GENETIC ALGORITHM FOR THE RECONSTRUCTION OF A LARGE AND HIGH-CONTRAST PENETRABLE OBJECT IN MULTI-FREQUENCY ANGULAR SPECTRAL DOMAIN

Sang-Yong YANG and Jung-Woong RA
Department of Electrical Engineering
Korea Advanced Institute of Science and Technology
373-1, Kusong-dong, Yusong-gu, Taejon, 305-701, Korea
Phone +82-42-869-8014 Fax +82-42-869-3410 email : ysy@mwlab3.kaist.ac.kr

Abstract

A large and high-contrast penetrable object is reconstructed by using the effective propagating modes in the angular spectral domain with the multi-incidence of multi-frequency sources and the genetic algorithm to find the global minimum of the cost function iteratively. For the object of the $3\lambda \times 3\lambda$ size with its relative dielectric constant of ε_r=4.0, where λ is the free space wavelength, a large cell discretization upto $0.5\lambda/\sqrt{\varepsilon_r} \times 0.5\lambda/\sqrt{\varepsilon_r}$ is employed to cope with the limited capability of the computer. In this inverse calculation, 10% gaussian noise is assumed in the measured scattered field.

1. Introduction

Although the moment method inversion[1] gives the reconstruction of a high-contrast object, it suffers from the ill-posedness when the noise is present in the scattered field and applies to the rather small size objects smaller than its diameter of $0.22\lambda/\varepsilon_r$ since the cell discretization in the moment method requires smaller one than $0.2\lambda/\sqrt{\varepsilon_r} \times 0.2\lambda/\sqrt{\varepsilon_r}$ [2]. For the reconstruction of a larger object, an iterative steepest descent algorithm is employed to minimize the cost function[3], where the cost function is defined as the summation of squared magnitude of the difference between the measured scattered fields and the scattered fields calculated from the assumed dielectric profile. Born iterative method[4] reconstructs two cylinders with its relative dielectric constant up to ε_r=2.0 in $6\lambda_{min} \times 6\lambda_{min}$ space domain by using the FDTD in the time domain for the calculation of the forward scattering field, where λ_{min} is the free space wavelength corresponding to the highest frequency component of the incident pulse.

For a high-contrast large object, the iterative minimization of the cost function by using the stochastic algorithms such as simulated annealing[5, 6] and genetic[7] algorithms may be used to reach the global minimum of the cost function. Because of the limited computation capability of the computer in the case of cell discretization within its size of $0.2\lambda/\sqrt{\varepsilon_r} \times 0.2\lambda/\sqrt{\varepsilon_r}$, the maximum size of the object is limited to $1.25\lambda \times 1.25\lambda$ [6].

It is shown here that the discretization of the object into the cells of $0.5\lambda/\sqrt{\varepsilon_r} \times 0.5\lambda/\sqrt{\varepsilon_r}$

for the moment method calculating the forward scattered fields is tolerable for the iterative search of the global minimum of the cost function. This enables the reconstruction of larger object since the conventional discretization of the object is $0.2\lambda/\sqrt{\varepsilon_r}\times 0.2\lambda/\sqrt{\varepsilon_r}$ and it requires much more computing time.

2. Formulation

When a TM wave u^i is incident upon a square dielectric cylinder, the scattered field u^s may be written as

$$u^s(\rho,\phi)=k_0^2\int\int_S d\rho' d\phi' \rho'[\varepsilon_r(\rho',\phi')-1]u(\rho',\phi')G(\rho,\rho') \tag{1}$$

where k_0 is the free space wave number, u is the total field inside the dielectric cylinder S, and G is the two-dimensional free space Green's function given as

$$G(\rho,\rho')=-\frac{j}{4}\sum_{m=-\infty}^{\infty}J_m(k_0\rho')H_m^{(2)}(k_0\rho)e^{jm(\phi-\phi')},\quad \rho'<\rho, \tag{2}$$

for $e^{j\omega t}$ dependence. Here J_m and $H_m^{(2)}$ are the mth order Bessel and second kind Hankel function and ω is the angular frequency.

The application of moment method converts eq.(1) into the following algebraic equation,

$$u^s(\rho,\phi)=\sum_{m=-\infty}^{\infty}H_m^{(2)}(k_0\rho)e^{jm\phi}\sum_{n=1}^{N}A_{mn}(\rho_n,\phi_n)(\varepsilon_n-1)u_n \tag{3}$$

where

$$A_{nm}(\rho_n,\phi_n)=-\frac{j\pi k_0 a}{2}J_1(k_0a)J_m(k_0\rho_n)e^{-jm\phi_n}, \tag{4}$$

$(\rho_n,\ \phi_n)$ is the center of the nth cell, and a is the radius of the equivalent circular cell having the same area of the original rectangular cell. One may obtain the mth order angular spectrum coefficient of the scattered fields u^s in eq.(3) as

$$U^s(\rho;m)=\sum_{n=1}^{N}A_{mn}(\rho_n,\phi_n)(\varepsilon_n-1)u_nH_m^{(2)}(k_0\rho). \tag{5}$$

One may define the cost function f with the parameters of the M propagating modes, the I incident angles, and L frequencies as

$$f=\frac{1}{2}\sum_{l=1}^{L}\sum_{i=1}^{I}\sum_{m=1}^{M}|F_{mil}^k|^2 \tag{6}$$

where the kth iterative error function is given by

$$F_{mil}^k=U_M^s(\rho,\varepsilon_n;f_l,\theta_i,m)-U_C^s(\rho,\varepsilon_n^k;f_l,\theta_i,m). \tag{7}$$

Here U_M^s and U_C^s, respectively, the measured and the calculated angular spectrum for the distribution of the target and the assumed dielectric constants, ε_n and ε_n^k.

A hybrid algorithm combining the genetic algorithm(GA)[8] and the Levenberg-Marquardt algorithm(LMA) is used to minimize the cost function in eq.(6) until to find the global minimum of the cost function iteratively, which yields the true distribution of ε_n. Fig. 1 shows this hybrid algorithm, where LMA may find one of the local minima of the cost function which is guided further by GA to reach the global minimum.

3. Numerical Results and Conclusions

Fig. 2 shows the cost functions versus the four different sizes of the discretized cells, (a) $0.155\lambda/\sqrt{\varepsilon_r}$, (b) $0.4\lambda/\sqrt{\varepsilon_r}$, and (c) $0.466\lambda/\sqrt{\varepsilon_r}$, and (d) $0.56\lambda/\sqrt{\varepsilon_r}$, where $\varepsilon_r=5$. Although the values of the global minima of the four different cost functions are different, their valley regions are closely located except the case of its cell size, $0.56\lambda/\sqrt{\varepsilon_r}$, various numerical examples show that these global minima are located in the error bound of 10% of the global minimum of (a) $0.155\lambda/\sqrt{\varepsilon_r}$.

A homogeneous square dielectric cylinder of its size $3\lambda\times3\lambda$ and its $\varepsilon_r=4$ is reconstructed from the angular spectral formulation in eq.(6) by using the hybrid algorithm of LMA and GA and the large cell discretization of $0.5\lambda/\sqrt{\varepsilon_r}$, as shown in Fig. 3, when 10% gaussian noise in the scattered field is assumed. For the discretization size of $0.5\lambda/\sqrt{\varepsilon_r}$, the total unknowns become $(3\lambda/0.25\lambda)^2=144$ and the reconstruction shown in Fig. 3 is obtained by taking 23 propagating modes for the scattered field for 4 different incidences of the plane wave with 3 different frequencies which gives total of 276 data points. The root mean square error of the reconstruction is calculated as 8.46% which is smaller than the error involved in the scattered field. By taking large cell division than $0.5\lambda/\sqrt{\varepsilon_r}$, one may show numerically that the reconstruction diverges.

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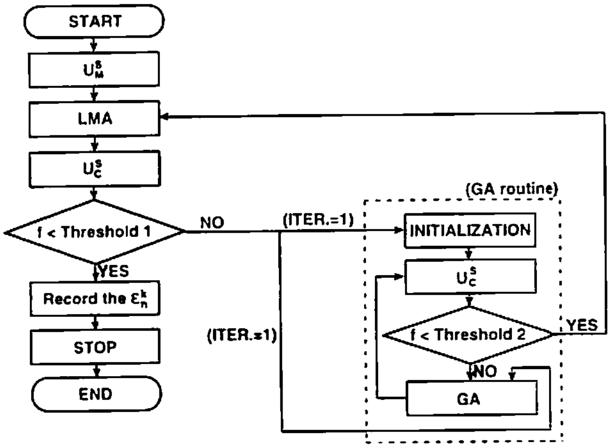

Fig. 1 Hybrid algorithm combining Levenberg-Marquardt algorithm(LMA) and genetic algorithm(GA)

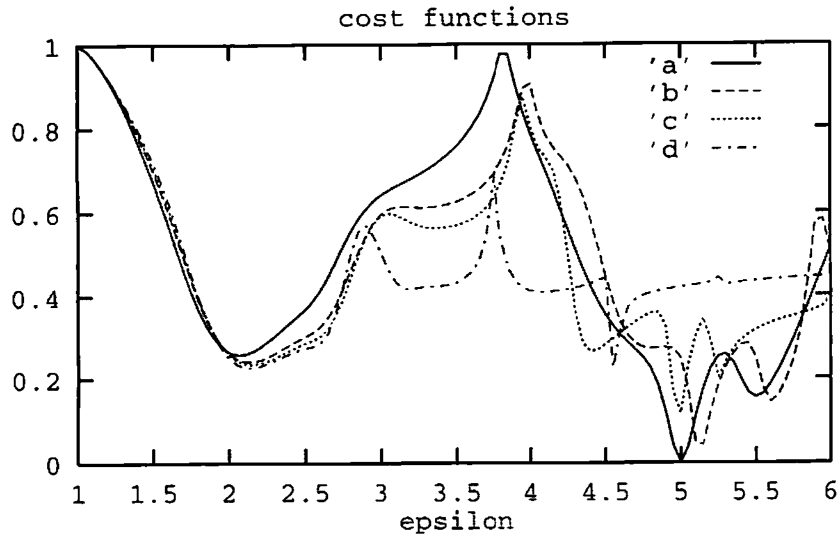

Fig. 2 Cost functions with different sizes of cell division; 'a' 0.155 $\lambda/\sqrt{\varepsilon_r}$, 'b' 0.4 $\lambda/\sqrt{\varepsilon_r}$, 'c' 0.466 $\lambda/\sqrt{\varepsilon_r}$, and 'd' 0.56 $\lambda/\sqrt{\varepsilon_r}$

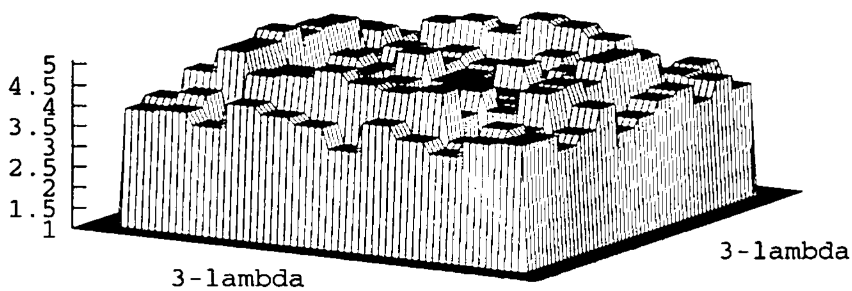

Fig. 3 Reconstructed profile of $3\lambda\times 3\lambda$ object for the discretization size of $0.5\lambda/\sqrt{\varepsilon_r}$ with ε_r=4