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Application of Particle Swarm Optimization for Microwave Imaging of a Buried Conductor

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Abstract—**In this paper, particle swarm optimization (PSO) is employed to determine the shape of a conducting cylinder buried in a half-space. Assume that a conducting cylinder of unknown shape is buried in one half-space and scatters the field incident from another half-space where the scattered filed is measured. 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. The inverse problem is resolved by an optimization approach, and the global searching scheme PSO is then employed to search the parameter space.**

Numerical results demonstrate that even when the initial guess is far away from the exact one, good reconstruction can be obtained by using PSO both with and without the additive Gaussian noise.

Index Terms—**Image reconstruction, Inverse scattering, Particle swarm optimization.**

I. Introduction

Microwave imaging of the electromagnetic properties of unknown scatterers by inverting scattered field measurements is of great interest because it is associated with numerous applications in biomedical imaging, nondestructive testing, geophysical exploration, etc [1]. Recently, a method has been proposed to reconstruct the shape of a 2-D PEC target by stochastic methods, such as genetic algorithms (G-As) [2]. In this paper, we present a method based on the particle swarm optimization (PSO) to recover the shape of a buried perfectly conducting cylinder. In Section II, a theoretical formulation for the inverse scattering is presented. Numerical results for reconstructing objects of different shapes are given in Section III. Finally, some conclusions are drawn in Section IV.

II. Theoretical Formulation

Let us consider a perfectly conducting cylinder which is buried in a lossy homogeneous half-space, as shown in Fig 1. Media in regions 1 and 2 are characterized by permittivity and conductivity $(\varepsilon_1, \sigma_1)$ and $(\varepsilon_2, \sigma_2)$, respectively and the permeability in both regions are μ_0, i.e. , non magnetic media are concerned here. The cross section of the cylinder is described in polar coordinates in x-y plan by the equation $\rho = F(\theta)$. The cylinder is illuminated by a plane wave with time dependence $e^{j\omega t}$.

For simplicity, the electric field vector is assumed to be parallel to the z-axis (i.e., transverse magnetic or TM polarization). Let E^{inc} denote the incident field from region 1 with incident angle ϕ_1.Owing to the interface between region 1 and region 2, the incident plane wave generates two waves which would exist in the absence of the conducting object: a reflected wave (for $y \le -a$) and a transmitted wave (for $y > -a$). Thus unperturbed field is given by

$$\vec{E}_i(\vec{r}) = E_i(x, y)\hat{z} \tag{1}$$

For a TM incident wave, the scattered field can be expressed as

$$E_s(x, y) = -\int_0^{2\pi} G(x, y; F(\theta'), \theta')J(\theta')d\theta' \tag{2}$$

$G(x, y; x', y')$ is the Green's function which can be obtained by Fourier transform.

The shape function $F(\theta)$ can be expanded as:

$$F(\theta) \cong \sum_{n=0}^{\frac{N}{2}} B_n \cos(n\theta) + \sum_{n=1}^{\frac{N}{2}} C_n \sin(n\theta) \tag{3}$$

where B_n and C_n are real coefficients to be determined, and N+1 is the number of unknowns.

In the inversion procedure, the particle swarm optimization is used to maximize the following object function:

$$OF = \left\{ \frac{1}{M} \sum_{m=1}^{M} \frac{\left| E_s^{\exp}(\bar{r}_m) - E_s^{cal}(\bar{r}_m) \right|^2}{\left| E_s^{\exp}(\bar{r}_m) \right|^2} \right\}^{-1/2} \tag{4}$$

where M is the total number of measurement points, and $E_s^{cal}(\vec{r}_m)$ and $E_s^{\exp}(\vec{r}_m)$ are the calculated scattered field and the measured scattered field, respectively. Therefore, the maximization of OF can be interpreted as the minimization of the least-squares error between the measured and the calculated fields.

The detailed formulae will be expounded in the full paper.

III. Simulated Results

Let us consider a perfectly conducting cylinder which is

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buried in a lossless half-space ($\sigma_1 = \sigma_2 = 0$). The permittivity in region 1 and region 2 is characterized by $\varepsilon_1 = \varepsilon_0$ and $\varepsilon_2 = 2.55\varepsilon_0$ respectively. A TM polarization plane wave of unit amplitude is incident from region 1 upon the object as shown in Fig. 1. The frequency of the incident wave is chosen to be 3GHz, i.e., the wavelength λ_0 is 0.1m. The object is buried at a depth a=λ_0 and the scattered field is measured on a probing line along the interface between region 1 and region 2. To reconstruct the shape of the object, the object is illuminated by incident waves from three different directions and 8 measurement points at equal spacing are used along the interface $y = -a$ for each incident angle. To save computing time, the number of unknowns is set to be 7.

In the example, the shape function is chosen to be $F(\theta) = [0.04 + 0.002\cos(\theta) + 0.017\cos(2\theta)]m$. Satisfactory results are obtained in Fig. 2. Normalized Gaussian noises standard deviations of 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5% and 25% are used in the simulations. The numerical results for this example are plotted in Fig. 3. It is understood that the effect of noise is negligible for normalized standard deviations below 10%. This example implies that good reconstruction can be obtained when the shapes of scatterers are more complex.

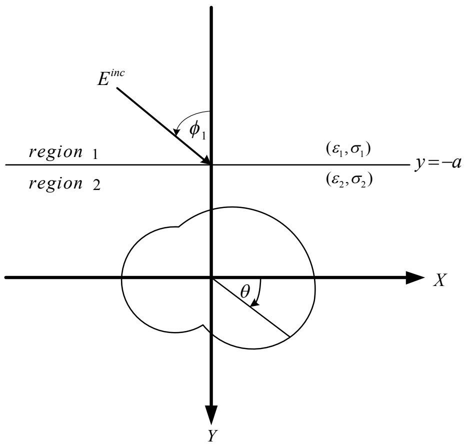

Fig. 1. Geometry of the problem in (x,y) plane

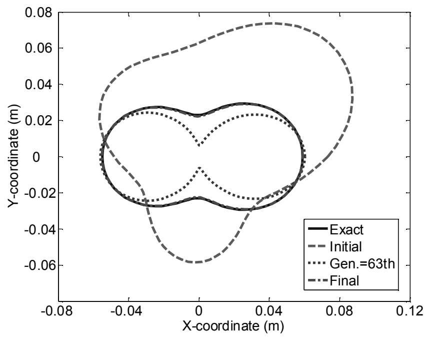

Fig. 2. Target profiles for example 2.
The solid curve represents the exact profile, while the dashed curves are calculated profiles in iteration process

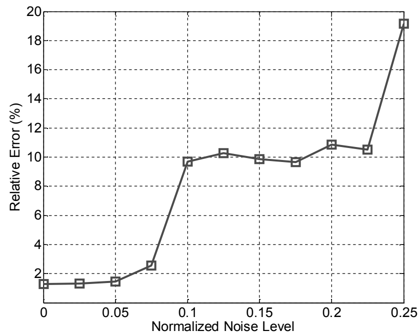

Fig. 3. the trend of relative error for example 2 with noise

IV. Conclusion

We have presented a study of applying the particle swarm optimization to reconstruct the shapes of a buried conducting cylinder. Based on the boundary condition and measured scattered field, we have derived a set of nonlinear integral equations and reformulated the imaging problem into an optimization problem. Good reconstruction has been obtained from the scattered fields both with and without the additive Gaussian noise.

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