Inverse Scattering for the Perfectly Conducting Cylinder by Asynchronous Particle Swarm Optimization

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***Abstract*—This paper reports a two-dimensional time-domain inverse scattering algorithm based upon the finite-difference time domain method for determining the shape of perfectly conducting cylinder. Finite difference time domain method (FDTD) is used to solve the scattering electromagnetic wave of a perfectly conducting cylinder. The inverse problem is resolved by an optimization approach and the global searching scheme asynchronous particle swarm optimization (APSO) is then employed to search the parameter space. By properly processing the scattered field, some EM properties can be reconstructed. One is the location of the conducting cylinder, the others is the shape of the perfectly conducting cylinder. Numerical result indicates that the APSO outperforms the PSO in terms of reconstruction accuracy and convergence speed.**

Keywords-Inverse Scattering, FDTD, Subgridding Finite Difference asynchronous particle swarm optimization (APSO).

I. INTRODUCTION

Numerical inverse scattering studies found in the literature are based on either frequency or time domain approaches. With frequency domain algorithms, the interaction of the entire medium with the incident field is considered simultaneously [1]. Time domain approaches can exploit causality to limit the region of inversion, potentially reducing the number of unknowns. The scatterer reconstruction belongs to the general category of limited angle microwave imaging problems. These problems are both nonlinear and ill-posed [2].

In general, the nonlinearity of the problem is coped with by applying iterative optimization techniques [3]. These algorithms based on stochastic strategies, offer advantages relative to local inversion algorithms including strong search ability simplicity, robustness, and insensitivity to ill-posedness. Compared with genetic algorithm (GA), particle swarm optimization (PSO) is much easier to implement and converge faster. Concerning the shape reconstruction of conducting scatterers, the PSO has been investigated whereas the PSO has been utilized in the reconstruction of dielectric scatterers [4]. In this case, the reported results indicate that the PSO is reliable tools for inverse scattering applications. Moreover, it has been shown that both differential evolution (DE) and PSO outperform real-coded GA in terms of convergence speed [5]. In recent decade years, some papers have compared different algorithm in inverse scattering [6]-[7]. However, to our knowledge, a comparative study about the performances of particle swarm optimization (PSO) and asynchronous particle swarm optimization (APSO) when applied to inverse scattering problems has not yet been investigated.

The present work focuses on comparing these two methods for inverse scattering problems under time domain. The forward problem is solved by the FDTD method, for which the subgridding technique [8] is implemented to closely describe the fine structure of the cylinder. The inverse problem is formulated into an optimization one, and then the global searching PSO and APSO are used to search the parameter space. Cubic spline interpolation technique [9] is employed to reduce the number of parameters needed to closely describe a cylinder of arbitrary shape as compared to the Fourier series expansion. In section II, the subgridding FDTD method for the forward scattering are presented. In section III and IV, inverse problem and the numerical results of the proposed inverse problem are given, respectively. Finally, in V section some conclusions are drawn for the proposed time domain inverse scattering.

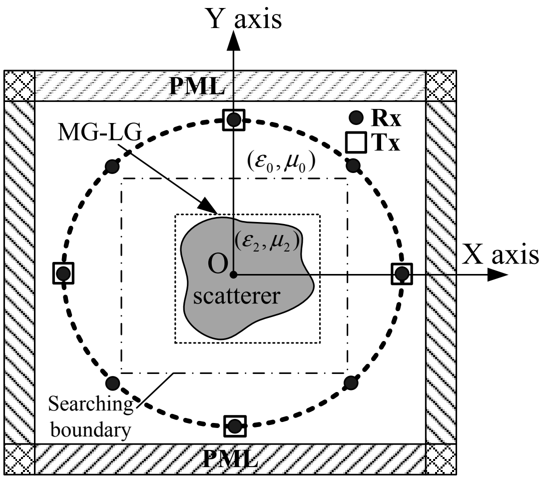
II. FORWARD PROBLEM

Let us consider a two-dimensional metallic cylinder in a free space as shown in Figure 1, the cylinder is parallel to z axis, while the cross-section of the cylinder is arbitrary. The object is illuminated by Gaussian pulse line source located at the points denoted by Tx and reflected waves are recorded at those points denoted by Rx. The computational domain is discretized by Yee cells. It should be mentioned that the computational domain is surrounded by the optimized perfect matching layers (PML) absorber [10] to reduce the reflection from the environment-PML interface.

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

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

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



III. NUMERICAL RESULTS

As shown in Figure 1, the problem space is divided in 68×68 grids with the grid size $\Delta x=\Delta y$ =5.95 mm. The metallic cylinder is located in free space. The cylindrical object is illuminated by a transmitter at four different positions, N_i=4. The scattered E fields for each illumination are collected at the eight receivers, *M*=8. Note that the simulated result using one incident wave is much worse than that by two incident waves. In order to get accurate result, four transmitters are used here. The transmitters and receivers are collocated at a distance of 24 grids from the origin. The incident current pulse $I_z(t)$ is expressed as:

$$I_z(t)=\begin{cases}Ae^{-\alpha(t-\beta\Delta t)^2} & ,t\le T_w\\ 0 & ,t>T_w\end{cases} \qquad (2)$$

where $\beta=24$, $A=1000$, $\Delta t=13.337\,ps$,

$T_w=2\beta\Delta t$, and $\alpha=\left(\frac{1}{4\beta\Delta t}\right)^2$.

The time duration is set to 250 Δt ($T=250$).

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

$$OF=\frac{\sum_{n=1}^{N_i}\sum_{m=1}^{M}\sum_{b=0}^{B}\left|E_z^{exp}(n,m,b\Delta t)-E_z^{cal}(n,m,b\Delta t)\right|}{\sum_{n=1}^{N_i}\sum_{m=1}^{M}\sum_{b=0}^{B}\left|E_z^{exp}(n,m,b\Delta t)\right|} \qquad (3)$$

Where E_z^{exp} and E_z^{cal} are experimental electric fields and the calculated electric fields, respectively. The N_i and *M* are the total number of the transmitters and receivers, respectively. *B* is the total time step number of the recorded electric fields.

Note that in order to accurately describe the shape of the cylinder, the subgridding FDTD technique is used both in the forward scattering (1:9) and the inverse scattering (1:5) parts – but with different scaling ratios as indicated in the parentheses. For the forward scattering, the E fields generated by the FDTD with fine subgrids are used to mimic the experimental data in (3).

For the example, the metallic cylinder with shape function $F(\theta)=29.75-5.95\cos(3\theta)$ mm is considered. The final reconstructed shapes by PSO and APSO at the 600th generation are compared to the exact shape in Figure 2. The discrepancy of shape Function (DF) of the reconstructed shape $F^{cal}(\theta)$ with respect to the exact values versus generations is shown in Figure 3. It is shown that the APSO scheme is able to achieve good convergences within 50 generations. Here, DF is defined as

$$DF=\{\frac{1}{N'}\sum_{i=1}^{N'}[F^{cal}(\theta_i)-F(\theta_i)]^2/F^2(\theta_i)\}^{1/2} \qquad (4)$$

where the N' is set to 720. The r.m.s. error DF for PSO and APSO are about 11.8% and 2.89% in the final generation, respectively.

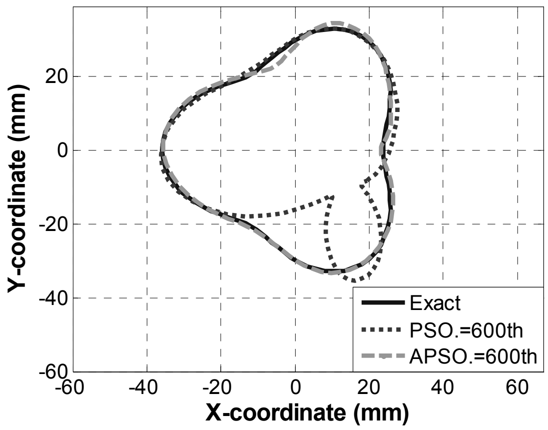


Figure 2. The reconstructed shapes of the cylinder for example 1 by PSO and APSO, respectively.

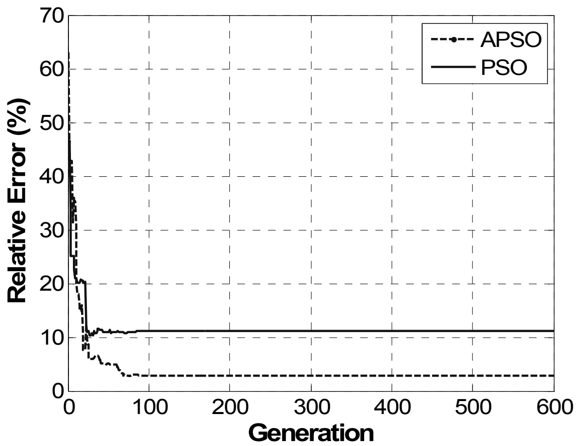


Figure 3. Shape function error versus generation for example 1 by PSO and APSO, respectively.

From the reconstructed results this object, we conclude the APSO scheme can be used to reconstruct metallic cylinder.

IV. CONCLUSION

In this paper, we study the time domain inverse scattering of an arbitrary cross section metallic cylinder in free space. By combining the FDTD method and the APSO, good reconstructed result is obtained. The key differences between PSO and APSO are about the convergence speed, the computation time and the accuracy, since APSO includes "damping boundary condition" scheme and mutation scheme. In order to describe the shape of the scatterer more effectively, cubic spline interpolation technique is utilized. The inverse problem is reformulated into an optimization one, and then the global searching scheme APSO is employed to search the parameter space. By using the APSO, the shape of the object can be successfully reconstructed. In our study, even when the initial guess is far from the exact one, the APSO can still yield a good solution for the properties of the object.

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