Fast Calculation Method of Target's Monostatic RCS Based on BCGM

X. F. Xu J. Li
Key Laboratory of Astronautic Dynamics, Xi'an Satellite Control Center
Xi'an 710043, China

***Abstract*-When the target's monostatic RCS (Radar Cross Section) is calculated by the traditional method sweeping with frequency and degree, the matrix equation of each interval point must be solved, which cost a lot of time. To solve the problem, the calculation method of monostatic RCS using method of moments is analyzed. Based on the BCGM (bistatic conjugate gradient method), one solving method using the last sweeping point result as the sweeping point initial iterative values is proposed. The numerical results indicate that the iterative times can be effectively reduced by the method, and the efficiency will be higher if the sweeping points are denser.**

I. INTRODUCTION

The RCS of the target is relative to the frequency and the angle, so the matrix equation of the electric current distribution of the target is needed to be solved in frequency and angle domain. Using traditional frequency sweeping and angle sweeping calculating method, the matrix equation must be solved repetively at a series of points in the hope frequency and angle domain. For accurate solution, we must reduce frequency or angle interval, which means that the repetition of matrix equation solving increases greatly. It inevitably makes significantly increased amount of calculation and spending a lot of calculation time and computer memory.

Matrix equation solving speed is a important factor that affects RCS computing time overall scanning range. Multilevel fast multipole technique can reduce the computing amount from $O(N^2)$ to $O(N\log N)$ [1-4]. Adopting conditional processing method can effectively reduce the number of iterations, which is very effective for the single scanning point [5,6]. But for the calculation of multiple scanning points, especially when scanning points are very dense, the iteration times of each scanning point won't decrease due to the increased scanning points. The total times of iteration is still more. In this paper, the method using the last point iterative value as the current scanning point initial iterative value is presented. The method can effectively reduce the times of iterations. There are more populous scanning points (the smaller scanning interval), the iterations times of single scanning point will be less, and there will be higher efficiency.

II. BASIC THEORY

For 3d scattering problem, according to the ideal conductor surface boundary conditions, the electric field integral equation can be obtained.

$$E_{inc}(r) = ik\eta\int_S G(r,r')\cdot J_s(r')dS' \qquad (1)$$

E_{inc} represents the incident field, $G(r,r')$ is the green's function. The surface current of the scatterer is expanded with the RWG basis function [7], and the current basis function of the nth edge is

$$f_n(r) = \begin{cases} \dfrac{l_n}{2A_n^+}\rho_n^+ & r\in T_n^+ \\ \dfrac{l_n}{2A_n^-}\rho_n^- & r\in T_n^- \\ 0 & other \end{cases} \qquad (2)$$

Scatterer surface current density can be approximated as

$$J_s(r) \approx \sum_{n=1}^{N} I_n f_n(r) \qquad (3)$$

Galerkin's method is adopted, which selects the basis functions as a test function. And the matrix equation was derived.

$$Z_{mn} = ik\eta\int_{\Delta_m} f_m(r)\cdot\int_{\Delta_n} G(r,r')\cdot f_n(r')dS'dS \qquad (4)$$

$$V_m = \int_{\Delta_m} f_m(r)\cdot E_{inc}(r)dS \qquad (5)$$

The scatterer surface currents can be got by solving the matrix equation, and the scattering field of the any point in the space will be calculated. The calculation formula of RCS is

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \frac{\left|E_s^2\right|}{\left|E_{inc}^2\right|} \qquad (6)$$

Observing from equation 1, we can get $Z_{mn} \approx Z_{nm}$, so the impedance matrix is a symmetrical complex matrix. Compared with the conjugate gradient method (CGM), one time matrix vector multiplication is only needed by using bistatic conjugate gradient method (BCGM). Under the same accuracy, BCGM needs a third of the iteration times of CGM. So, the computing can be speeded up 5 ~ 6 times by using BCGM. But due to the calculation error, the generated impedance matrix is only a approximate symmetric matrix. In order to make the impedance matrix symmetry, after filling impedance matrix, a standard plural symmetric matrix is generated using the following method, and half of storage can be saved.

$$Z_{mn} = \frac{Z_{mn}+Z_{nm}}{2}, \quad Z_{nm} = Z_{mn} \qquad (7)$$

For the monostatic RCS calculation of the complex structure scatterer, if want to get accurate results, scanning points require relatively close, so scanning interval will be very small. Imagining that, if the angle or frequency interval are close to zero ($\Delta\theta \to 0, \Delta f \to 0$), then every changing of a scanning point, scatterer surface current distribution almost unchange, so the two adjacent scanning points' results will be slightly different. Based on this idea, this paper puts forward a method of that using the last scanning point iteration value as the current scanning point initial iteration. It is easy to judge, the method will reduce the times of iterations and speed up the convergence. When $\Delta\theta \to 0, \Delta f \to 0$, it may not require iteration or a few times of iteration, the computation will quickly converge and meet the accuracy requirements.

III. NUMERICAL CALCULATION AND ANALYSIS

In order to verify the validity of the method, firstly, the monostatic RCS of a combination model of a sphere and a cone is calculated with angle sweeping. The sphere diameter and the bottom diameter and the height of the cone are all λ. The sphere center is located in the apex of the cone. For the incident wave frequency, the unknown number is 3717, and $\varphi = 0°$. With changing the angle of the incident wave, the monostatic RCS with different $\Delta\theta$ are shown in figure 1.

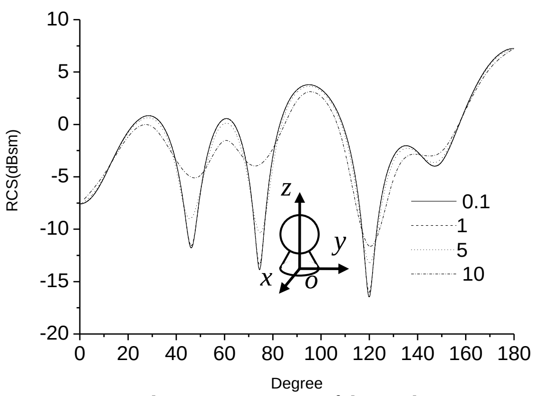

Figure 1. The monostatic RCS of the combination.

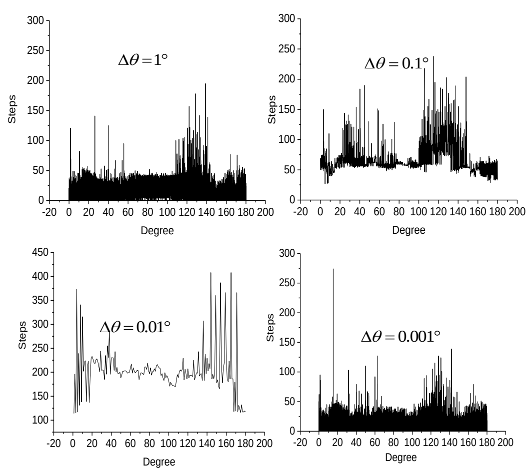

Figure 2. The iterative times of each scanning point.

As can be seen from figure 1, the monostatic RCS will be more precise with the increase of the scanning points ($\Delta\theta$ reduced). For the irregular surface structure targets, more scanning points are needed to obtain accurate numerical results. The iterative times of each scanning point with different $\Delta\theta$ are shown in figure 2. As can be seen from figure 2, $\Delta\theta$ is smaller, the iteration times of each scanning point is less. The average iteration times of each scanning point with different $\Delta\theta$ are shown in table1.

TABLE I
THE AVERAGE ITERATION TIMES OF EACH SCANNING POINT

$\Delta\theta$	1.0°	0.1°	0.01°	0.001°	0.0001°
The number of scanning points	181	1801	18001	180001	1800001
The total iteration times	37477	123586	261929	285842	289286
The average iteration times	207.06	68.62	14.55	1.59	0.16

As can be seen from figure 2, $\Delta\theta$ is smaller, the average iteration times is less.

Secondly, the affection to monostatic RCS with different scanning intervals of frequency is studied. The monostatic RCS of a metal sphere is calculated. $\varphi = 0°$ and $\theta = 0°$, by sweeping the frequency of incident wave, the structure and the monostatic RCS are shown in figure 3.

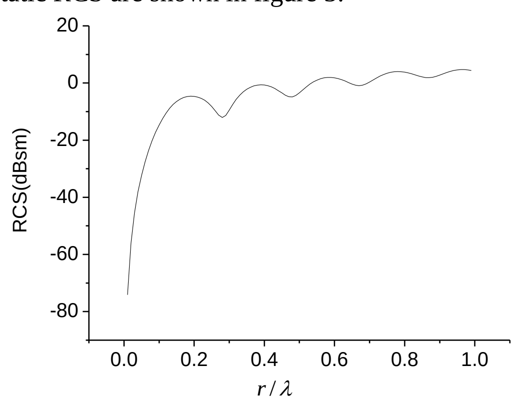

Figure 3. The monostatic RCS of a metal sphere.

The average iteration times of each scanning point with different Δf (frequency interval) are shown in figure 4. Δf is smaller, the average iteration times is less, by which the effection of the method is also verified.

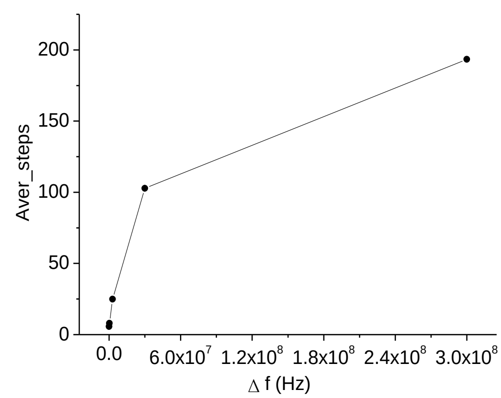

Figure 4. The iterative times of each scanning point.

IV. CONCLUSION

For the calculation of the monostatic RCS of the targets with irregular surface structure, the scanning points are denser, and the results are more accurate. The numerical calculation indicates that, the method presented in this paper is very suitable for solving the dense scanning points problem. The scanning points populated more densely (the scanning interval are smaller), the less iteration times is needed, so the monostatic RCS calculating speed of the whole scanning range can be effectively improved.

REFERENCES

[1] Z. H. Fan, J. L. Liu, Y. Q. Hu, etc., "Multilevel Fast Multipole Algorithm for EM Scattering of Conducting Objects Above Lossy Half-space," Chinese Journal of Computational Physics, vol. 27(1), pp. 95-100, 2010.

[2] J. Hu, Z. P. Nie, J. Wang, etc., "Multilevel fast multipole algorithm for solving scattering from 3-D electrically large object," Chinese Journal of Radio Science, vol. 19(5), pp. 509-514, 2004.

[3] M. S. Tong, W. C. Chew, "Multlevel fast multipole algorithm for elastic wave scattering by large three-dimensional objects," Journal of Computational Physics, vol. 228, pp. 921-932, 2009.

[4] X. F. Xu, X. Y. Cao, J. J. Ma, "Efficient calculation of vehicular antennas' radiation patterns," Progress In Electromagnetics Research Symposium. pp. 255-257, 2009.

[5] J. L. Guo, J. Y. Li, Y. L. Zhou, etc., "Incomplete LU pre-conditioner technology for fast analysis of conducting objects," Chinese Journal of Radio Science, vol. 23(1), pp. 141-145, 2008.

[6] S. G. Wang, X. P. Guan, D. W. Wang, etc., "A Preconditioner in Iterative Solution of Higher-Order MoMs," Joournal of Microwaves, vol. 24(4), pp. 20-23, 2008.

[7] S. M. Rao, D. R. Wilton, A. W. Glisson, "Electromagnetic scattering by surfaces of arbitrary shape," IEEE Trans. Antennas Propagat, vol. 30 (5), pp. 409-418, 1982.