Application of Genetic Algorithm for Microwave Imaging of a Partially Immersed Imperfectly Conducting Cylinder

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Abstract—**This paper presents a computational approach to the imaging of a partially immersed imperfectly conducting cylinder. The shape and conductivity of an imperfectly conducting cylinder and scatters is unknown, the transverse magnetic (TM) wave illuminated while the scattered field is recorded outside in free space. Based on the boundary condition and the measured scattered field, a set of nonlinear integral equations is derived and the imaging problem is reformulated into an optimization problem We use genetic algorithm (GA) to reconstruct the shape and the conductivity of a partially immersed imperfectly conducting cylinder.**

Keywords- Inverse Problem, Partially Immersed, Steady-State Genetic Algorithm.

I. INTRODUCTION

In inverse scattering, one attempts to infer the profile of an object from the measurement data collected away from the scatterer. Needless to say, this is very important for a number of sensing and remote sensing applications [1]-[4]. However in inverse problem, main difficulties are highly ill-posed and nonlinearity. In the past few years, several numerical techniques have been reported for electromagnetic imaging reconstruction. To the best of our knowledge, there are no investigations on the electromagnetic imaging of partially immersed imperfectly conducting cylinder. In this paper, the electromagnetic imaging of a partially immersed imperfectly conducting cylinder is first reported using GA. In section II, the relevant theory and formulation are presented. The numerical results for reconstructing objects of different shapes are shown in section III. Finally, some conclusions are drawn in section IV.

II. THEORETICAL FORMULATION

Let us consider an imperfectly conducting cylinder which is partially immersed in a lossy homogeneous half-space, as shown in Figure1. Media in regions 1 and 2 are characterized by permittivities and conductivities (ε_1, σ_1) and (ε_2, σ_2) respectively. An imperfectly conducting cylinder is illuminated by a transverse magnetic I plane wave. The cylinder is of an infinite extent in the z direction, and its cross-section is described in polar coordinates in the x, y plane by the equation $\rho=F(\theta)$, i.e., the object is of a star-like shape. We assume that time dependence of the field is harmonic with the factor exp ($j\omega t$). Let E^{inc} denote the incident field from region 1 with incident angle Φ_1. Owing to the interface between regions 1 and 2, the incident plane wave generates two waves that would exist in the absence of the conducting object. Thus, the unperturbed field is given by

$$E^i(x,y)=\begin{cases} E_1^i(x,y)=e^{-jk_1(x\sin\phi_1+(y+a)\cos\phi_1)}+Re^{-jk_1(x\sin\phi_1-(y+a)\cos\phi_1)} & ,y\le -a \\ E_2^i(x,y)=Te^{-jk_2(x\sin\phi_2+(y+a)\cos\phi_2)} & ,y>-a \end{cases} \quad \text{..........(1)}$$

$$R=\frac{1-n}{1+n},\quad T=\frac{2}{1+n},\quad n=\frac{\cos\phi_2}{\cos\phi_1}\sqrt{\frac{\varepsilon_2-j\sigma_2/\omega}{\varepsilon_1-j\sigma_1/\omega}},$$
$$k_i^2=\omega^2\varepsilon_i\mu_0-j\omega\mu_0\sigma_i,\quad \mathrm{Im}(k_i)\le 0,$$
$$k_1\sin\phi_1=k_2\sin\phi_2,\quad i=1,2.$$

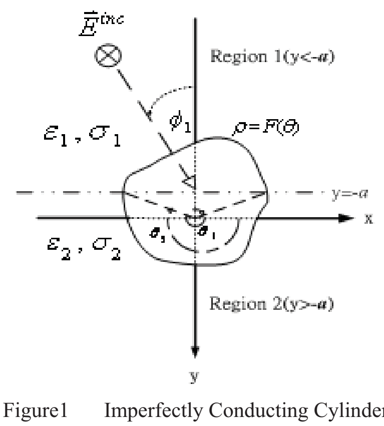

Figure1 Imperfectly Conducting Cylinder

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Since the cylinder is partially immersed, the equivalent current exists both in the upper half space and the lower half space. As a result, the details of Green's function are given first as follows:

When the equivalent current exists in the upper half space, the Green's function for the line source in the region 1, can be expressed as

$$G_1(x,y;x',y')=\begin{cases} G_{21}(x,y;x',y') & ,y>-a \\ G_{11}(x,y;x',y')=G_{f11}(x,y;x',y')+G_{s11}(x,y;x',y') & ,y\le -a \end{cases} \quad (2)$$

Where

$$G_{21}(x,y;x',y')=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{\gamma_1+\gamma_2}e^{-j\gamma_2(y+a)}e^{j\gamma_1(y'+a)}e^{-j\alpha(x-x')}d\alpha \quad (2.1)$$

$$G_{f11}(x,y;x',y')=\frac{j}{4}H_0^{(2)}[k_1\sqrt{(x-x')^2+(y-y')^2}\,] \quad (2.2)$$

$$G_{s11}(x,y;x',y')=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{2\gamma_1}\left(\frac{\gamma_1-\gamma_2}{\gamma_1+\gamma_2}\right)e^{j\gamma_1(y+2a+y')}e^{-j\alpha(x-x')}d\alpha \quad (2.3)$$

$$\gamma_i^2=k_i^2-\alpha^2,\quad i=1,2,\quad \mathrm{Im}(\gamma_i)\le 0,\quad y'<-a$$

When the equivalent current exists in the lower half space, the Green's function for the line source in the region 2, is

$$G_2(x,y;x',y')=\begin{cases} G_{12}(x,y;x',y') & ,y\le -a \\ G_{22}(x,y;x',y')=G_{f22}(x,y;x',y')+G_{s22}(x,y;x',y') & ,y>-a \end{cases}$$

……………………………………………………..…..(3)

Where

$$G_{12}(x,y;x',y')=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{\gamma_1+\gamma_2}e^{j\gamma_1(y+a)}e^{-j\gamma_2(y'+a)}e^{-j\alpha(x-x')}d\alpha \quad (3.1)$$

$$G_{f22}(x,y;x',y')=\frac{j}{4}H_0^{(2)}[k_2\sqrt{(x-x')^2+(y-y')^2}\,] \quad (3.2)$$

$$G_{s22}(x,y;x',y')=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{2\gamma_2}\left(\frac{\gamma_2-\gamma_1}{\gamma_2+\gamma_1}\right)e^{-j\gamma_2(y+y'+2a)}e^{-j\alpha(x-x')}d\alpha \quad (3.3)$$

$$\gamma_i^2=k_i^2-\alpha^2,\quad i=1,2,\quad \mathrm{Im}(\gamma_i)\le 0,\quad y'>-a.$$

The scatterer of interest here is a nonmagnetic ($\mu=\mu_0$), imperfectly conductivity with minimum radius of curvature α. The surface impedance is expressed as

$$Z_s(\omega)\cong\sqrt{j\omega\mu_0/\sigma}.$$

This approximation is valid as long as

$$|\,\mathrm{Im}(N_c)ka\,|>>1 \text{ and } \sigma>>\omega\varepsilon_0$$

where "Im" means taking the imaginary part, and N_c is the complex index of refraction of the conductor, given by

$$N_c=\sqrt{1+\frac{\sigma}{j\omega\varepsilon_0}}.$$

Then, the shape function F(θ) can be expanded as:

$$F(\theta)=\sum_{n=0}^{N/2}B_n\cos(n\theta)+\sum_{n=1}^{N/2}C_n\sin(n\theta) \quad (5)$$

where B_n and C_n are real numbers to be determined, and N+1 is the number of unknowns for the shape function.

III. Numerical Results

Let us consider an imperfectly conducting cylinder which is partially immersed in a lossless half-space ($\sigma_1=\sigma_2=0$) and the parameter a is set to zero. The permittivity in region 1 and region 2 is characterized by $\varepsilon_1=\varepsilon_0$ and $\varepsilon_2=2.56\varepsilon_0$, respectively. The frequency of the incident wave are chosen to be 1GHz, with incident angles Φ_1 equal to 45° and 315°, respectively. For each incident wave 8 measurements are made at the points equally separated on a semi-circle with the radius of 3m in region 1. The population size of 100 is chosen and rank selection scheme is used with the top 30 individuals being reproduced accords to the rank. In the following cases the searching range for the unknown coefficients is chosen from 0 to 0.2. The extreme values of the coefficient of the shape function can be determined by the prior knowledge of the objects. The crossover rate is set to 0.1 such that only 10 iterations are performed per generation. The mutation probability is set to 0.05.

Here, the shape function discrepancy is defined as

$$DR=\{\frac{1}{N'}\sum_{i=1}^{N'}[F^{cal}(\theta_i)-F(\theta_i)]^2/F^2(\theta_i)\}^{1/2} \quad (6)$$

where N′ is set to 360.

The conductivity discrepancy is defined as

$$DSIG=\left|\frac{\sigma^{cal}-\sigma}{\sigma}\right| \quad (7)$$

In this example, the shape function is chosen to be F(θ)=(0.028+0.008cos3θ) m. The chosen conductivity is

100 S/m. The reconstructed shape function for the best population member is plotted in Figure2 with the shape and the conductivity error shown in Figure3. The reconstructed shape error is <5%.

IV. Conclusion

In this paper, we present a method of applying genetic algorithm to reconstruct the shape and the conductivity of an imperfectly conducting cylinder by TM waves. Base on the imperfect conducting cylinder approximate boundary by assuming that the total tangential electric field on the scatterer surface is related to the surface current density through the surface impedance and the measured scattered fields, we have derived a set of nonlinear integral equations and reformulated the imaging problem into an optimization one. By using the genetic algorithm, the shape and conductivity of the object can be reconstructed, even when the initial guess is far from exact one. Numerical results show that good reconstruction for the shape and conductivity of the object can be obtained from the scattered fields.

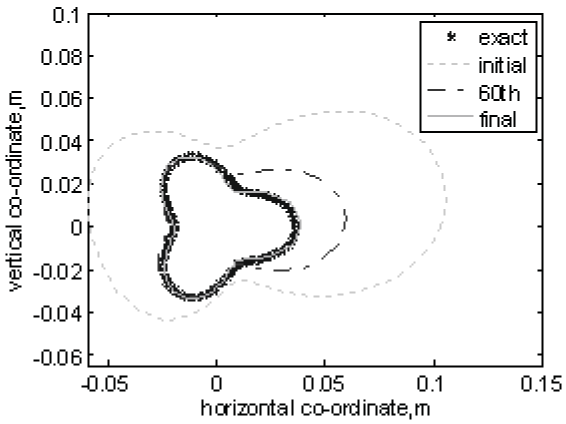

Figure2 Shape function for example

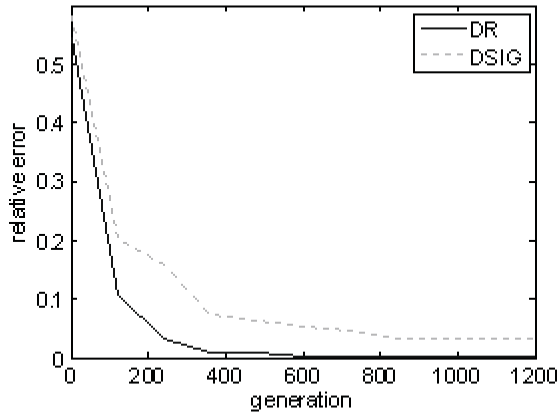

Figure3 The shape and conductivity function errors versus generation

Acknowledgement

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