Breast Cancer Localization in Three Dimensions using Time Reversal DORT Method

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1. Introduction

Breast cancer is a common type of cancer among women all over the world. Successful treatment and prevention of death greatly depends on early detection. Mammography is so far the gold standard for screening breast cancer. But mammogram has high false positive rates for early stage detection and especially not highly reliable for younger women since their breasts are composed of dense breast tissues. Despite continued efforts and some progress, efficient early stage breast cancer detection is still an unsolved challenge. Radar based microwave imaging can be a promising alternative to mammography as it is a non-ionising as well as a non-invasive technique. In the microwave frequency range of interest the attenuation due to breast tissue is low enough to obtain image of the entire breast. All these facts have motivated the researchers to develop microwave imaging techniques for the early detection of breast cancer [1-3].

Time reversal (TR) imaging method can be useful for imaging and detecting targets immersed inside complex media and has also been applied with the microwave imaging for breast cancer detection [1, 2, 4-6]. When compared with the traditional microwave imaging techniques, the TR method offers self-averaging and statistical stability properties when used for heterogeneous media. The main difference between TR method and the traditional signal processing methods is that the time reversal (TR) utilizes the information of the wave propagation environment. Microwave imaging techniques for breast cancer detection usually exploit the fact that normal healthy and malignant breast tissues have significant contrast in dielectric property domain over an ultra-wide bandwidth of microwave spectrum [3, 7]. The radar based microwave imaging of the breast utilises the strength of received scattered energy due to the target malignant tissue as well as other surrounding breast tissues. If the target malignant tissue has higher dielectric property contrast when compared to the surrounding tissues, then it produces stronger scattered signal to be processed at the receiver. Breast is usually composed of fatty adipose tissues, fibro-glandular and fibro-connective tissues, and transitional tissues. As women age, the dense fibro-glandular and fibro-connective tissues degenerate into fatty tissues. For younger women, the breast tissues consist of mainly dense fibro-glandular and fibro-connective tissues whose dielectric properties are of the same order of magnitude with those of malignant breast tissues, hence can potentially cause uncertainties in the detection process that uses back scattered energy. Hence it is quite challenging to detect tumorous (malignant) embedded inside dense breasts using conventional radar based microwave imaging. Thus, it is of interest to explore methods to enhance the radar based microwave imaging so that the malignant breast tissues even in the presence of dense fibro-glandular tissue surroundings can be localised and detected.

We propose, in this paper, to apply the time reversal based decomposition of time reversal operator (DORT) technique for localising the malignant breast tissues embedded in dense breast phantoms without the aid of any contrast agents. So far, the DORT technique was applied only on 2D breast phantoms [2] where high dielectric contrast was assumed to exist between healthy and malignant tissues. We propose to investigate DORT on 3-D numerical breast phantom where the dielectric contrast can be as low as 18%. We used FDTD simulations to obtain the scattered field from the breast.

The remainder of the paper is organised as follows. Section 2 describes the breast model along with FDTD simulation set-up. We explain breast cancer detection using DORT technique in Section 3. Section 4 contains the results followed by the conclusion of this study in Section 5.

2. FDTD Simulation with 3D Breast Phantom

We carried out FDTD simulation on 3D numerical breast phantoms derived from published data in the literature. A summary of the dielectric properties of different breast tissues are provided in Table 1. The breast model is composed of three types of tissues- fatty tissue, dense glandular tissue and transitional tissue. The glandular and fatty tissues are further divided into three goups- low, moderate and dense and their dielectric constants and conductivities are distributed within the range mentioned in Table 1. Depending on the presence of glandular tissues breasts are classified as fatty, lightly dense, moderate dense and dense breasts. A hemispherical moderately dense breast model of radius 48mm containing an embedded tumor along with array elements positions is illustrated in Figure 1. The breast model is covered with a 2mm thick skin.

The simulations set-up includes a hemispherical transceiver array consisting of 29 elements. Each of the elements sequentially illuminates the 3-D breast phantom and the scattered field is received by the array. The excitation is a differentiated Gaussian pulse with maximum frequency upto 5 GHz. The maximum dimension of the tumour is 7mm. The FDTD grid size is chosen to be 0.5mm. The breast model along with the transceiver array is immersed in a matching liquid to minimize reflection from the skin layer. Skin artefact removal is an important issue. We have used a homogenous fatty breast model as the reference model and subtracted the scattered field of this reference model from the model under investigation to remove skin artefact.

The scattered field, $\mathbf{E}^s$ is obtained by subtracting the incident field, $\mathbf{E}^i$ from the total field, $\mathbf{E}^t$. Each of the array elements records the electric field along x, y and z axis separately. The m,n-th element of the Multistatic matrix, $\mathbf{K}_{\mathbf{m,n}}$ is the scattered field recorded at m-th array element when the n-th element was excited.

$$\mathbf{K}_{m,n} = \mathbf{E}^s_{m,n} = \mathbf{E}^t_{m,n} - \mathbf{E}^i_{m,n} \quad (1)$$

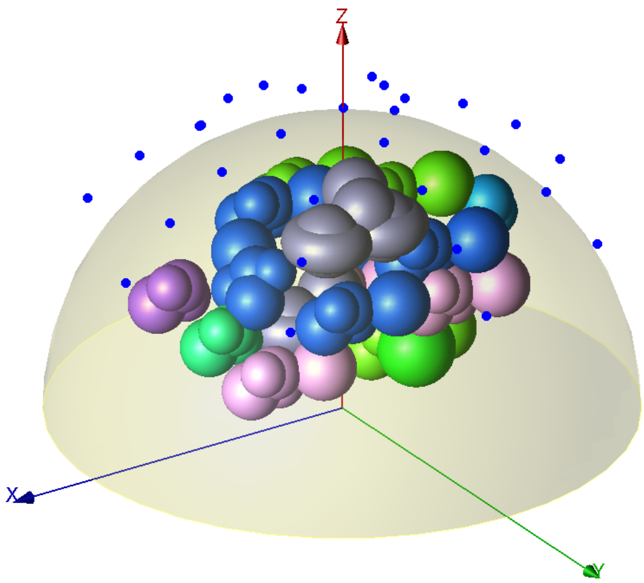

Figure 1: 3D FDTD Breast Model with Embedded Tumor

Table 1: Dielectric Properties of Different Tissues

Tissue Type	Glandular	Fatty	Transitional	Tumor	Skin
ε_r	36 – 46.5	3.0 – 8.0	20.0 – 24.0	57.0	36.0
σ (S/m)	3.5 – 6.0	0.1 – 0.2	2.1 – 2.3	7.0	4.0

3. Detection of Tumour using DORT

Time reversal localization by DORT technique is based on the eigenvalue decomposition of the time reversal operator or equivalently singular value decomposition of the multistatic matrix. The eigen values of the multistatic matrix are related to the scattering strength of the scatterers and the eigen vectors are used to estimate the location of the target. The details of DORT method can be found in the contemporary literature and hence are not elaborately explained here.

To obtain the location of the scatterer, which is the tumour in our problem, the significant eigen Vectors are back propagated. The back propagation is carried out using the dyadic Green's function of the breast. Assuming a homogenous breast, the dyadic Greens function is given by

$$\overline{\mathbf{G}}(\mathbf{r}\,|\,\mathbf{r}') = (\overline{\mathbf{I}} + \frac{1}{k^2}\nabla\nabla)\mathbf{G_o}(\mathbf{r}\,|\,\mathbf{r}') \tag{6}$$

where, $\mathbf{G_o}(\mathbf{r}\,|\,\mathbf{r}')$ is the vector Green's function of the medium and k is the wave number. Assuming the tumour to be the only strongest scatterer, it can be localized using the DORT imaging function as follows.

$$I(r) = \sum_{n=1}^{L} \left| \mathbf{v}_n^* . \overline{\mathbf{G}}(r) \right|^2 \tag{7}$$

Here L is the number of significant eigen values and $\mathbf{v_n}$ is the n-th eigen vector.

4. Detection Result

The DORT method is applied to a 3D breast model as shown in Figure 1. A tumour is assumed to be located inside the breast within the region x=[-28 -22], y=[25 32], z=[17 23]. The image obtained by DORT method is shown in Figure 2. The result indicates the maximum intensity of the image is at the location of the tumour thus helping to detect the presence of the tumour. Hence, this technique can be used to accurately estimate the tumour location even when the breast contains dense fibro-glandular and fibro-connective tissues. The singular values of the scattered field along z-axis are illustrated in Figure 3.

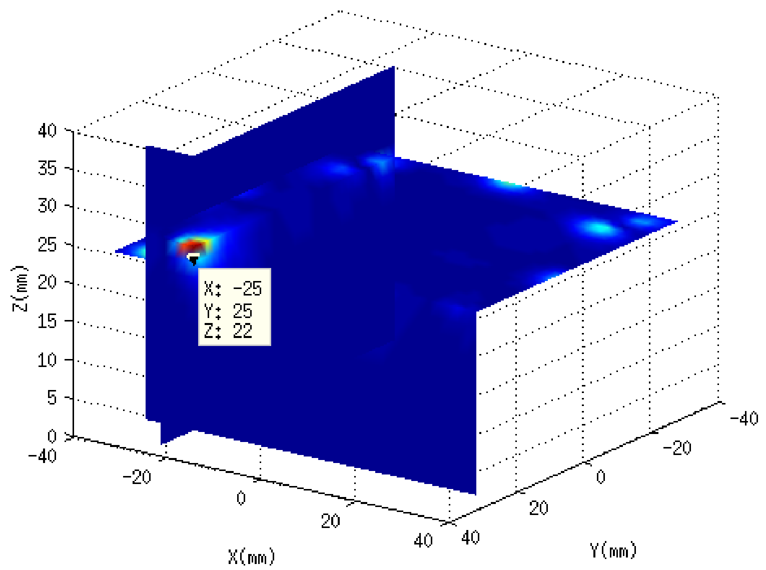

Figure 2: Detection of Tumor by DORT Technique

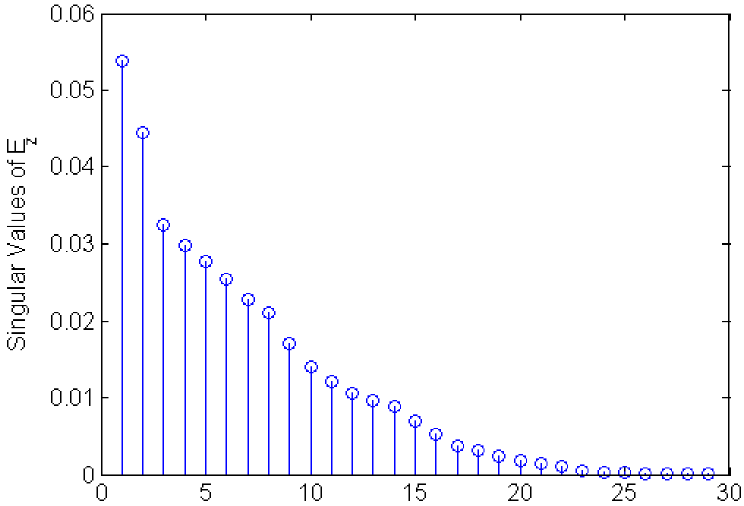

Figure 3: Singular Values

5. Conclusion

The presence of a number of significant singular values indicates the presence of dense tissues in the breast. Still the tumour location was accurately identified. Hence we conclude that DORT technique can be a very useful tool for enhancing the radar based microwave imaging for early stage breast cancer detection.

Acknowledgments

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References

[1] P. Kosmas and C. M. Rappaport, "FDTD-based time reversal for microwave breast cancer detection-localization in three dimensions," *IEEE Transactions on Microwave Theory and Techniques,* vol. 54, pp. 1921-1927, 2006.

[2] P. Kosmas, "Application of the DORT technique to FDTD-based time reversal for microwave breast cancer detection," in *Proc. European Microwave Conference*, 2007, pp. 306-308.

[3] M. Lazebnik, M. Okoniewski, J. H. Booske, and S. C. Hagness, "Highly accurate debye models for normal and malignant breast tissue dielectric properties at microwave frequencies," *IEEE Microwave and Wireless Components Letters,* vol. 17, pp. 822-824, 2007.

[4] M. J. Abedin and A. S. Mohan, "UWB imaging for early breast cancer detection using time reversal MUSIC algorithm," in *Proc. Asia-Pacific Microwave Conference (APMC)*, 2007, pp. 1-4.

[5] J. Yuanwei, J. M. F. Moura, J. Yi, M. Wahl, Z. He, and H. Qiuhong, "Breast cancer detection by time reversal imaging," in *Proc. 5th IEEE International Symposium on Biomedical Imaging: From Nano to Macro*, 2008, pp. 816-819.

[6] C. Yifan, E. Gunawan, K. S. Low, S. c. Wang, C. B. Soh, and T. C. Putti, "Time-reversal ultrawideband breast imaging: pulse design criteria considering multiple tumors with unknown tissue properties," *IEEE Transactions on Antennas and Propagation,* vol. 56, pp. 3073-3077, 2008.

[7] A. Mashal, F. Gao, and S. C. Hagness, "Heterogeneous anthropomorphic phantoms with realistic dielectric properties for microwave breast imaging experiments," *Microwave and Optical Technology Letters,* vol. 53, pp. 1896-1902, 2011.