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Through-Wall Imaging for a Metallic Cylinder by Dynamic Differential Evolution

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Abstract— **Through wall imaging for estimating shape of a metallic cylinder is proposed. The ability of dynamic differential evolution (DDE) stochastic searching algorithm for shape reconstruction of 2-D conducting targets hidden behind a homogeneous building wall is demonstrated by using simulated backscattered fields. After an integral formulation, a discretization using the method of moment (MoM) is applied. The through-wall imaging (TWI) problem is recast as a nonlinear optimization problem with an objective function defined by the norm of a difference between the measured and calculated scattered electric field. Thus, the shape of metallic cylinder can be obtained by minimizing the objective function. Simulations show that DDE can successfully reconstruct the through-wall imaging for a metallic cylinder.**

Keywords- Inverse Scattering, Dynamic Differential Evolution.

I. INTRODUCTION

Through-wall imaging (TWI) consists of imaging objects hidden behind an obstacle by using electromagnetic (EM) waves at the microwave frequencies. This problem is of great interest, as the aim of detecting and localizing hidden objects is shared in many applicative contexts (i.e., both military and civilian) such as in search and rescue, security, peacekeeping, and law enforcement operations [1]-[3].

The focus of the present work is on the reconstruction using inverse scattering approach. Among the inverse scattering approaches, several numerical reconstruction methods have been applied for through-wall imaging. General speaking, two main kinds of approaches have been developed. The first is based on local searching schemes such as the contrast source inversion (CSI) [4]. Recently, subspace-based optimization method (SOM) [5]-[6] has been proposed to solve inverse scattering problems. However, for a gradient-type method, it is well known that the convergence of the iteration depends highly on the initial guess. If a good initial guess is given, the speed of the convergence can be very fast. On the other hand, if the initial guess is far away from the exact one, the searching tends to get fail [7]. In general, they tend to get trapped in local minima when the initial trial solution is far away from the exact one. Thus, some population-based stochastic methods, such as genetic algorithms (GAs) [8], differential evolution (DE) [9],[10] and particle swarm optimization (PSO) [11]-[13] are proposed to search the global extreme of the inverse problems to overcome the drawback of the deterministic methods for TWI or buried problems.In our knowledge, there are still no numerical results by the DDE algorithm for metallic cylinder scatterers hidden behind a homogeneous wall. The DDE algorithm is used to recover the shape of the scatterer. The outline of the paper is as follows. In Section II, we describe the forward scattering for TWI. Section III and IV present inverse problem and dynamic differential evolution (DDE), respectively. Two numerical examples are presented in Section V. Section VI is the conclusion.

II. FORWARD PROBLEM

Let us consider a two-dimensional slab structure as shown in Fig.1, where (ε_i,σ_i) $i=1,2,3$, denote the permittivities and conductivities in each region. Here the permeabilities of all three regions are assumed to be μ_o and a conducting cylinder is buried in region 3. In our simulation, a priori information is assuming that scatterer is a metallic cylinder. 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.) is illuminated by an incident plane wave whose electric field vector is parallel to the z axis (i.e., TM polarization). We assume that the time dependence of the field is harmonic with the factor exp($j\omega t$). Let E_{inc} denote the incident field form region 1 with incident angle θ_1 as follow:

$$E_{inc} = E_1^{+} e^{jk_1 \cos\theta_1 y} e^{-jk_1 \sin\theta_1 x} \hat{z} \qquad (1)$$

At an arbitrary point (x, y) (or (r, θ) in polar coordinates) in regions 3 the scattered field, $E_s = E - E_i$, can be expressed as

$$E_s(x,y) = -j\omega\mu_0 \int_c G(x,y,F(\theta'),\theta')\, J_s(\theta')\, \sqrt{F(\theta)+F'(\theta)}\, d\theta \qquad (2)$$

Where $J_s(\theta')$ is the induced surface current density, which is proportional to the normal derivative of the electric field on the conductor surface. $F(\theta)$ is the shape function, and $F'(\theta)$ is the differentiation of $F(\theta)$. c is cross section for detect domain. Note that G_1 and G_3 denote the Green's function which can be obtained by tedious mathematic manipulation for the line source in region 3. More detail on subgriding FDTD can be found in [9]

The direct scattering problem is to calculate the scattered electric fields while the shape and location of the scatterer are given. The shape function $F(\theta)$ of the scatterer is described by the trigonometric series in the direct scattering problem

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

where *Bn* and *Cn* are real coefficients to expand the shape function.

III. INVERSE PROBLEM

For the inverse scattering problem, the shape of the metallic cylinder is reconstructed by the given scattered electric field

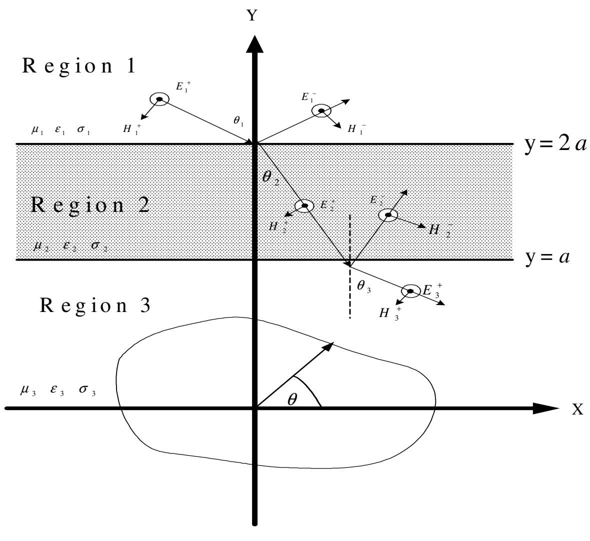

Fig. 1. Geometrical configuration of the problem.

measured at the receivers. This problem is resolved by an optimization approach, for which the global searching scheme DDE is employed to minimize the following objective function (*OF*):

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

Where E_z^{exp} and E_z^{cal} are experimental electric fields and the calculated electric fields, respectively.

IV. EVOLUTIONAL ALGORITHMS

Dynamic Differential Evolution

DDE algorithm starts with an initial population of potential solutions that is composed by a group of randomly generated individuals which represents shape function of the cylinders. Each individual in DDE algorithm is a *D*-dimensional vector consisting of *D* optimization parameters. The initial population may be expressed by $\{x_i : i = 1, 2, \cdots, Np\}$, where *Np* is the population size. After initialization, DDE algorithm performs the genetic evolution until the termination criterion is met. DDE algorithm, like other EAs, also relies on the genetic operations (mutation, crossover and selection) to evolve generation by generation.

The key distinction between a DDE algorithm and a typical DE [12] is on the population updating mechanism. In a typical DE, all the update actions of the population are performed at the end of the generation, of which the implementation is referred as static updating mechanism. Alternatively, the updating mechanism of a DDE algorithm is carried out in a dynamic way: each parent individual will be replaced by his offspring if the offspring has a better objective function value than its parent individual does. Thus, DDE algorithm can respond the progress of population status immediately and to yield faster convergence speed than the typical DE. Based on the convergent characteristic of DDE algorithm, we are able to reduce the numbers of cost function evaluation and reconstruct the microwave image efficiently.

V. NUMERICAL RESULT

We illustrate the performance of the proposed inversion algorithm and its sensitivity to random noise in the scattered field. Consider a lossless three-layer structure ($\sigma_1 = \sigma_2 = \sigma_3 = 0$) and a perfectly conducting cylinder buried in region 3. The permittivity in each region is characterized by, $\varepsilon_1 = \varepsilon_0$, $\varepsilon_2 = 8.0\varepsilon_0$ and $\varepsilon_3 = \varepsilon_0$ respectively, as shown in Fig. 1. The incident angles equal to 45° , 90° and 315° , respectively. The frequency of the incident wave is chosen to be 3GHz. The width of the second layer is 0.1 m. There are seven measurement points are equally separated on a circle of radius 3m about center at equal spacing in region 1. Thus there are totally 21 measurements in each simulation. The number of unknowns is set to be 7 (i.e., N+1=7). To save computing time, the number of unknowns is set to be 7. Moreover, to avoid inverse crime, the discretization number for the direct problem is two times that for the inverse problem in the simulation. In forward problem, the shape function $F(\theta)$ is discretized to 30. Reconstruction is carried out on an Intel PC (3.4 GHz/ 4G memory /500 G). The software is developed on FORTRAN VISION 6.0 in WINDOWS XP system environment. The search range for the unknown coefficient of the shape function is chosen to be from 0 to 0.1. The operational coefficients for the DDE algorithm are set as below: The crossover rate *CR*=0.8. Both parameters λ and ξ are set to be 0.8. The population size *Np* is set to be 70. It should be noted that the termination criterion is set to 2000 generations in our simulation based on our empirical rule.

In the first example, the shape function is chosen to be $F(\theta) = (0.025 + 0.015\cos 3\theta)$ (unit:m). The reconstructed shape function for the best population member is plotted in Fig.2 with the shape error shown in Fig.3. It is observed that DDE algorithm can be quickly achieved within 150 generation to minimize the relative errors of the shape and has good convergences. The typical CPU time for each example is about 2 minutes. Here, the shape function discrepancy is defined as

$$DF = \{\frac{1}{N'}\sum_{i=1}^{N'}[F^{cal}(\theta_i) - F(\theta_i)]^2 / F^2(\theta_i)\}^{1/2} \times 100\% \quad (5)$$

where N' is set to 1000. The relative error is about 0.01%.

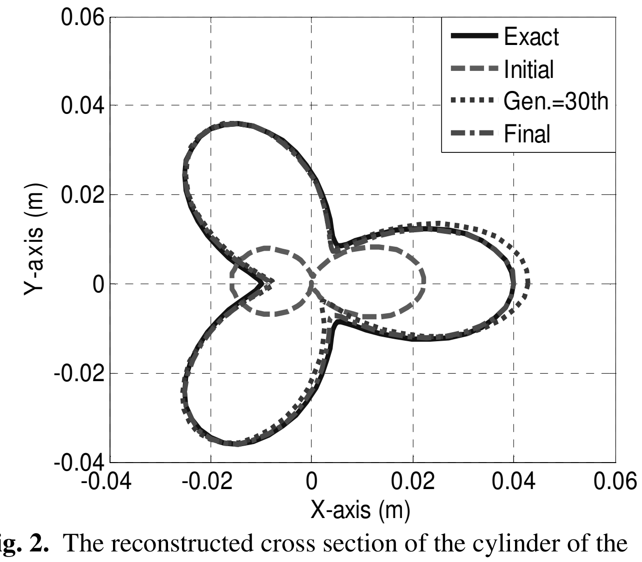

Fig. 2. The reconstructed cross section of the cylinder of the example at different generations.

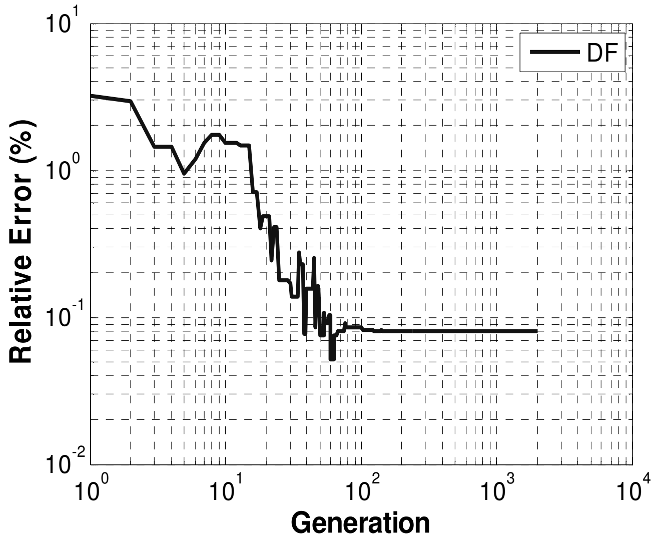

Fig. 3. Shape function error at different generations

IV. CONCLISIONS

In this paper, a computational approach to microwave imaging of homogeneous dielectric scatterer with arbitrary cross section in time domain has been presented. Scattering fields are obtained by FDTD method. The subgridding scheme is employed to closely describe the shape of the cylinder for the FDTD method. The approach has been formulated as a global nonlinear optimization problem and NU-SSGA has been applied. It has been shown that the location, shape and permittivity of the dielectric object can be successfully reconstructed even when the dielectric object with fairly large permittivity

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