Microwave Mammography with a Small Sensor

Naoyuki Ozawa Yoshihiko Kuwahara
Graduate School of Integrated Science and Technology
Shizuoka University
Hamamatsu, Japan
tykuwab@ipc.shizuoka.ac.jp

***Abstract*— We propose a microwave mammography system with a small sensor. This system has features of use of multiple polarizations to collect a variety of data, fixation of the breast by suction to prevent the imaging mistakes, and applying a commercial electromagnetic simulator to model the sensor accurately. Effectiveness of the proposed system is demonstrated by a preliminary numerical experiments.**

Keywords—Microwave Tomography; FDTD Method; Forward Problem; Inverse Problem;

I. INTRODUCTION

Breast cancer is the most susceptible cancer in women, and early detection and early treatment is important. In the recent, microwave imaging for early breast cancer detection have been attracted attention. There are two methods of the microwave imaging. Microwave tomography reconstructs distribution of the electromagnetic property [1], while UWB radar reconstructs distribution of the scattering [2][3]. Microwave tomography is more effective for diagnosis because it offers tissue properties in addition with the shape.

In the literature [1] that introduced clinical test by microwave tomography, patient's breast is put in a tank filled with the matching liquid. There is a circular array of 18 monopole antennas which operates in the liquid and moves up and down in the tank. While the height is changed, transmission parameters for all combination between receiving and transmitting are collected. Then, the distribution of complex dielectric properties are reconstructed by solving the inverse scattering problems. In such an imaging system, the reliability of the data is lost due to body motion like breathing. In addition, it is difficult for a patient with a small breast to reconstruct the image. Because her breast cannot be put in the tank and also diversity of the data is limited.

In this paper, we propose a microwave mammography system with a small sensor. This system has features as follows: (a) a structure of aspirating and fixing patient's breast to prevent imaging mistakes and to offer an important prior knowledge of breast shape [4], (b) the polarization diversity of microwave in order to downsize the imaging sensor and to collect a variety of observations [5], (c) commercial electro-magnetic (EM) simulator for the forward solver to reduce the modeling error. We have carried out some numerical simulations to confirm the effectiveness of the proposed system.

II. RESONSTRUCTION OF COMPLEX DIELECTRIC PROPERTIES DISTRIBUTION BY SOLVING INVERSE SCATTERING PROBLEM

In this paper, distorted Born iterative method (DBIM) is used to reconstruct distributions of complex dielectric properties within patient's breast. In DBIM, the relationship between relative permittivity ε, conductivity σ, and scattering field $\mathbf{e}^s$ is expressed as follows[6] :

$$\begin{bmatrix} \Re[\mathbf{e}^s] \\ \Im[\mathbf{e}^s] \end{bmatrix} = \begin{bmatrix} \Re\left\{\begin{bmatrix} \frac{\partial F}{\partial \varepsilon}\mathbf{B} & \frac{\partial F}{\partial \sigma}\mathbf{B} \end{bmatrix}\right\} \\ \Im\left\{\begin{bmatrix} \frac{\partial F}{\partial \varepsilon}\mathbf{B} & \frac{\partial F}{\partial \sigma}\mathbf{B} \end{bmatrix}\right\} \end{bmatrix} \begin{bmatrix} \varepsilon_1 - \varepsilon_1^b \\ \vdots \\ \varepsilon_K - \varepsilon_K^b \\ \sigma_1 - \sigma_1^b \\ \vdots \\ \sigma_K - \sigma_K^b \end{bmatrix}$$

$$\mathbf{B} = \begin{bmatrix} \mathbf{H}_{1,1}^T & \mathbf{H}_{1,2}^T & \cdots & \mathbf{H}_{M,N}^T \end{bmatrix}^T, \quad F = \varepsilon + \frac{\sigma}{j\omega\varepsilon_0}$$

$$\mathbf{H}_{m,n} = \left[\overline{\mathbf{G}}^b(\mathbf{r}_n \mid \mathbf{v}_1)\mathbf{E}^b(\mathbf{v}_1 \mid \mathbf{r}_m) \cdots \overline{\mathbf{G}}^b(\mathbf{r}_n \mid \mathbf{v}_K)\mathbf{E}^b(\mathbf{v}_K \mid \mathbf{r}_m)\right] \in C^{3\times K}$$

$$m = 1,\ldots,M, n = 1,\ldots,N \qquad (1)$$

In equation (1), $\Re$ and $\Im$ denotes the real part and imaginary part, respectively. ε^b and σ^b denotes relative permittivity and conductivity in the background, respectively. K is number of discretized voxels in the breast region, M and N is number of transmitters and receivers, respectively. F is a complex relative permittivity. $\overline{\mathbf{G}}^b(\mathbf{r}_n \mid \mathbf{v}_k)$ is dyadic Green's function for n-th receiver at position $\mathbf{r}_n$ and k-th voxel at position $\mathbf{v}_k$. $\mathbf{E}^b(\mathbf{v}_k \mid \mathbf{r}_m)$ is background electric field at $\mathbf{v}_k$ when m-th transmitter is used.

It is transformed to the normal equation and then Tikhonov regularization is applied, because Equation (1) is ill-posed in general. We solve Equation (1) and achieve the solutions $\Delta\varepsilon_k = \varepsilon_k - \varepsilon_k^b$ and $\Delta\sigma_k = \sigma_k - \sigma_k^b$. After that, we update the relative permittivity and conductivity using the solutions as follows :

$$\varepsilon_{k+1} = \varepsilon_k + \Delta\varepsilon_k \ , \ \ \sigma_{k+1} = \sigma_k + \Delta\sigma_k \tag{2}$$

The DBIM iterates above procedure till terminating conditions are satisfied.

III. IMAGING SENSOR WITH POLARIZATION DIVESITY

A breast is modeled by a set of voxels. In the inverse scattering problem, we have to detect changes of the electric fields at the receiving points caused by changes of permittivity at each voxels. Therefore, high signal-to-noise ratio (SNR) is required, and it is necessary to put close the antenna to the breast. Although the living body has lower transmission loss at lower frequency, lower frequency results in lower resolution. From this point of view, frequency range from 1 to 4 GHz is often used.

To solve inverse scattering problem accurately, many observations are needed. However, a small system that achieves a high SNR restricts the space for antennas. Antennas putting close each other make less varieties of observations and fail to solve the inverse scattering problem. To overcome this problem, it is suggested to collect observations using multiple-frequencies. However, when multiple-frequencies are used, parameters to be estimated increase since the Debye model should be used. Also, structure of the wide-band antennas is more complicated than that of the single-frequency. This may cause modeling errors not to be ignored. Therefore, we propose use of multiple polarizations to achieve varieties of observations.

The imaging sensor with multiple polarizations is shown in figure 1. This sensor is a cuboid, and the aperture size is $96\times96\times48$ ㎜. 6 printed dipole antennas are located on each four side and 12 ones are located on the top. On each side, polarizations of the antennas change alternately. Detail of the printed dipole antennas is shown in figure 2. The thickness of the substrate is 0.784 mm, the relative permittivity is 3.7, and tanδ is 0.002. To simplify the model, the etching patterns are parallel to either of x, y, or z axes. The dipole antennas are embedded in the dielectric block of which permittivity and conductivity are almost the same of adipose tissue. The resonant frequency is 1.65 GHz.

A hemisphere space with radius of 45 mm and height of 40 mm for the breast is prepared at the bottom of the dielectric block. Furthermore, a valve for aspirating the breast is prepared on the top in order to form the breast to a hemisphere and to be fixed it. By the proposed structure, the breast shape which is an important prior knowledge can be used in the inverse scattering problems.

We can carry out electromagnetic analyses with small modeling errors by importing the CAD data of the imaging system to a commercial EM simulator. In this paper, we utilize XFdtd that is 3D-CAE software by Remcom Inc. XFdtd implements the finite-difference time-domain (FDTD) methods and EM simulation can be accelerated by using graphics processing units (GPU). In addition, XFdtd supports QtScripts, so we can perform any operation by using script functions. In our image reconstruction algorithm, the procedure of image reconstruction is executed by MATLAB and that of EM analysis is executed by XFdtd. We can exploit the script functions to link them. The flow chat of image reconstruction program is shown in figure 3.

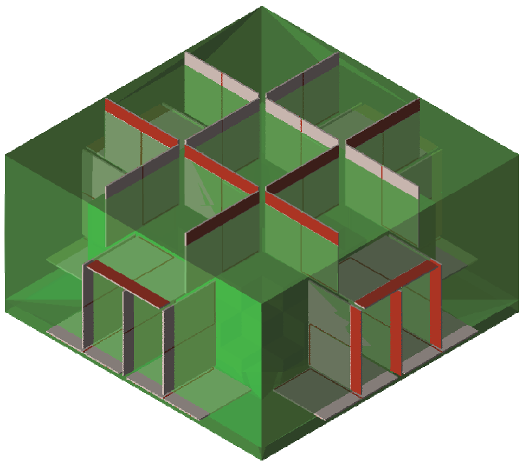

Figure 1 : Sensor model

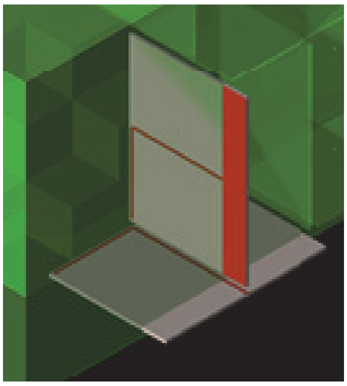

Figure 2 : Orthogonally printed dipole antenna

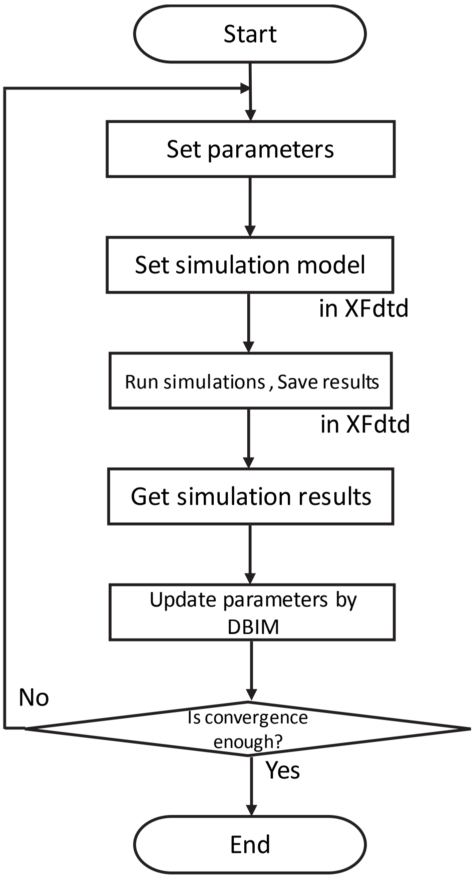

Figure 3 : Flow chart of image reconstruction

IV. SIMULATION

A. The breast model

The breast region is divided into voxels whose side is 12 mm. We assume that the breast region consists of adipose tissues and malignant tissues. Table 1 shows that the relative permittivity and conductivity of each tissue. We assign the dielectric properties of malignant tissue to one voxel and adipose tissue to the other voxels.

Table 1 : dielectric properties of biological tissues

	resinous block	adipose tissue	malignant tissue
Relative permittivity ε	6.2	7.0	52
Conductivity σ [S/m]	0.12	0.4	4.0

B. Experimental results

We show the result in figure 4 in which the reconstructed distribution of relative permittivity and conductivity after 10 iteration are presented. Red solid lines represent the true relative permittivity and conductivity, and blue asterisks show the estimated relative permittivity and conductivity by the presented reconstruction algorithm. Although the image reconstruction is not complete, we can discriminate the voxel of malignant tissue assigned above. We calculate $\mathbf{e}^s$ by multiplying a complex calibration coefficients to the S-parameters of antennas at each iteration.

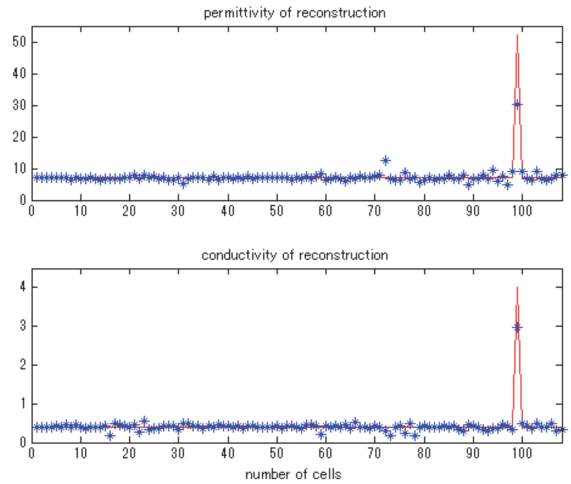

Figure 4 : Reconstruction results

(upper : relative permittivity, lower : conductivity)

V. CONCLUSION

We have proposed a microwave mammography system with a small sensor using multiple polarization and commercial EM simulator. In the future, we will manufacture a prototype and evaluate it.

REFERENCES

[1] T. M. Grzegorczyk, P. M. Meaney, P. A. Kaufman, R. M. diFlorio-Alexander, and K. D. Paulsen, "Fast 3-D Tomographic Microwave Imaging for Breast Cancer Detection,"IEEE Trans. Med. Imag. Vol.31, No.8, pp.1584-1592, 2012.

[2] M. Klemm, J. A. Leendertz, D. Gibbins, I. J. Craddock, A. Preece, and R. Benjamin, "Microwave Radar-Based Breast Cancer Detection: Imaging in Inhomogeneous Breast Phantoms, "IEEE Antennas and Wireless Propagat. Letters, VOL. 8, pp. 1349-1351, 2009.

[3] W. C. Khor, M. E. Bialkowski, A. Abbosh, N. Seman, and S. Crozier, "An Ultra Wideband Microwave Imaging System for Breast Cancer Detection, " IEICE Trans. Vol.E90-B No.9 pp.2376-2381, 2007.

[4] Y. Kuwahara, S. Miura, Y. Nishina, K. Mukumoto, H. Ogura, and H. Sakahara, "Clinical Setup of Microwave Mammography," IEICE Trans. Vol. EB96, No.10 pp.2553-2562, 2013.

[5] Latifah Mohamed, Yoshihiko Kuwahara, "Polarization Diversity on Microwave Tomography, " Proc. of iWAT 2014 , Mar 2014.

[6] J. D. Shea, P. Kosmas, S. C. Hagness, and B. D. V Veen, "Three-dimensional microwave imaging of realistic numerical breast phantoms via a multiple-frequency inverse scattering technique, " Med. Phys.37(B), pp.4210-4226, 2010.