ML based Time Reversal Microwave Imaging for the Localisation of Breast Tissue Malignancies

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Introduction

Imaging of malignant tissues at early stage is a challenging problem because of higher tissue heterogeneities create clutter signature very similar to the response from tumour. This requires a powerful imaging algorithm which can perform well even when the dielectric contrast between background and target tissue is very small. Therefore, the detection of malignant breast tissues at early stage is one of the challenging problems for microwave imaging. High rate of false alarms can occur due to tissue heterogeneities which can undermine the detectable tumour response. Here, we investigate the use of time reversal (TR) microwave imaging [1] coupled with maximum likelihood (ML) estimation for the localisation of breast tissue malignancies that are embedded in a background cluttered with heterogeneous breast tissues.

Time reversal (TR) imaging technique is a well known technique that has been applied successfully for the localisation [2]. TR imaging has also been successfully coupled with both MUSIC and Capon beamformer. However, in medium to high tissue heterogeneities along with lower dielectric contrast between target and the background and at lower signal to noise ratios (SNR), the existing time reversal methods may not perform adequately. Recently, Maximum Likelihood estimation technique was used with time reversal imaging for the localisation of point targets in a homogeneous dielectric background [3]. In this paper, we focus on TR-ML for a 2-D breast model with heterogeneous background. The dielectric properties for the breast model used in this paper are taken according to the data given in[4] where three different adipose tissue contents are considered viz., less (N1) moderate (N2) and higher(N3). The localisation performance of TR-ML for these three types of tissue background is investigated.

Modeling of the Breast

Majority of the studies on microwave breast cancer detection reported in the literature [1] are created from high resolution MRI data. The 2-D models consider the breast to be an infinite cylinder that is surrounded by the skin layer. The cylindrical model can approximate the patient lying in a supine position. Here, we consider the shape to semicircular with a diameter of 6 cm. As shown in the recent studies, depending on the percentage of adipose tissue content, the dielectric properties of healthy tissue may not have a significant contrast from those of malignant tissues[4]. As a result, the back scattering from malignant tissue may not be significantly different from the clutter which makes the tumour detection very challenging. In this study, we incorporate the background according to [4].

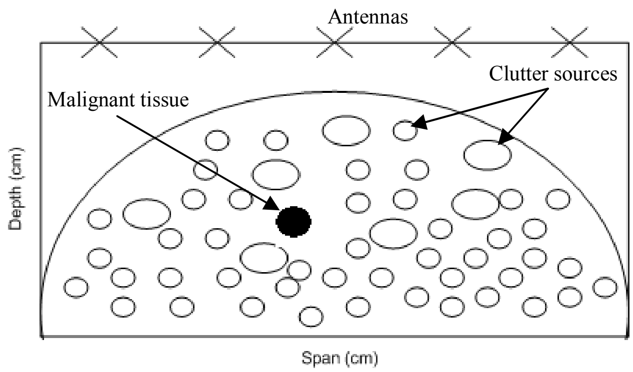

Fig.1: 2-D Numerical Breast Model

In our 2-D TM scattering model, both tumor and clutter sources are assumed to be two dimensional dielectric cylinders with variable diameters and dielectric properties as shown in Fig.1. Further, the relative dielectric constants and the conductivity of healthy and malignant tissue are taken as [1], for healthy tissue ε_Δ=10, σ_Δ=0.15S/m, ε_α=7,τ=7.0ps and for malignant tissue ε_Δ=54, σ_Δ=0.7S/m, ε_α=4, τ=7.0ps. In order to determine the dielectric constants the first order Debye dispersion equation is applied for the UWB frequencies [4]. The skin layer is assumed to be 2 mm thick with dielectric parameters ε_r=36, σ=4 S/m and the total transmission coefficient through the skin layer is calculated by using a slab model [1].

Backscattered Signal

Here, we represent the signal in such a way that the time reversal technique can be applied along with signal processing algorithm to image target tissue embedded in a two dimensional dielectric background. To sample the backscattered response at different points, an array of antennas is used. The receiver antennas are placed in such as way that it forms a ULA above the breast surface. The scattered fields are calculated using Mie scattering approach. The wave field at the receiver can be represented by the outward propagation of cylindrical waves due to the scattering from circular shaped dielectric cylinder

$$E^s(r) = \frac{\omega\mu I_e}{4}\sum_v \alpha_v H_v^{(2)}(kr)e^{-jv\phi} \qquad (1)$$

We use a multistatic radar approach where every antenna element in the ULA sends a probing pulse $p(t)$ sequentially and all the other elements receive the backscattering response from medium. Now, the observed backscattered wave field by i-th antenna at $r_{s,i}$ can be written as

$$\psi_i(t) = p(t)\otimes E^s(r_t, r_{s,i}, t) + \sum_{n=1}^{N} p(t)\otimes E^s(r_{c,n}, r_{s,i}, t) \qquad (2)$$

In equation(1), μ_0 is the permeability of free space and I_e is the line source excitation function. And α_v represents the back scattering amplitude which given by

$$\alpha_v = \frac{J_v^{'}(z_b)J_v(z_c) - \sqrt{1+\gamma}J_v(z_b)J_v^{'}(z_c)}{\sqrt{1+\gamma}H_v^{(2)}(z_b)J_v^{'}(z_c) - H_v^{(2)'}(z_b)J_v(z_c)} \quad (3)$$

where J_v and $H_v^{(2)}$ is the Bessel function of first kind and Hankel function of second kind respectively and J_v' and $H_v'^{(2)}$ are the derivatives of the Bessel and Hankel function respectively, $z_b = k_b d/2$ and $z_c = k_c d/2$ where d is the diameter of the breast tissues which act as scattering sources and k_b and k_c are the wave numbers in the breast tissue and clutter sources respectively.

Maximum Likelihood Method with Time Reversal Technique

Once the multistatic matrix is formed from the backscattered data collected at various receiver antennas, the numerical time reversal algorithm coupled with ML estimation can be applied. The aim is to determine the location parameters of the target tissue. The received multistatic matrix is represented by

$$\mathbf{Y} = \mathbf{K}(\mathbf{x}) + \mathbf{N} \quad (4)$$

where N is the additive noise and **K** is the multistatic response matrix with a size of $Nr \times Nt$. By utilising the recorded data **Y** a log likelihood function can be formulated in terms of probability density function of unknown parameters which are assumed to be Gaussian here. The parameters can be estimated by maximising the function given by

$$\hat{x}, \hat{\sigma}^2 = \arg\max_{x,\sigma^2} \frac{1}{(\pi\sigma^2)N_r N_t} \exp\left(-\|Y - K(x)\|_F^2 / \sigma^2\right) \quad (5)$$

where $\|.\|_F$ is the Frobenius norm. The noise variance σ^2, can be determined as

$$\hat{\sigma}^2 = \frac{1}{MN} \sum_{n=1}^{N} |x(n) - As(n)|^2 \quad (6)$$

The location co ordinate of target is found as

$$\hat{\mathbf{x}} = \arg\min_x \|Y - K(x)\|_F^2 \quad (7)$$

Now, determination of $\hat{\mathbf{x}}$ through solving (7) leads to a computationally expensive optimisation procedure. Here, a Genetic algorithm based optimization technique is employed to determine the location parameter $\hat{\mathbf{x}}$ from(7). Now, the likelihood time reversal image is created by using (8)-(9) within the breast which are given by

$$D(x) = \frac{1}{Tr\left[\mathbf{P}_{g(x)}^{\perp}\mathbf{Y}\right]} \quad (8)$$

where

$$\mathbf{P}_g^{\perp} = 1 - \mathbf{g}[\mathbf{g}^H\mathbf{g}]^{-1}\mathbf{g}^H \quad (9)$$

Result and Discussion

We test our proposed imaging method on a 2D breast model given in Fig1 that is created numerically according to MRI data [1]. Further, we also incorporated dielectric property variations in the breast according to [4]. To construct image of the background, the maximum likelihood based time reversal imaging techniques is employed. The constructed image using the proposed method is shown in Fig.2, for the case of moderate adipose tissue (N2). In Fig2, the bright image indicates the presence of the malignant tissue. We observe that the imaging performance of our method is not affected even for a closer dielectric variation between target tissue and the background at a lower input SNR. This provides some evidence that for localisation in highly cluttered environment such as breast cancer detection, the maximum likelihood based time reversal imaging approach can be utilized.

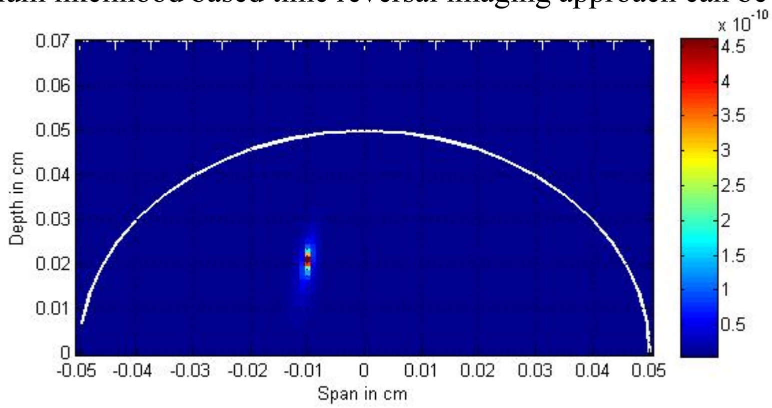

Fig. 2: Localisation of a malignant tissue for the model shown in Fig1. SNR=20dB

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