Microwave Imaging of Buried 2D Homogeneous Dielectric Cylinder Using Dynamic Differential Evolution

Wei Chien, Chien-Ching Chiu, Chung-Hsin Huang and Yu-Sheng Fan

Abstract—This paper presents the studies of time domain inverse scattering for a two dimensional homogeneous dielectric cylinder buried in a half-space which based on the finite difference time domain (FDTD) method and the dynamic differential evolution (DDE). For the forward scattering, the FDTD method is employed to calculate the scattered E fields, while for the inverse scattering the DDE scheme are utilized to determine the shape, location and the permittivity of the buried cylindrical scatterer with arbitrary cross section. The subgirdding technique is implemented for the FDTD code in order to model the shape of the cylinder more smoothly. In additions, in order to describe an unknown cylinder with arbitrary cross section more effectively during the course of searching, the closed cubic-spline expansion is adopted to represent the scatterer contour instead of the frequently used trigonometric series. Numerical results demonstrate that, even when the initial guess is far away from the exact one, good reconstruction can be obtained. In addition, the effects of Gaussian noise on the reconstruction results are investigated. Numerical results show that even the measured scattered fields are contaminated with Gaussian noise, DDE is able to yield good reconstructed quality.

***Index Terms*— Time domain inverse scattering, FDTD, subgridding technique, dynamic differential evolution, homogenous dielectric cylinder.**

I. INTRODUCTION

The objective of the inverse scattering is to determine the electromagnetic properties of the scatterer from scattering field measured outside. Inverse scattering problems have attracted much attention in the past few years. This kind of problem has several important applications such as medical imaging, microwave remote sensing, geophysical exploration, and nondestructive testing. Traditional iterative inverse algorithms are founded on a functional minimization via some gradient-type scheme [1]. In general, during the search of the global minimum, they tend to get trapped in local minima when the initial guess is far from the exact one. Some global optimal searching methods such as genetic algorithm [2], particle swarm optimization (PSO) [3], have been proposed to search the global extreme of the nonlinear functional problem. In the 2006, the dynamic differential evolution (DDE) was first proposed to deal with the shape reconstruction of conducting cylinder [4].

In this paper, the computational methods combining the FDTD method and the DDE algorithm are presented. The forward problem is solved by the FDTD method, for which the subgridding technique [5] 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 scheme DDE is used to search the parameter space. Cubic spline interpolation technique [6] is employed to reduce the number of parameters needed to closely describe a cylinder of arbitrary shape as compared to the Fourier series expansion.

Manuscript received November 19, 2009; revised December 31, 2009. This work was supported by the National Science Council, Republic of China, under Grant NSC-98-2221-E-237-001.

Wei Chien is with Electronic Engineering Department, De Lin Institute of Technology Tu-Cheng, Taipei, R.O.C. (e-mail: air180@seed.net.tw).

Chien-Ching Chiu, Chung-Hsin Huang and Yu-Sheng Fan are with the Electrical Engineering Department, Tamkang University, Tamsui, Taiwan, R.O.C. (e-mail: chiu@ee.tku.edu.tw).

II. SUBGRID FDTD

Consider a 2-D homogeneous dielectric cylinder in a half space as shown in Figure 1. The cylinder is assumed infinite long in z direction, while the cross-section shape is arbitrary in this study. The object is illuminated by line source with Gaussian pulse located at these points denoted by Tx around the scatterer. The incident waves of TM_z polarization are generated by a home made FDTD code with fine grid to mimic the experimental data, and only reflected waves are recorded at those points denoted by Rx. In order to closely describe the shape of the cylinder for the forward scattering procedure the subgridding technique is implemented in the FDTD code, the details are presented next.

The FDTD method solves an EM problem using the Maxwell's curl equations directly in time domain, which can be discretized to yield the following update equations of the E field for TM_z case

$$E_z^{n+1/2}\left(i+\frac{1}{2},\, j+\frac{1}{2}\right) = EA(m)\bullet E_z^{n-1/2}\left(i+\frac{1}{2},\, j+\frac{1}{2}\right) + EB(m)\bullet\left[\frac{H_y^n(i+1,j)-H_y^n(i,j)}{\Delta x} - \frac{H_x^n(i,j+1)-H_x^n(i,j)}{\Delta y}\right] \qquad (1)$$

with $EA(m)=\dfrac{1-\dfrac{\sigma(m)\Delta t}{2\varepsilon(m)}}{1+\dfrac{\sigma(m)\Delta t}{2\varepsilon(m)}}$, $EB(m)=\dfrac{\dfrac{\Delta t}{\varepsilon(m)}}{1+\dfrac{\sigma(m)\Delta t}{2\varepsilon(m)}}$

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

where $E_z^{n+\frac{1}{2}}(i+\frac{1}{2},j+\frac{1}{2})$ is defined by using the Yee-cell geometry as shown in Figure 2. The expressions of the H field H_x^{n+1} and H_y^{n+1} are not given here for brevity. The boundary of the test domain is surrounded by the optimized perfect matching layer in this study [7].

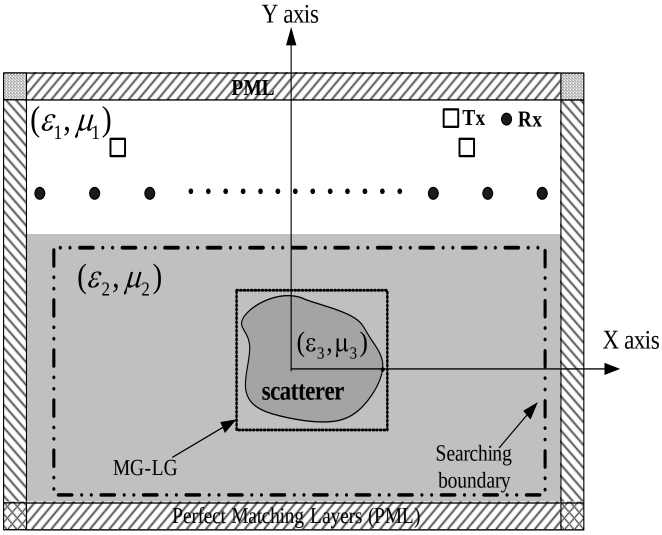

Fig. 1 Geometry for the inverse scattering of a arbitrary shape dielectric cylinder in half space.

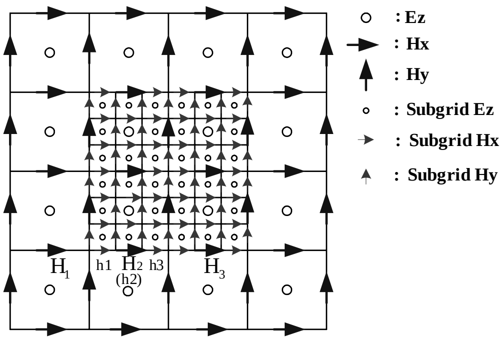

Fig. 2 The structure of the TM$_z$ FDTD major grids and local grids for the scaling ratio (1:3), H fields are aligned with the MG-LG boundary.

A subgridding scheme is employed to divide the problem space into regions with different grid sizes. The grid size in coarse region is about $(\frac{1}{20}\sim\frac{1}{10}\lambda_{\max})$ as in normal FDTD, while in the fine region the grid size is scaled by an integer ratio. As an example, the Yee cells with subgridding structure are shown in Figure 2, of which the scaling ratio is 1:3. For the time domain scattering and/or inverse scattering problem, the scatterers can be assigned with the fine region such that the fine structure can be easily described. This can also avoid gridding the whole problem space using the finest resolution such that the computational resources are utilized in a more efficient way, which is quite important for the computational intensive inverse scattering problems.

In Figure 2, E and H stand for the fields on the major grids, while e and h denote those on the local grids. If the scaling ratio is set at 1:3, 1:5 and 1:7, etc, then the E and H fields coincide with e and h fields in the fine region and in the time domain as shown in Figure 2. Since the local grid size is one third of the main grid size, the time stepping interval $\Delta t'$ for the e and h fields on the local grids is also one third of that for the E and H fields on the main grids.

III. NUMERICAL RESULTS

As shown in Figure 1, the problem space is divided in 68×68 grid cells with grid size $\Delta x=\Delta y$ =5.95mm. The homogeneous dielectric cylinder is located in free space and illuminated by transmitters at four different positions (N_i=4). The scattered E fields for each illumination are collected by eight receivers (M=8) that are uniformly distributed along a circle. The transmitters and receivers are collocated at a distance of 24 grids from the origin. The excitation waveform $I_z(t)$ of the transmitter is the Gaussian pulse, given by:

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

where $\beta=32$, $A=1000$, $\Delta t=13.337\,ps$, $T_w=2\beta\Delta t$, and $\alpha=\left(\frac{1}{4\beta\Delta t}\right)^2$.The time duration is set to 300 Δt ($K=300$). For the inverse scattering problem, the shape, location and permittivity of the dielectric cylinder are reconstructed through the given scattered electric fields obtained at the receivers. This problem is formulated into an optimization approach, for which the global searching scheme DDE is employed to minimize the following objective function (OF):

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

where $E_z^{\exp}$ and E_z^{cal} are the experimental electric fields and calculated electric fields, respectively. The N_i and M are the total number of the transmitters and receivers, respectively. K is the total time step number of the recorded electric fields. The r.m.s. error (DF) of the reconstructed shape $F^{cal}(\theta)$ and the relative error (DIPE) of ε_r^{cal} with respect to the exact values versus generation. Here, DF and DIPE are defined as

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

$$DIPE=\frac{\left|\varepsilon_r^{cal}-\varepsilon_r\right|}{\varepsilon_r} \tag{5}$$

where the N' is set to 720.

Consider a 2-D homogeneous dielectric cylinder in a half space as shown in Figure 1. The cylinder is assumed infinite long in z direction, while the cross-section of the cylinder is arbitrary. For he example, a simple circular cylinder is tested, of which the shape function $F(\theta)$ is chosen to be $\mathrm{F}(\theta)=29.7+5.95\cos(3\theta)$ mm, and the relative permittivity of the object is $\varepsilon_r=8.2$. The reconstructed images at different generations and the relative error of the final example are shown in Fig. 3 and Fig 4, respectively. As shown in Figure 4,

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

the r.m.s. error DF is about 1.7% and DIPE=0.67% in final generation. It is seen that the reconstruction is good.

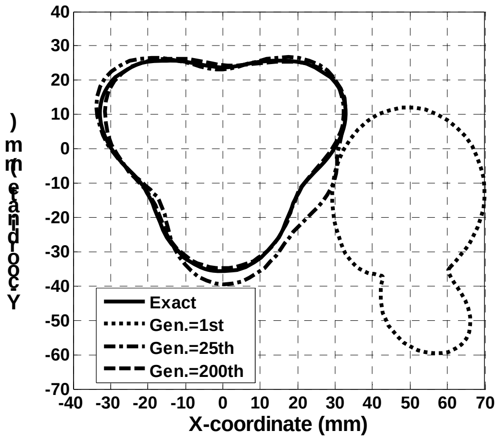

Fig. 3 Reconstructed cross section of the cylinder at different generations.

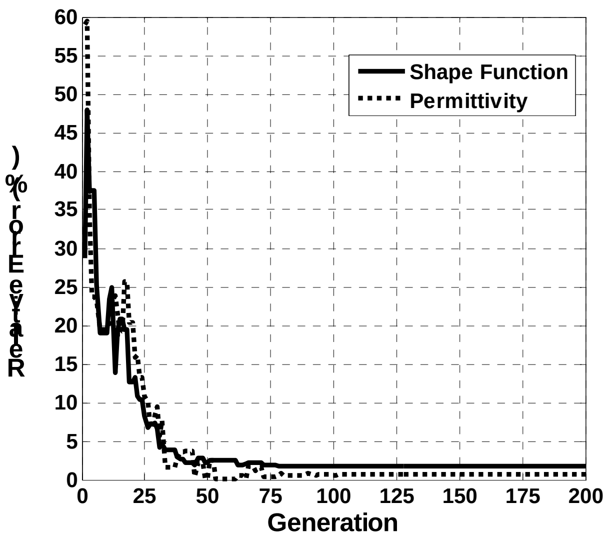

Fig. 4 Shape-function error and permittivity error versus generations for example.

IV. CONCLUSION

We present a study of the time domain inverse scattering of homogeneous dielectric cylinders of arbitrary cross section in half space. By combining the FDTD method and the DDE scheme, good reconstructed results are obtained. The subgridding scheme is employed to closely describe the shape of the cylinder for the FDTD method. The forward problem is solved by using the subgridding FDTD method and the shape function of the cylinder is expressed in terms of Fourier series expansion. The inverse problem is reformulated into an optimization one, and then the global searching scheme DDE is employed to search the parameter space. Interpolation technique through cubic spline is utilized to reduce the number of parameters needed to describe an arbitrary shape for the inverse scattering problem. Through the DDE scheme, the shape, location and dielectric constant of the object can be successfully reconstructed even when the dielectric constant is fairly large. This study shows that even when the initial guess is far from the exact one, the DDE can still yield a good solution for the properties of the object, while the gradient-based methods often get stuck in a local extreme. The effects of noise upon the microwave imaging are examined, and good reconstruction has been obtained even in the presence of white Gaussian noise in experimental data.

ACKNOWLEDGMENT

This work was supported by National Science Council, Republic of China, under Grant NSC-98-2221-E-237-001.

REFERENCES

[1] C. C. Chiu and Y. W. Kiang, “Microwave imaging of multiple conducting cylinders,” *IEEE Trans. Antennas Prop*. 40, 933-941 (1992).

[2] S. Caorsi, A. Massa, and M. Pastorino, “A computational technique based on a real-coded genetic algorithm for microwave imaging purposes,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 38, No. 4, pp. 1697-1708, July 2000.

[3] M. Donelli and A. Massa, “Computational approach based on a particle swarm optimizer for microwave imaging of two-dimensional dielectric scatterers,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, No. 5, pp. 1761 - 1776, May. 2005

[4] A. Qing, Dynamic differential evolution strategy and applications in electromagnetic inverse scattering problems, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 44, no. 1, pp. 116-125, 2006.

[5] M. W. Chevalier, R. J.Luebbers and V. P. Cable, “FDTD local grid with materical traverse,” IEEE Trans. Antennas and Propagation, vol. 45, No. 3, March 1997.

[6] C. de Boor, “*A Practical Guide to Splines*,” Springer-Verlag, New York, 1978.

[7] C. L. Li, C. W. Liu and S. H. Chen, “Optimization of a PML absorber's conductivity profile using FDTD,” *Microwave and Optical Technology Letters*, Vol. 37 No. 5, pp. 69-73 , Jun. 2003

ISBN: 978-988-18210-4-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)