손실 반공간에 묻힌 2차원 원통형 파이프의 검출 및 식별

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Iterative Reconstruction of Multiple Cylinders Buried in the Lossy Half Space

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Abstract

Several dielectric as well as conducting cylinders buried in the lossy half space are reconstructed from the scattered fields measured along the interface between the air and the lossy ground. Iterative inversion method by using the hybrid optimization algorithm combining the genetic and the Levenberg-Marquardt algorithm enables us to find the positions, the sizes, and the medium parameters such as the permittivities and the conductivities of the buried cylinders as well as those of the background lossy half space. Illposedness of the inversion caused by the errors in the measured scattered fields are regularized by filtering the evanescent modes of the scattered fields out.

I. Introduction

The detection and identification of various cylindrical pipes buried in the lossy half earth is important for the application of the ground penetration radar. The shape of a conducting cylinder[1] buried in the lossy half space and the shape and the dielectric constant of the dielectric cylinder[2] are recovered by using Newton-Kantrovitch algorithm, where either conductor or dielectric object is assumed apriori, their size is smaller than the wavelength with its dielectric costant low and the expansion of shape function for the object is used. The shape and the distribution of permittivities and conductivities of a two-dimensional scatterer are reconstructed[3] by using the iterative inversion method with the bybrid optimization algorithm combining either the genetic(GA) or the simulated anealing(SA) algorithm and the Levenberg-Marquardt(LM) algorirhm without any apriori assumption. Multiparameter optimization of the above iterative inversion method gives not only the reconstruction of the size and the medium parameters of the scatterer, the air tunnel, but also the positions of the target and the source and receiver, and the medium parameters of the background medium, the granite rock[4].

In order to apply to more practical problems like to reconstruct several pipes of conductors and dielectrics buried in the ground, it is shown here that two pipes, one conducting and the other dielectric, in the lossy half space from the scattered fields along the air-ground interface are successfully reconstructed by this multi-parameter optimization method and give 12 physical parameters such as the center position of the pipes, the diameters of the pipes, the dielectric constants and conductivities of the pipe materials and the background medium properties. For the iterative inversion, the numerical calculations by using boundary element method calculates the scattered fields.

II. Formulation

Two two-dimensional cylindrical objects are buried in the lossy half ground in the depth of 0.5 λ, where λ is defined as $\lambda_0/\sqrt{\varepsilon_b}$ and λ_0 is the free space wavelength., departed by x_d as shown in Fig. 1. A continuous wave line source is in the air region just above the ground interface and the receiving antenna is parallel to the line source and separated by 0.5λ along the interface. With the analytic integral expressions, one may set up integral equation in the boundaries of two cylinders and the boundary element method satisfying the boundary conditions of continuity of fields and their normal derivatives calculated the boundary fields numerically and the scattered fields at the receiving antenna are obtained as

$$u_s(x,y) = -\int_{\Gamma_1+\Gamma_2}\left\{G(x,y;x',y')\frac{\partial u(x',y')}{\partial n} - u(x',y')\frac{\partial G(x,y;x',y')}{\partial n}\right\}dl \quad (1)$$

where u and $\partial u/\partial n$ are electric fields in the boundaries obtained μ_0 and ε_0 are the permeability and the permittivity of the free space, respectively, and G is the two dimensional half space Green's function having air-ground interface. Γ_1, Γ_2 are the surface boundaries of the pipes. The half space green function of air medium and ground medium is given by

By taking the discrete Fourier transformation $U_s^M(k)$of $u_s(x,y)$along x as

$$U_s^M(k) = \sum u_s(x_m)\,e^{jkx_m} \quad (3)$$

and take it for the measured spatial frequency spectrum of the scattered field.

One may define the cost functional f as the squared magnitude of the difference between spatial spectrum of the measured and calculated field from the assumed unknown parameters as

$$f_k = \frac{1}{2}\sum_{l=1}^{L}\sum_{m=1}^{M}\left|U_s^M(k_m,f_l) - U_s^C(k_m,f_l,p^k)\right|^2 \quad (4)$$

where f_l and k_m are the l-th frequency and m-th wave number, respectively, for the kth distribution of parameters p^k. L and M are the total number of the used frequencies and the sampled spectral components, respectively. U_s^M and U_s^C are the measured and calculated spectral coefficients of the fields, respectively. One then minimize this cost functional iteratively by updating the unknown parameters ε_k until the original parameters are found by using the hybrid algorithm combining the LMA and GA. When the LMA finds one of the local minima of the cost function, the LMA switches to GA to find the lower values of the cost functional. Then it switches to LMA again to find the nearest local minima in the same valley, and it repeats until it finds the global minimum of the cost functional.

III. Numerical Results and Conclusion

The transmitting and receiving antennas separated by 0.5λ moves along the interfaces, 0.05λ above the ground interface. One may assume two targets as homogeneous circular cylindrical objects. They are buried in the depth of 0.5λ and the radii of the

$$G(\rho,\rho') =$$

$$\frac{1}{2\pi}\int_{-\infty}^{\infty}dk_x\frac{e^{-jk_x(x-x')}}{2j\sqrt{k_2^2-k_x^2}}\left[e^{-j\sqrt{k_2^2-k_x^2}|y-y'|} + \frac{\sqrt{k_2^2-k_x^2}-\sqrt{k_0^2-k_x^2}}{\sqrt{k_2^2-k_x^2}+\sqrt{k_0^2-k_x^2}}e^{-j\sqrt{k_2^2-k_x^2}(y+y')}\right],\quad y'\le 0,\ y\le 0, \quad (2a)$$

$$\frac{1}{2\pi}\int_{-\infty}^{\infty}dk_x\frac{e^{-jk_x(x-x')}}{j\sqrt{k_2^2-k_x^2}+\sqrt{k_0^2-k_x^2}}e^{j\sqrt{k_2^2-k_x^2}y'}e^{-j\sqrt{k_0^2-k_x^2}y},\quad y'\le 0,\ y\ge 0, \quad (2b)$$

targets are 0.5λ. The relative dielectric constant and conductivity of a dielectric target is 80.0 and 0.1[S/m]. The background medium is assumed homogeneous and to have the relative dielectric constant of 6.0 and the conductivity of 0.001[S/m]. By taking the measurement step of 0.1λ to the total measurement length of 6λ, one may obtain the total bandwidth of 10 $k_0\sqrt{\varepsilon_b}$ and its interval $\Delta k=0.2\, k_0\sqrt{\varepsilon_b}$ from the Nyqust sampling theorem. By filtering out the evanescent modes and keeping the propagating modes for which $|k_m|<2\, k_0\sqrt{\varepsilon_b}$, one may use 25 propagating modes for use of single frequency, 60MHz. The spatial frequency spectrum is shown in Fig. 2

12 physical parameters recovered from this multiparameter inversion are the centers(4), the radii(2), the relative dielectric constants(2) and the conductivities(2) of two cylindrical objects and the relative dielectric constant(1) and the conductivity(1) of the background medium. A priori given parameters for this reconstruction are positions of measuring antennas, homogeneity of the lossy half space and the targets, the circular cross sections, and the number of the targets.

Table 1 shows the reconstructed results of a dielectric and a conducting cylinder separated by x_d=1.0λ when the measurement error(noise) in the scattered field is assumed to be 0% and 10%, respectively. Table 2 shows the reconstructed results when x_d=0.5λ. The targets are reconstructed successfully both target distances, 1.0λ and 0.5λ. The root mean square error is below 10% for all results.

References

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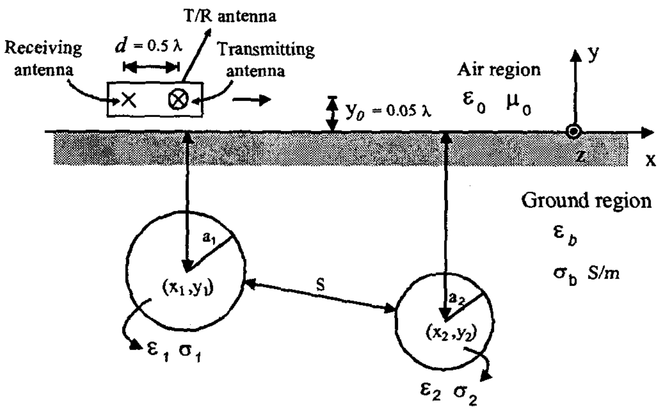

Fig. 1 Geometry of the targets and antennas

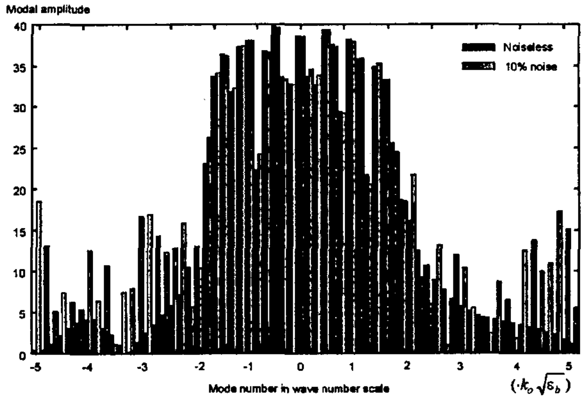

Fig. 2 Spectrum of the scattered fields when 10% Gaussian-distributed measurement error is included

Table 1 Reconstructed results of two cylinders buried and separated by 1.0 λ in the ground

		noiseless	10 % noise	original value
cylinder 1 (dielectric)	center x_1	2.03 [m]	2.02 [m]	2.0 [m]
	center y_1	-2.03 [m]	-2.14 [m]	-2.0 [m]
	radius a_1	1.05 [m]	1.16[m]	1.0 [m]
	ε_1	75.2	73.1	80.0
	σ_1	0.2 [S/m]	0.16 [S/m]	0.1 [S/m]
cylinder 2 (conducting)	center x_2	-2.02 [m]	-2.02 [m]	-2.0 [m]
	center y_2	-2.09 [m]	-2.12 [m]	-2.0 [m]
	radius a_2	1.08 [m]	1.13 [m]	1.0 [m]
	ε_2	546.8	450.2	·
	σ_2	208.6 [S/m]	190.3 [S/m]	·
earth medium	ε_b	6.13	6.32	6.0
	σ_b	1.2×10^{-3} [S/m]	1.3×10^{-3} [S/m]	1.0×10^{-3} [S/m]
RMSE		5.98 %	8.6 %	

Table 2 Reconstructed results of two cylinders buried and separated by 0.5 λ in the ground

		noiseless	10 % noise	original value
cylinder 1 (dielectric)	center x_1	1.55 [m]	1.553 [m]	1.5 [m]
	center y_1	-2.13 [m]	-2.19 [m]	-2.0 [m]
	radius a_1	1.16 [m]	1.2[m]	1.0 [m]
	ε_1	73.1	71.8	80.0
	σ_1	0.18 [S/m]	0.116 [S/m]	0.1 [S/m]
cylinder 2 (conducting)	center x_2	-1.52 [m]	-1.52 [m]	-1.5 [m]
	center y_2	-2.04 [m]	-1.99 [m]	-2.0 [m]
	radius a_2	1.06 [m]	1.02 [m]	1.0 [m]
	ε_2	590.7	660.5	·
	σ_2	195.2 [S/m]	125.3 [S/m]	·
earth medium	ε_b	6.28	6.29	6.0
	σ_b	1.5×10^{-3} [S/m]	1.43×10^{-3} [S/m]	1.0×10^{-3} [S/m]
RMSE		8.6 %	8.9 %	