Breast Cancer Imaging Using Ultra-Wideband Radar and Modified Kirchhoff Migration

Takuya Sakamoto[1, 2, 3, (a)], Hang Song[4], and Takamaro Kikkawa[4]

[1]Graduate School of Engineering
University of Hyogo
Himeji 671-2280, Japan

[2]Graduate School of Informatics
Kyoto University
Kyoto 606-8501, Japan

[3]Department of Electrical Engineering
University of Hawaii at Manoa
Honolulu, HI 96822, USA
(a) t-sakamo@i.kyoto-u.ac.jp

[4]Research Center for Nanodevioces and Systems
Hiroshima University
Higashihiroshima 739-8527, Japan

Introduction: Radar-based breast cancer imaging is a promising technique for detecting early-stage cancerous tumors because of its simplicity and low cost compared with other systems such as X-ray mammography and magnetic resonance imaging [1]. Unlike those conventional techniques, radar imaging can directly produce three-dimensional tomographic images. In addition, radar-based breast cancer imaging does not cause discomfort or pain due to breast compression. Moreover, radar systems do not use ionizing radiation. A high-resolution radar imaging technique using modified Kirchhoff migration was recently proposed in the field of concealed weapon detection systems [2, 3]. In the present study, we applied modified Kirchhoff migration to experimental echo data from a breast cancer phantom measured using an ultra-wideband array radar system developed at Hiroshima University [4-6].

Materials and Methods: We used a radar system with a center frequency of 3.3 GHz and −10-dB bandwidth of 2.9 GHz. The system comprises eight transmitting and eight receiving antennas, forming a 4×4 multiple-input multiple-output (MIMO) antenna array. The entire array is mechanically rotated from 0º to 360º at intervals of 3º and effectively functions as a virtual large-scale antenna array. Figure 1 shows a photograph of two cubic-shaped cancer tumor phantoms measuring 10 × 10 × 10 mm^3 embedded in a breast phantom, the relative permittivity of which was $\varepsilon_r = 6$.

The modified Kirchhoff migration generates an image $I(\boldsymbol{r})$ as follows:

$$I(\boldsymbol{r}) = \int_{S_1}\int_{S_2} \frac{\partial R_1}{\partial n_1}\frac{\partial R_2}{\partial n_2}\frac{1}{R_1 R_2}\left\{\frac{1}{c}\frac{\partial^2}{\partial t^2} + \frac{1}{c}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\frac{\partial}{\partial t} + \frac{1}{R_1 R_2}\right\} s_0(\boldsymbol{r}_1, \boldsymbol{r}_2, t+\tau)\,\mathrm{d}S_1\mathrm{d}S_2\Bigg|_{t=0}$$

where S_1 and S_2 are the transmitting and receiving scan surfaces, respectively; $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ are the positions of the transmitting and receiving elements; $R_1 = |\boldsymbol{r}_1 - \boldsymbol{r}|$ and $R_2 = |\boldsymbol{r}_2 - \boldsymbol{r}|$ are the propagation path lengths; n_1 and n_2 are parameters along the normal vectors of S_1 and S_2; c is the speed of the radio wave in the medium; $s_0(\boldsymbol{r}_1, \boldsymbol{r}_2, t)$ is the signal for the transmitting and receiving element at $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$; and $\tau = (R_1 + R_2)/c$ is the delay time [2, 3].

Results and Discussion: The left and right images in Figure 2 are the radar images generated using conventional delay-and-sum (DAS) migration and modified Kirchhoff migration. The images were generated by rendering −3-dB contour surfaces of the normalized three-dimensional images. The target images formed by modified Kirchhoff migration were smaller than those formed by DAS migration, indicating the improvement of the image resolution. In particular, the target image size in the z-direction improved by an average of 19% using modified Kirchhoff migration. Figure 2 also shows that modified Kirchhoff migration emphasizes high-frequency components and thus lowers the signal-to-noise ratio of the image, whereas conventional DAS migration can reconstruct smooth target surfaces.

Conclusions: In this study, we applied the modified Kirchhoff migration imaging technique to the radar echo data from a breast phantom and breast cancer tissue phantom measured using ultra-wideband MIMO radar. Compared with the conventional DAS migration technique, modified Kirchhoff migration showed the ability to generate high-resolution images. The experimental results exhibited 19% improvement in the z-direction spatial resolution.

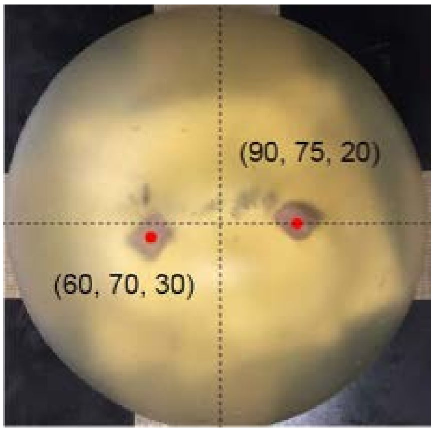

Fig. 1. Breast and cancer tissue phantom used for measurement.

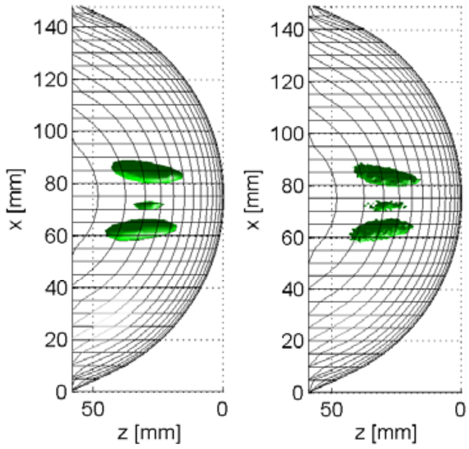

Fig. 2. Images generated using DAS migration (left) and modified Kirchhoff migration (right).

References:
1. Hang Song, et al., *IEEE Access*, **2015**, 3, 2111-2121.
2. Takuya Sakamoto, et al., *IEEE Trans Antennas Propag*, **2015**, 63(8), 3502-3512.
3. Xiaodong Zhuge, et al., *IEEE Trans Geosci Remote Sens*, **2010**, 48(6), 2692-2703.
4. Hang Song, et al., *Proc 11th Eur Conf Antennas Propag* **2017**, 3474-3475.
5. Hang Song, et al., *Proc Intl Conf Electromagn Adv Appl* **2016**, 321-322.
6. Takuichi Hirano, et al., *Proc IEEE Conf Ant Meas Appl*, **2016**.

Biography: Takuya Sakamoto received a BE degree in electrical and electronic engineering from Kyoto University, Kyoto, Japan in 2000 and ME and PhD degrees in communications and computer engineering from the Graduate School of Informatics, Kyoto University in 2002 and 2005, respectively. From 2006 through 2015, he was an assistant professor at the Graduate School of Informatics, Kyoto University. From 2011 through 2013, he was also a visiting researcher at Delft University of Technology, Delft, the Netherlands. Since 2015, he has been an associate professor at the Graduate School of Engineering, University of Hyogo, Himeji, Japan. He is also a researcher at Kyoto University and a visiting scholar at the University of Hawaii at Manoa, Honolulu, HI, USA. He is a recipient of the 2016 Masao Horiba Award.