Self-Adapting Control Parameters in Dynamic Differential Evolution on Inverse Scattering Problems

SADDE for inverse scattering

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Abstract—**The application of two techniques for the reconstruction of shape reconstruction of the perfectly conducting cylinder from scattered field measurements is studied in the present paper. These approaches are applied to two-dimensional configurations. After an integral formulation, a discretization using the method of moment (MoM) is applied. The inverse scattering problems are transformed into optimization problems. Considering that the microwave imaging is recast as a nonlinear optimization problem, an objective function is defined by the norm of a difference between the measured scattered electric field and that calculated for an estimated the shape of the perfectly conducting cylinder. Thus, the shape of metallic cylinder can be obtained by minimizing the objective function. In order to solve this inverse scattering problem, two techniques are employed. The first is based on a dynamic differential evolution (DDE). The second is a new version of the DDE algorithm with self-adaptive control parameters (SADDE). Numerical results indicate that the self-adaptive dynamic differential evolution algorithm (SADDE) outperforms the DDE in terms of reconstruction accuracy.**

Keywords- Inverse Scattering, FDTD, Self-Adaptive Dynamic Differential Evolution.

I. INTRODUCTION

The detection and reconstruction of buried and inaccessible scatterers by inverting microwave electromagnetic measurements is a research field of considerable interest because of numerous applications in geophysical prospecting, civil engineering, and nondestructive testing [1]. Numerical inverse scattering studies found in the literature are based on either frequency or time domain approaches. However, it is well known that one major difficulty of inverse scattering is its ill-posedness in nature [2].

During the imaging process, a huge amount of parameters has to be retrieved starting from a limited number of independent measurements. Thus, if neither *a-priori* information are available nor other physical constraints are imposed, there is the need to collect other information by means of suitable techniques be sides the use of effective retrieval techniques. One way for solving the nonlinear inverse problem is solving the forward scattering problem iteratively to minimize an error function known as the objective function. This function represents the error between the measured scattered fields and the simulated fields during the updates of the evolving objects in each inversion [3]-[10]. Recently, several papers for inverse scattering problems have been published on the subject of 2-D object about deal with shape reconstruction problems by using Gauss-Newton's method [3]. 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 [4]. 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) [5]-[8], differential evolution (DE) [9]-[10] and particle swarm optimization (PSO) [11] are proposed to search the global extreme of the inverse problems to overcome the drawback of the deterministic methods.

Recently, dynamic differential evolution (DDE) [9]-[10] is proposed to search the global extreme of the inverse problems to overcome the drawback of the deterministic methods. However, these methods present certain drawbacks usually related to the intensive computational effort they demand to achieve the global optimum and the possibility of premature convergence to a local optimum. Hence, it is seemingly natural to use evolutionary algorithms, not only for finding solutions to a problem but also for tuning these algorithms to the particular problem. Technically speaking, we are trying to modify the values of parameters during the run of the algorithm by taking the actual search progress into account. The proof of convergence of EAs with self-adaptation is difficult because control parameters are changed randomly and the selection does not affect their evolution directly [12].

Technically speaking, we are trying to modify the values of parameters during the run of the algorithm by taking the actual search progress into account. To the best of our knowledge, there is still no investigation about a-priori information using the DDE and SADDE to reconstruct the electromagnetic imaging of buried perfect conducting cylinder. If a-priori range setting greater, the robustness of the algorithm must be re-examined. In Section II, a theoretical formulation for the inverse scattering is presented.

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 are described in polar coordinates in xy plane by the equation $\rho = F(\theta)$. The cylinder is illuminated by a plane wave with time dependence $e^{j\omega t}$.

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

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

with

$$J(\theta) = -j\omega\mu_0\sqrt{F^2(\theta)+F'^2(\theta)}J_s(\theta)$$

$$G(x,y;x',y') = \begin{cases} G_1(x,y;x',y') & ,y \le -a \\ G_2(x,y;x',y') = G_f(x,y;x',y') + G_s(x,y;x',y'), & y > -a \end{cases} \tag{3}$$

Where

$$G_1(x,y;x',y') = \frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{\gamma_1+\gamma_2}e^{j\gamma_1(y+a)}e^{-j\gamma_2(y'+a)}e^{-j\alpha(x-x')}d\alpha \tag{3a}$$

$$G_f(x,y;x',y') = \frac{j}{4}H_0^{(2)}[k_2\sqrt{(x-x')^2+(y-y')^2}] \tag{3b}$$

$$G_s(x,y;x',y') = \frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{j}{2\gamma_2}\left(\frac{\gamma_2-\gamma_1}{\gamma_2+\gamma_1}\right)e^{-j\gamma_2(y+2a+y')}e^{-j\alpha(x-x')}d\alpha \tag{3c}$$

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

Here $J_s(\theta)$ is the induced surface current density which is proportional to the normal derivative of electric field on the conductor surface. $G(x,y;x',y')$ is the Green's function which can be obtained by Fourier transform. In (3b), $H_0^{(2)}$ is the Hankel function of the second kind of order zero.

The boundary condition on the surface of the scatterer states that the total tangential electric field must be zero and this yields an integral equation for $J(\theta)$:

$$E_2(x,y) = \int_0^{2\pi} G_2(F(\theta),\theta;F(\theta'),\theta')J(\theta')d\theta' \tag{4}$$

The total field E^{out} in region 1 is given by

$$E^{out}(r) = E_1(r) - \int_0^{2\pi} G_1(r;F(\theta'),\theta')J(\theta')d\theta' \quad (y \le -a) \tag{5}$$

The direct problem is to compute the total field in region 1 when the shape function $F(\theta)$ is given. This can be achieved by first solving for J from equation (4) and then calculating E^{out} by (5).

For numerical calculation of the direct problem, the contour is first divided into sufficient small segments so that the induced surface current can be considered constant over each segment. Then the moment method is used to solve equations (4) and (5) with pulse basis functions for expanding and the Dirac delta function for testing.

Let us consider the following inverse problem, determine by the shape $F(\theta)$ of the object giving the scattered electric field E_s measured outside the scatterer. Assume the approximate center of the scatterer, which in fact can be any point inside the scatterer, is known. Then the shape function $F(\theta)$ can be expanded as:

$$F(\theta) \cong \sum_{n=0}^{\frac{N}{2}} B_n\cos(n\theta) + \sum_{n=1}^{\frac{N}{2}} C_n\sin(n\theta) \tag{6}$$

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

III. INVERSE PROBLEM

For the inverse scattering problem, the shape of the PEC is reconstructed by the given scattered electric field measured at the receivers. This problem is resolved by an optimization approach, for which the global searching scheme DDE and SADDE are employed to minimize the following objective function (*OF*):

$$OF=\left\{\frac{1}{M_t}\sum_{m=1}^{M_t}\left|E_s^{\exp}(\bar{r}_m)-E_s^{cal}(\bar{r}_m)\right|^2/\left|E_s^{\exp}(\bar{r}_m)\right|^2\right\}^{1/2} \tag{7}$$

where M is the total number of measured points. $E_s^{\exp}(\bar{r}_m)$ and $E_s^{cal}(\bar{r}_m)$ are the measured scattered field and the calculated scattered field respectively.

IV. Dynamic Differential Evolution (DDE) and Self-Adaptive Dynamic Differential Evolution (SADDE)

DDE algorithm starts with an initial population of potential solutions that is composed by a group of randomly generated individuals which represents the center position and the geometrical radiuses 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 mutation operation of DDE algorithm is performed by arithmetical combination of individual. For each parameter vector x_i of the parent generation, a trial vector v_i is generated according to following equation:

$$(\mathrm{V}_j^{g+1})_i=(\mathrm{X}_j^g)_i+\mathrm{F}\cdot[(\mathrm{X}_{best}^g)_i-(\mathrm{X}_j^g)_i]+\lambda\cdot[(\mathrm{X}_{r1}^g)_i-(\mathrm{X}_{r2}^g)_i],$$
$$\mathrm{r1},\mathrm{r2}\in[0,\mathrm{N_p}-1]\ ,\ \mathrm{r1}\neq\mathrm{r2} \tag{8}$$

where F and λ are the scaling factors associated with the vector differences $(\mathrm{X}_{best}^g-\mathrm{X}_j^g)$ and $(\mathrm{X}_{r1}^g-\mathrm{X}_{r2}^g)$, respectively. The disturbance vector V due to the mutation mechanism consists of parameter vector X_j^g, the best particle X_{best}^g and two randomly selected vectors.

SADDE are based on DDE scheme. Each vector is extended with its own λ , F and *CR* values. Therefore the control parameters are self-adjusted in every generation for each individual according to the following scheme:

$$F_{i,G+1}=\begin{cases}F_l+rand_1*F_u, & if\quad rand_2<0.1\\ F_{i,G+1}, & otherwise\end{cases} \tag{9}$$

$$\lambda_{i,G+1}=\begin{cases}\lambda_l+rand_3*\lambda_u, & if\quad rand_4<0.1\\ \lambda_{i,G+1}, & otherwise\end{cases} \tag{10}$$

$$CR_{i,G+1}=\begin{cases}rand_5, & if\quad rand_6<0.1\\ CR_{i,G+1}, & otherwise\end{cases} \tag{11}$$

where *rand1*, *rand2*, *rand3*, *rand4, rand5* and *rand6* are uniform random numbers with thin values uniformly between 0 and 1. And F_l, F_u, λ_l and λ_u are the lower and the upper limits of F and λ, respectively .Both F_l and λ_l are set to 0.1 and both F_u and λ_u are set to 0.9 [23]. Based on the self-adaptive concept, the F , λ and CR parameters adjust automatically while the time complexity does not increase. More details about the SADE and SADDE algorithm can be found in [12]. It should be noted that the value of Fourier series used to describe the shape of the cylinder will be determined by the DDE and SADDE scheme.

V. NUMERICAL RESULT

Let us consider a perfectly conducting cylinder which is buried in a lossy homogeneous half-space, as shown in Fig 1. In order to simulate sandy soil environment, the permittivity in region 1 and region 2 is characterized by $\varepsilon_1=\varepsilon_0$ and $\varepsilon_2=2.7\varepsilon_0$, 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. The parameters and the corresponding searching ranges are listed follows: The operational coefficients are set as below: The crossover rate *CR* is set to be 0.8. Both parameters F and λ are set to be 0.8. The population size *Np* is set to be 110. In DDE and SADDE scheme, the search range for the unknown coefficient of the shape function is chosen to be from 0 to 1. The shape function is chosen to be $F(\theta)=0.03+0.01\cos(3\theta)$ m. The final reconstructed shape at the 2000th generation is compared to the exact shape by DDE and SADDE in Figure 2. Here DR, which is called shape function discrepancies. The DR value is about 0.1% in the final generation by SADDE scheme. It is seen that the reconstruction is good.

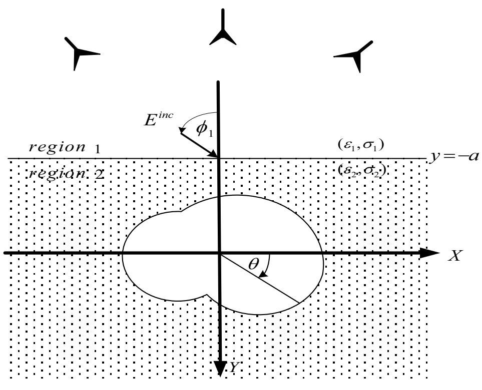

Fig. 1 Geometry of the problem in (x,y) plane.

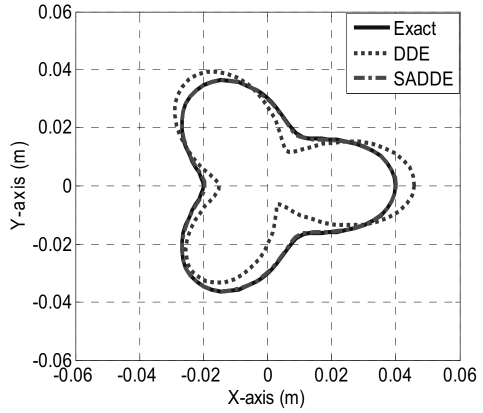

Fig. 2 The reconstructed shape of the cylinder for example

VI. Conclusions

The problem of shape reconstruction of metallic cylinder has been investigated.. The inverse problem is reformulated into an optimization one. Numerical results show that the SADDE has better reconstructed results compared with DDE when the same number of iterations is applied. With self-adaptive concept, a part of the solution has the opportunity to jump to the optimal solution; it can increase the optimization speed.

Self-adaptive concept has been introduced for DDE and implemented on inverse scattering problems. Numerical results show that SADDE can control parameter settings, is better than those without the self-adaptive setting. Since the self-adaptive method could be simply incorporated into DDE, it is suitable for inverse scattering problems.

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