Towards a Planar Microwave Tomography System for Early Stage Breast Cancer Detection

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Abstract

In this paper, the advantages of planar Microwave Tomography (MT) applied to early stage breast cancer detection are presented. In the proposed planar configuration, the breast is compressed between two dielectric plates in a configuration similar to that of X-ray mammography. This approach would allow the future implementation of a dual modality imaging system where the advantages of both techniques can be exploited. The research efforts made both at DRÉ/L2S (Supelec) and Poly-grames (École Polytechnique de Montréal), for the development of a planar MT system are described, as well as, the key features of the latter. A numerical validation is used to show how the breast compression can lead to an enhancement of the reconstructed images.

1 Introduction

Active microwave imaging has been considered as a good candidate for early-stage breast cancer detection [1]. Two different approaches have been considered for the implementation of active microwave imaging, namely Confocal Microwave Imaging (CMI) and Microwave Tomography (MT). In CMI the breast is illuminated with a series of ultra wide-band pulses and radar based algorithms are used to create an image of significant scatterers [2-3]. On the other hand, MT is used to estimate the complex permittivity inside the breast by solving an inverse scattering problem from the electromagnetic fields scattered by the breast under different independent illuminations [1]. In this paper we focus in the MT approach where detailed information of the complex dielectric profile of the body can be obtained at the expense of solving a complicated non-linear and ill-posed inverse scattering problem.

Measurement setups in active microwave include a series of transmitting and receiving antennas in order to provide data (the scattered field or the reflected signals) to the reconstruction algorithm. In the most popular configuration, the patient is lying prone on a table with the breast pendant in a liquid for maximizing the energy coupling. In such a configuration, the antennas can be arranged in cylindrical [3] or hemi-spherical [2] surfaces. This configuration has the advantage that no breast compression is used and the comfort of the patient is maximized. However, breast compression can be seen as an advantage for a MT system for breast cancer detection:

- It allows to place both transmitting and receiving antennas very close to the breast enhancing the measured component of the evanescent scattered field.
- It can lead to simplifications of the reconstruction algorithm since one of the dimensions is precisely known.
- A combined approach of both X-ray mammography and MT can take advantage of the benefits of both techniques. One possibility is to use image registration to obtain an image fusion from the

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two techniques. In this case, high resolution images can be obtained from X-ray mammography and quantitative information obtained from MT can overcome the drawbacks of mammography [1]. Such a combined approach has already been used with other techniques, i.e. mammography - optical imaging or positron emission tomography - computed tomography [4]. Other possibilities are i) to use the X-ray mammography results as initial guess for the iterative MT reconstruction algorithm or ii) to apply data fusion to a single model that accounts for the physics of both techniques.

Planar MT systems have been an active subject of research both at Supelec and École Polytechnique de Montréal (EPM). For the implementation of such a system, a fast and accurate near-field measurement setup is needed. Among the different techniques available for near-field measurement, the Modulated Scattering Technique (MST) is a fast and accurate method for such purpose [5]. An MST-based imaging system consists in a set of small modulated probes (tipically dipoles loaded by a non-linear device) which scatter fields towards a collecting device (in the bi-static configuration). The modulated field scattered by the probe is proportional to the electric field at the position of the probe. By modulating the probes at a low frequency (hundreds of kHz) and using a simple homodyne receiver, the electric fields can be sampled at a very fast rate. These facts make a MST based measurement system a good candidate for the implementation of a planar MT system. The microwave camera [6], based on electrical modulation developed at Supelec and the optically modulated MST system developed at EPM [7], are two good examples of this principle. A preliminary investigation has shown the potential use of the planar microwave camera using a multi-view experimental platform working at a single frequency (f=2.45 GHz) [8]. Simple 2D breast phantoms were successfully reconstructed using a scalar 2D Newton-Kantorovich (N-K) reconstruction algorithm [9].

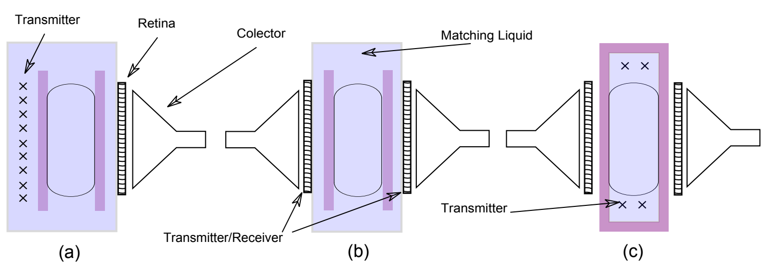
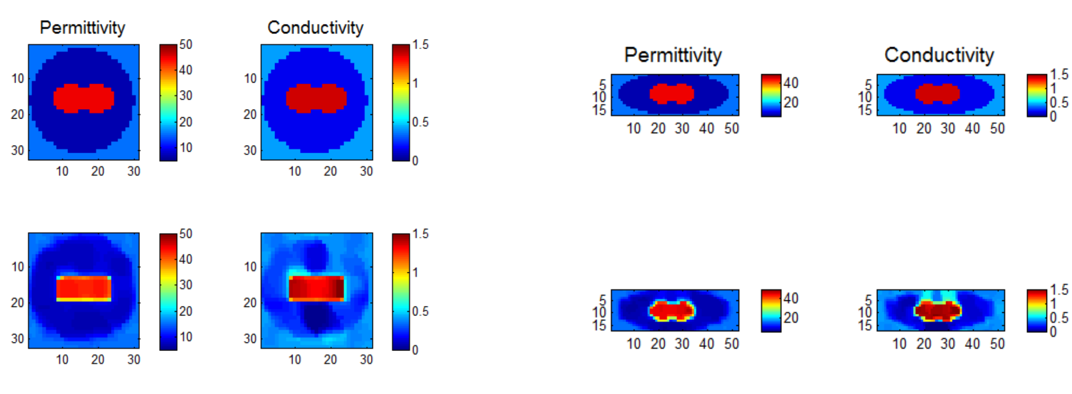


Figure 1: Different configurations for a planar MT system. (a) Single retina camera. (b) Double retina Camera. (c) Waveguide.

Multiple possibilities for the position of both transmitters and receivers are possible in a planar MT system. The first option, depicted in Figure 1a, is a classical multi-incidence approach. In this case, a set of transmitting antennas is placed on one side of the compressed breast and the electric field is measured using an array of modulated scattering probes (retina). The advantages of this configuration are the simplicity of its implementation and the high Signal to Noise Ratio (SNR) and dynamic range of the system, since the transmitting antennas can be designed to efficiently illuminate the compressed breast and, hence, to maximize the field measured by the retina. Another possible configuration is the double retina configuration (Figure 1b) which has been proposed in [10]. In this case, two retinas based on the MST technology are used as transmitter-receiver pairs each of them operating at two different frequencies (f_1 and f_2). More details about the implementation of this particular configuration can be found in [10]. The advantage of this configuration is that it provides twice more information than the single retina configuration, since each element of both retinas can be used as a transmitter. However, the SNR and dynamic range are lower in this case, because the MST probes present in the retina are generally optimized to accurately sample the electric field to be measured and do not represent an efficient radiator. Finally, the waveguide configuration is shown in Figure 1c. In this case, the whole structure can be seen as a multilayer dielectric waveguide, where different antennas inside the matching liquid can launch different modes in the structure and two retinas placed in the air region are used to measure the desired electric fields, more information about this configuration can be found in [11]. In this case, the amount of available information is also doubled compared to the single camera approach, however, this configuration can also suffer from reduced SNR and dynamic range due to the increased distance the guided waves have to cover to illuminate the breast and possible outside interferences coming from the air region. All different aspects for the implementation of a planar MT system are currently being studied both experimentally and numerically and will be discussed in details at the conference.

2 Numerical Validation

Recently, two independent studies have shown that, in MT for breast cancer detection, the quality of the reconstructed images can be enhanced through compression of the breast [10-11]. In both cases, using two different reconstruction algorithms, the N-K and the Contrast Source Inversion (CSI) [12], and synthetic data, reconstructions of simple phantoms with and without compression were obtained. The results show that a compression of the breast could improve the reconstruction process. Here we present an example for a 2D simple breast-like object, with realistic permittivity values for the different type of tissues [13], for the cases with and without compression. In both cases the object is illuminated by a set of 32 transmitters located on a line on one side of the breast and a step of 6.5 mm between them, while 32 receivers are placed symmetrically on the other side of the breast (single retina configuration shown in Figure 1a). The distance between the transmitters or receivers and the surface of the breast is 10mm for both the compressed and uncompressed cases. The operating frequency is 2.45 GHz. First of all, an uncompressed breast composed of fat ($\epsilon_r = 7$ and $\sigma = 0.16 S/m$) and glandular tissue ($\epsilon_r = 45$ and $\sigma = 1.36 S/m$) is considered. The fat region is represented by a circle of radius 30 mm and the glandular region is the superposition of two ellipses with semi-major and semi-minor axes equal 10 and 8 mm, respectively. Second, the same object is deformed to simulate a compression of the breast. The fat region is now an ellipse with a semi-minor axis of 36 mm. The glandular tissue region is supposed to remain constant since it is much stiffer than the fat tissue [11]. The reconstruction domain is partitioned into 32×31 pixels for the uncompressed case and 52×19 pixels for the compressed case. Synthetic data are generated using a MoM code with the same pixel size as the one used for inversion but a complex Gaussian noise with a SNR of 30 dB is added in order to avoid committing inverse crime. The object is reconstructed using the CSI method and the results are displayed in Figure 2. As it can be seen, the shape of the glandular region is better reconstructed for the compressed case. An artifact appears in the reconstructed conductivity for both cases. It is due to the aspect-limited data provided by the single retina configuration [11].



(a) No Compression (b) Compression

Figure 2: Reconstruction results for the object with and without compression after 3000 iteration steps. The permittivity (columns 1 and 3) and conductivity (columns 2 and 4) of the original (top) and reconstructed object (bottom). The axes are indexed by pixel number.

3 Conclusion

In this paper we have discussed several aspects of the steps needed towards a planar MT system for early stage breast cancer detection. The advantages of such a planar configuration for the measurement setup have been briefly introduced and summarized. A numerical example has been shown to point out the benefits that breast compression can provide to the quality of the reconstructed images. Finally, the different possibilities for the configuration of the measurement setup have been introduced and will be discussed along with more numerical and experimental results in the conference.

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