Comparison of Image Reconstruction by Using Near-Field and Far-Field Data for an Imperfect Conductor

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ABSTRACT: Image reconstruction by using near-field and far-field data for an imperfectly conducting cylinder is investigated. A conducting cylinder of unknown shape and conductivity scatters the incident wave in free space and the scattered near and far fields are measured. By using measured fields, the imaging problem is reformulated into an optimization problem and solved by the genetic algorithm. Numerical results show that the convergence speed and final reconstructed results by using near-field data are better than those obtained by using far-field data. This work provides both comparative and quantitative information. © 2001 John Wiley & Sons, Inc. Int J RF and Microwave CAE 11: 69–73, 2001.

Keywords: imperfectly conducting cylinder; image reconstruction; near-field data; far-field data; genetic algorithm

I. INTRODUCTION

The electromagnetic inverse scattering problem of conductors has been a subject of considerable importance in remote sensing and noninvasive measurement. In the past 20 years, many rigorous methods have been developed to solve the exact equation. However, inverse problems of this type are difficult to solve because they are ill-posed and nonlinear. As a result, many inverse problems are reformulated as optimization problems. Generally speaking, two main kinds of approaches have been developed. The first is based on the gradient search approach such as the Newton-Kantorovitch method [1–3] and the Levenberg–Marquart algorithm [4–5]. Since this first approach applies the gradient search method to find extreme values of the cost function, it is highly dependent on the initial guess and tends to get trapped in local minima and maxima. In contrast, the second approach is based on the genetic algorithm [6–8]. The genetic algorithm is a well-known algorithm that uses stochastic random choice to search through a coding of a parameter space. Compared to gradient search optimization techniques, the genetic algorithm is less prone to convergence to a local minimum, which in turn renders it an ideal candidate for global optimization. It usually converges to the global extreme of the problem, no matter what the initial estimate is [9].

In this article, a comparison of image reconstruction by using near-field and far-field data for an imperfectly conducting cylinder is presented. The genetic algorithm is used to reconstruct the shape and conductivity of a scatterer. In Section II, the theoretical formulation is briefly presented. Numerical results by using near-field and far-field data are given in Section III. Finally, conclusions are drawn in Section IV.

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II. THEORETICAL FORMULATION

Let us consider an imperfectly conducting cylinder with cross section described in polar coordinates in the xy plane by the equation $\rho = F(\theta)$ located in free space. An incident plane wave whose electric field vector is parallel to the z axis is illuminated upon the metallic cylinder. By using the induced current concept, the scattered field can be expressed as the integral of the two-dimensional Green's function multiplied by the induced surface current density, which is proportional to the normal derivative of the electric field on the conductor surface [3, 6]. In addition, for an imperfectly conducting scatterer with finite conductivity, the boundary condition can be approximated by assuming that the total tangential electric field on the scatterer surface is related to surface current density through a surface impedance [3, 10]. As a result, for the direct scattering problem, the scattered field is calculated by assuming that the shape and the conductivity of the object are unknown. We can use the boundary condition to solve the surface current density and then calculate the scattered field by using the Green's function. For numerical calculation of the direct problem, the contour of the object is first divided into sufficiently small segments so that the induced surface current density can be consider constant over each segment. Then the moment method is used to solve the equations with a pulse basis function for expanding and a Dirac delta function for testing.

Let us consider the following inverse problem: given the scattered field, determine the shape and the conductivity of the object. Here the shape $F(\theta)$ is assumed to be starlike. In other words, $F(\theta)$ can be expanded as

$$F(\theta) = \sum_{n=0}^{N/2} B_n \cos(n\theta) + \sum_{n=1}^{N/2} C_n \sin(n\theta),$$

where B_n and C_n are real coefficient to be determined and $N + 1$ is the number of unknowns for the shape function of the object. In the inversion procedure, the genetic algorithm is used to minimize the root mean square error of the measured scattered field and the calculated scattered field through three genetic operators: reproduction, crossover, and mutation. When the root mean square error changes by less than 1% in two successive generations, the genetic algorithm is terminated and a solution is then obtained. Note that the regularization term can be added to avoid ill-posed problems. Please refer the references [3, 6] for details.

III. NUMERICAL RESULTS

Using a numerical simulation we compare the image reconstruction by using near-field and far-field data. Let us consider an imperfectly conducting cylinder in free space and a plane wave of unit amplitude incident upon the object. The frequency of the incident wave is chosen to be 3 GHz. In our calculation, three examples are considered. To reconstruct the shape and conductivity of the cylinder, the object is illuminated by four incident waves with incident angles $\phi = 0$, 90, 180, and 270°, and eight measurement points are taken on a circle of radius R' at equal spacing. In our cases, R' is chosen much smaller than or much larger than $2D'^2/\lambda$, corresponding to the near-field or far-field measurement, where D' is the largest dimension of the scatterer. Here $R' = 0.06$ m for near-field measurement and $R' = 7$ m for far-field measurement. The number of unknowns is set to 10 (i.e., $N + 2 = 10$) to save computing time. The population size is chosen as 300. The binary string length of unknown coefficients, B_n (or C_n), is set to 16 bits. The binary string length of conductivity is also set to be 16 bits. The search range for unknown coefficients of the shape function is chosen to be from 0 to 0.1. The search range for unknown conductivity is chosen from 3 to 7×10^7. The extreme value of the coefficient of the shape function and conductivity can be determined by the prior knowledge of the objects. The crossover probability and mutation probability are set to be 0.8 and 0.04, respectively.

In the first example, the shape function is chosen to be $F(\theta) = (0.04 + 0.002\cos 2\theta + 0.02\sin 3\theta)$ m with aluminum material (i.e., $\sigma = 3.54 \times 10^7$ s/m). The reconstructed relative root mean square (rms) errors for the shape and conductivity (ES and EC) obtained by using the near-field and far-field data are plotted in Figure 1. Here the shape function is also plotted for reference. From Figure 1, it is clear the convergence speed and final rms error obtained by using the near-field data are better than those obtained by using far-field data. The final rms errors for conductivity obtained by using the near-field and far-field data are 1.6×10^{-2} and 3.1×10^{-2}, respectively. Note that the convergence is achieved

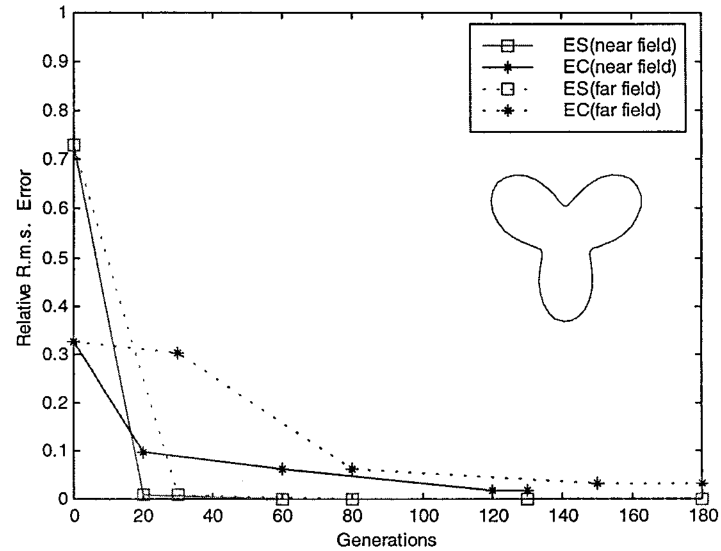

Figure 1. Shape function errors (ES) and conductivity errors (EC) for example 1 in each generation by using near-field and far-field data.

at the 130th generation when using the near-field measurement. However, for the far-field measurement, the convergence is not achieved until the 180th generation. This is due to the fact that the kernel of the integral for far-field measurement is smoother (less singular) than that for near-field measurement. As a result, the near-field measurement is less ill-posed than the far-field measurement. The typical CPU time for this example is about 30 min on a Pentium III microprocessor.

In the second example, we select the peanut-shaped function $F(\theta) = (0.026 + 0.009 \cos 2\theta)$ m with silver material (i.e., $\sigma = 6.17 \times 10^7$ s/m). The purpose of this example is to show that different shape and conductivity has similar results. Reconstructed results are shown in Figure 2.

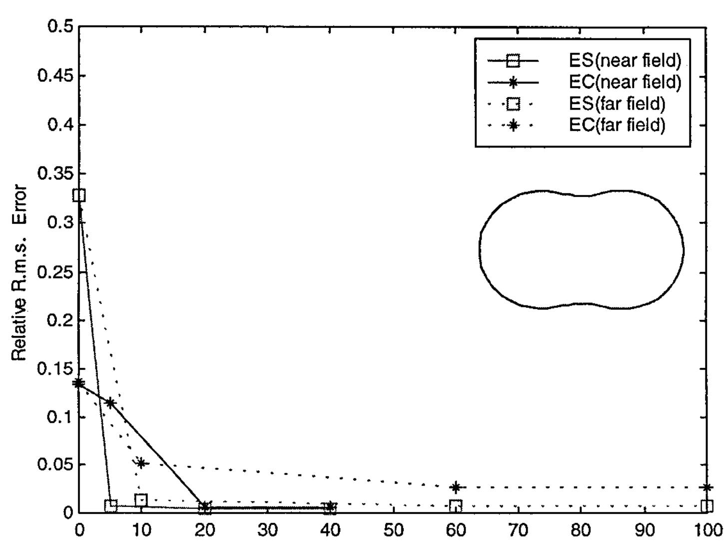

Figure 2. Shape function errors (ES) and conductivity errors (EC) for example 2 in each generation by using near-field and far-field data.

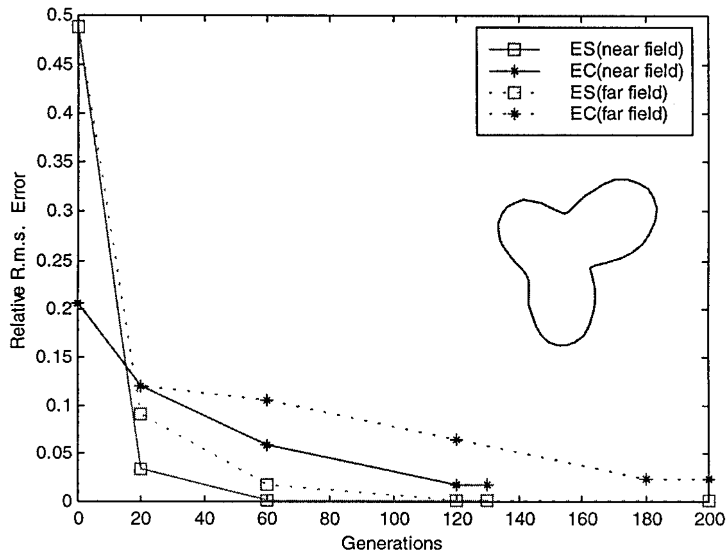

Figure 3. Shape function errors (ES) and conductivity errors (EC) for example 3 in each generation by using near-field and far-field data.

In the third example, the shape function is selected to be $F(\theta) = (0.02 + 0.004\sin 2\theta + 0.008\sin 3\theta)$ m, where copper material is selected (i.e., $\sigma = 5.8 \times 10^7$ s/m). Note that the shape function is not symmetrical about either the x axis or the y axis. This example has further verified the reliability of our conclusions. Refer to Figure 3 for details.

IV. CONCLUSIONS

We have compared the image reconstruction results for an imperfectly conducting cylinder obtained by using near-field and far-field data. The reconstructed results for near-field measurement are found to be better than those obtained by the far-field measurement. This result can be explained by the fact that the near-field measurement is less ill-posed than the far-field measurement. Finally, it is worth noting that in these cases the present work provides not only comparative information, but also quantitative information.

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BIOGRAPHIES

Chien-Ching Chiu was born in Taoyuan, Taiwan, Republic of China, on January 23, 1963. He received the BSCE degree from National Chiao Tung University, Hsinchu, Taiwan, in 1985 and MSEE and PhD degrees from National Taiwan University, Taipei, Taiwan, in 1987 and 1991, respectively. From 1987 to 1989, he served in the ROC Army Force as a communication officer. In 1992 he joined the faculty of the Department of Electrical Engineering, Tamkang University, where he is now a professor. He was a visiting scholar at MIT and University of Illinois, Urbana, from 1998 to 1999. His current research interests include microwave imaging, numerical techniques in electromagnetics, and indoor wireless communications.

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