electric field, and $\mathbf{E}_s$ represents the receiving electric field. And R_{sm} represents the distance from the beginning of system of coordinates of triangle up to the phase center of the receiving antenna.

2.4. Modeling of Near-field Electromagnetic Scattering in Missile-target Encounter

There are four systems of coordinates need to be found: system of coordinates of relative positioning of a rocket and the aerodynamic target, system of coordinates of the target and system of coordinates of the antenna and system of coordinates of the elementary reflector (ER) in The trajectory of relative movement of the target represents the direct line. The relative system of coordinates is established to describe missile-target encounter with parallel track. In SCT calculation of intensity of a resulting field of scattering of object is carried out, and in system of coordinates of the antenna basis of the irradiating and reflected waves in a direction on ER are formed. In system of coordinates of ER calculation of intensity of a field of scattering of the reflector is carried out. For definition basis of the irradiating and reflected waves should be set in system of coordinates of ER. Then according to the formula (2) and formula (3) as well as formula (5), we can derive total near-field EM scattering characteristics in missile-target encounter.

3. FAST ALGORITHM FOR CALCULATING NEAR-FIELD EM SCATTERING CHARACTERISTICS

The method mentioned above cost a lot of time for calculating just one trajectory of the target. This article investigates a new method calculate the echo power of fuse.

We use multipoint model and the target is represented as a set of projective cubes, each of which limits the certain element of a surface of the target (Fig. 1). To each of cubes the local point is appointed. This point is formed as an average point of all triangular elements getting in limits of the given cube. In other words, representation of the purpose as a set of cubes corresponds to its representation as a set of local points $P_k,\ k = 1, \ldots, N_p$. The amount of cubes (local reflectors) is defined from a condition of maintenance of required resolution on any parameter of a signal and accuracy of operation of fuse. On Fig. 1, the model of airplane consisting of 20 cubes (local points) is shown. Thus the fuselage of the plane is submitted by set of 8 points laying on an axis of the plane, and each of wings — accordingly from 6 points. To each of cubes there corresponds a file of triangular elements and the sharp edges getting in area of the given cube.

After dividing the target into several independent cubes, then we use the PO and PTD and GO methods to calculate the RCS of each cube. Calculation of RCS is carried out for corners of an azimuth $\alpha_i = \{0^\circ \sim 360^\circ\}$ and corners of a vision $\beta_i = \{0^\circ \sim 360^\circ\}$ in local system of coordinates of a reflector for the set distance R from the antenna to a local reflector. In multipoint model for each local reflector the array of values of RCS in local system of coordinates $\sigma_{ij} = \sigma\ (\alpha_i,\ \beta_j)$ is formed. As shown in Fig. 3. According to representation of the target as a set of local reflectors

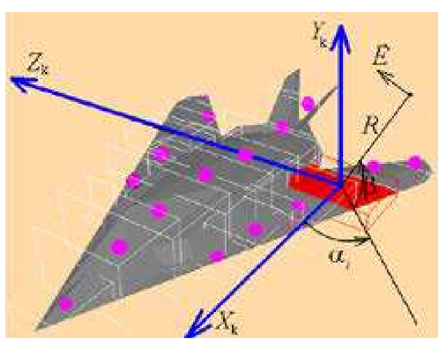
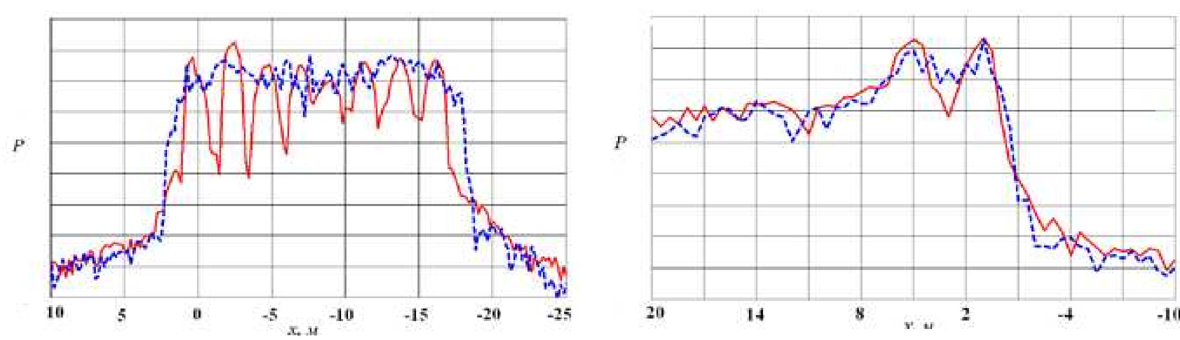


Figure 1: Formation of multipoint target on the base of its fast algorithm.



(a) Angel of the beams is 90°

(b) Angel of the beams is 45°

Figure 2: Power of fuse in dependence from coordinate X of airplane model (Continuous line — fast algorithm, Shaped line — traditional algorithm).

power of input signal of fuse we shall consider as:

$$P = \frac{P_i D_i D_s \lambda^2}{(4\pi)^2} \left| \sum_{m=1}^{N_p} \frac{F_{im} F_{sm} \sqrt{\frac{\sigma_m}{4\pi}} \exp(i\varphi_m)}{R_m^2} \right|^2 \tag{6}$$

where N_p — number of local points of the target, $\sigma_m = \sigma_{i,j}$ — the array of values of RCS of the multipoint model for each local reflector, F_{im}, F_{sm} — values of the normalized functions of direction of transmitting and reception aerials in a direction on local point, located on distance R_m from the conditional (phase) center of aerials.

Because the RCS of the cubes can be calculated beforehand and store in the database, the formula (6) leave out the process for calculating RCS of every facets of target in the real time and it would dramatically reduced the time expenses. At the same time, the RCS store in the database can be used in various of conditions of missile target encounter. And the emulation results show that the general time of calculation of echo power of fuse from fast algorithm on all trajectory of the target is less than 1 sec.

As an example on Fig. 2 results of calculation of power of fuse from airplane model are shown on the base of its tradition model and with use of fast model. On both figures the continuous line designates a curve calculated on fast algorithm, and by a shaped line — a curve calculated on the base of tradition algorithm. We can see that the emulation results calculated by fast algorithm are with a good agreement with tradition algorithm. At the same time, the emulation results show that the general time of calculation of echo power of fuse from fast algorithm on all trajectory of the target is less than 1 sec. And the proposed method would be especially valuable in engineering application.

4. CONCLUSION

In conclusion, the proposed method for calculating the echo power of fuse in this article is precise and useful. And the emulation results show that the general time of calculation of echo power of fuse from fast algorithm on all trajectory of the target is less than 1 sec. And the proposed method would be especially valuable in engineering application.

REFERENCES

1. Jeng, S.-K., "Near-field scattering by physical theory of diffraction and shooting and bouncing rays," *IEEE Trans. on Antennas and Propagation*, Vol. 46, No. 4, 551–558, 1998.
2. , ,, . , 2005.
3. Youssef, N. N., "Radar cross section of complex targets," *Proceeding of the IEEE*, Vol. 77, No. 5, May 1989.
4. Crispin, J. W. and K. M. Siegel, *Method of Radar Cross Section Analysis*, Academic Press, New York and London, 1968.
5. "SAF analysis of shipboard antenna performance, coupling, and radar in complex near-field scattering environments," *IEEE Antennas and Propagation Society International Symposium, AP-S. Digest*, 1995.
6. , (), , 1994.