§19. Computational Study for Microwave Tomography System Implementation

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The purpose of study is to develop the image reconstruction method for the microwave computerized tomography (microwave CT) with high space resolution. A new microwave imaging system is under development on the basis of the advanced measurement technology that has been built up for the microwave imaging reflectometry (MIR) of high temperature plasma. The system will serve purposes of practical imaging such as the breast cancer detection and the concrete pillar diagnostics. The system will be able to emit microwaves to objects with frequency variable and higher than those of the conventional practical imaging systems, and receive the scattered waves with phase information.

Test measurement results of our new microwave imaging system are verified by using a computational simulation with the Finite-Difference Time-Domain method (FDTD). For a dielectric cylinder phantom (Fig.1a), the time evolution of total electric field is computed (Fig.1b) in case of the experimental setup with a fixed frequency incident EM wave. Amplitudes and phases of the received electric fields at 4 antennae were simulated by spectral analysis of the FDTD-computed electric field by, and were compared with the experimental results.

Through survey of the recent works of microwave imaging studies, the fundamental strategy of the image reconstruction method for the imaging system is established and formulated as follows (Fig. 2 and Table 1).

In microwave tomography, reconstruction of the contrast function $c(\boldsymbol{r})$ of a dielectric object from scattered field data can be realized by simultaneously solving the state equation (1) and the data equation (2). The state equation (1) that represents the total electric field in the reconstruction region S, and the data equation (2) represents the consistency of the received scattered field. Eqs. (1) and (2) are rewritten in the discrete form as in Eqs. (3) and (4), respectively. These discrete forms of state and data equations have nonlinearity since the coefficient matrix A of the data equation includes the solution $\boldsymbol{c}$.

The recent works take iterative solutions for this nonlinear problem. For example, the distorted Born iterative method (DBIM) gets an initial solution by using the Born approximation, and then updates the solution by giving it back to data and state equations iteratively, with the aid of the FDTD computation.

Though our reconstruction method is based on these iterative solutions, we try to establish a fast alternative algorithm to update the solution and the coefficient matrix, by using least square nonlinear solvers, instead of the current time-consuming FDTD computation.

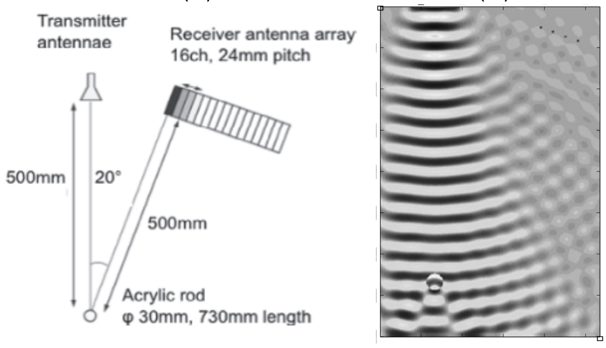

Fig. 1 (a)Experimental setup of microwave measurement test, and (b) its FDTD simulation result.

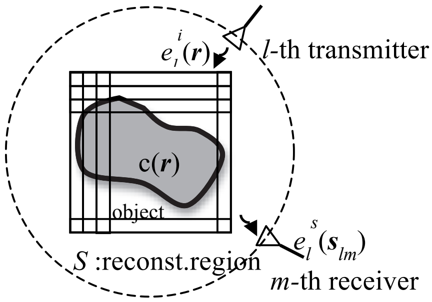

Fig. 2 Schematic diagram of microwave tomography.

State equation

$$e_l(\mathbf{r}) = e_l^i(\mathbf{r}) + \iint_S k_0^2 c(\mathbf{r}')e_l(\mathbf{r}')G(\mathbf{r},\mathbf{r}')\,d\mathbf{r}' \quad (1)$$

Data equation

$$e_l^s(\mathbf{s}_{lm}) = \iint_S k_0^2 c(\mathbf{r}')e_l(\mathbf{r}')G(\mathbf{s}_{lm},\mathbf{r}')\,d\mathbf{r}' \quad (2)$$

State equation (Discrete form)

$$(I - k_0^2 G^r C)\mathbf{e}_l = \mathbf{e}_l^i \quad (3)$$

Data equation (Discrete form)

$$\mathbf{e}_l^s = k_0^2 G_l^s E_l \mathbf{c} = A(\mathbf{c})\mathbf{c} \quad (4)$$

Table 1 Basic equations for microwave tomography.

The basic framework of the new reconstruction method is planned to reduce time and hardware costs of update calculation by introducing applied mathematical techniques. Our method can be accelerated by using generalized minimal residual method (GMRES) or the conjugate gradient descent method as fast nonlinear solvers. To find the optimal nonlinear solution, introducing the evolutional computation methods is also considered. Furthermore, we have discussed about possibilities of different types of approaches, such as the time-domain inverse scattering method and the 3-dimensional series expansion method, and also studied large-scale linear equation solvers as preparations of the 3D reconstruction application.

The implement of our algorithm and its improvements driven by feedbacks from practical applications remain as future works.

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