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***Abstract*—Microwave tomography is currently being researched for breast cancer detection. Our research has shown that clinical imaging preferably has to be made in a full 3D setting. In this paper we show results in order to evaluate the performance of a clinical system under construction.**

I. Introduction

Breast cancer is a serious health problem for women. According to national statistics of Sweden from year 2007 it is the most common cause of death from cancer among women, with about 30 yearly deaths per 100,000 inhabitants, [1]. The situation is similar in the rest of Europe, Northern America and Australia, [2]. Worldwide breast cancer is the second most common form of cancer after lung cancer. In year 2002 1.15 million new cases of breast cancer were diagnosed world wide. A relatively favorable prognosis, compared to other cancer forms, resulted in about 410,000 deaths the same year, [2].

The standard method for breast cancer diagnosis today is X-ray mammography. Despite its recognized ability to detect tumors it suffers from some limitations. Neither the false positive nor the false negative detection rates are negligible. This leads to a number of unnecessary additional investigations and, more seriously, a fraction of the tumors are not detected at an early stage which is a prerequisite for efficient treatment. An important reason for the limitations using the X-ray technique is that the contrast between the tumor and the surrounding tissue sometimes can be as low as a few percent.

An interesting alternative being researched extensively today is microwave tomography. From measurements on excised tissue a dielectric contrast has been observed between the healthy and malignant tissue. Depending on the mixture between fatty and glandular tissue in the breast the contrast varies largely between individual patients, from about 10% for a breast with a large portion of glandular tissue and up to $>$100% for breasts consisting of mostly fatty tissue, [3]. In some recent clinical studies the ability to detect breast cancer tumors with microwaves have been shown, [4].

II. Microwave measurement technique

In microwave tomography the object under investigation is surrounded by a number of transmitting and receiving antennas. In the measurements each antenna is operated as a transmitter as well as a receiver for every possible combination of antennas. In our work we use wide band measurements, which leads to a square multistatic data matrix for each frequency component. For the measurements we use a network analyzer, Agilent E8362 B. To be able to control the experiment a 2:32 switch multiplexer module, Cytec CXM/128-S-W, is used to automatically connect and disconnect the transmitting and receiving antennas to the PNA.

In most of our previous work we have used a flat antenna array, where the antennas have been placed on a circle, and a two-dimensional (2D) reconstruction algorithm, [5]- [8]. This setup is also most suitable for imaging 2D objects with dielectric properties that are constant in the z-direction perpendicular to the antenna plane. When it comes to imaging three-dimensional (3D) objects we have seen that the accuracy is seriously limited. The reason for this is twofold. Firstly it is not possible to make accurate models of the real world antennas in a 2D algorithm. Secondly the propagation model of the real world 3D wave pattern in a 2D model is not accurate. For example objects in this measurement setup above and below the antenna plane will introduce scattering that will be measured but that can not be modeled in the 2D model. Another problem is that small spherical tumors or inclusions are not modeled well in a 2D algorithm where these objects effectively are described as cylindrical objects. We have also developed a 3D algorithm that we have used with this measurement setup, [9]. In this algorithm we can make accurate models of the antennas but since we have no antennas outside the plane we still can get no information about the objects in the z-direction and therefore still only image 2D objects.

In our current strive to develop a clinical prototype we have therefore found that the most suitable design for a clinical prototype consists of an antenna array where antennas are placed also outside the plane in a 3D pattern. Our aim is therefore to construct a cylindrical antenna array. Together with a 3D reconstruction software the potential for improved accuracy is optimized. However the price that has to be paid for this approach is a significantly increased computational burden in the reconstruction algorithm.

In this paper we will investigate and evaluate the design of a clinical prototype for reaching the performance required for accurate image reconstruction in the clinical situation. The principal design of the antenna array under investigation can be found in Fig. 1

III. Image reconstruction

In this work an iterative electromagnetic time-domain inversion algorithm has been used for reconstructing the dielectric

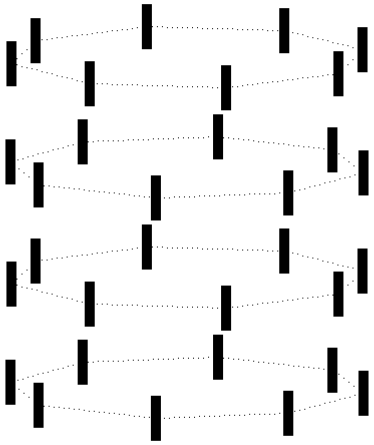


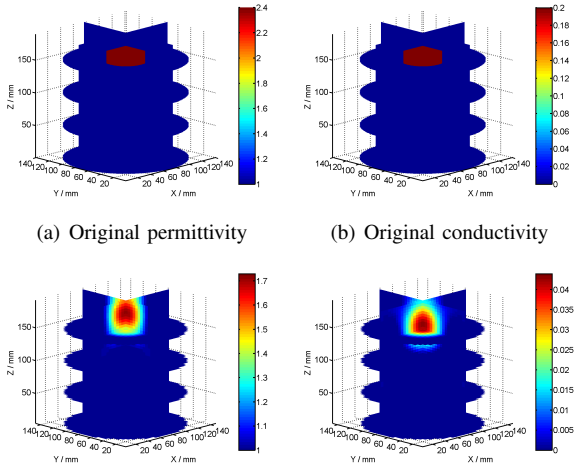
Fig. 1. The principal design of the antenna array for a clinical microwave tomography system. The antenna array consist of 32 antennas on total, configured in four circles with eight antennas in each circle.

parameters of the target object under test. It is based on FDTD simulations of the electromagnetic problem and computation of the adjoint Maxwell problem to compute gradients used in an conjugate-gradient optimization algorithm. Since we make the measurements with a network analyzer the time domain signals have to be synthezised from the frequency data via an inverse Fourier transform.

The basic idea for the image reconstruction is to use the scattering measurements of wide band transient pulses for the transmitter/receiver combinations and to compare the measured data with a numerical simulation of the system. The difference between the measured and the simulated signals is used to update the dielectric properties in the target region. As the reconstruction of the target object is iteratively refined, the simulated and measured signals converge. The assumption is that when the difference is sufficiently small the reconstruction is completed. In other words, the aim of the reconstruction procedure is to minimize the objective functional, F, defined as

$$F(\epsilon,\sigma) = \int_0^T \sum_{m=1}^{M}\sum_{n=1}^{N} |\mathbf{E}_m(\epsilon,\sigma,\mathbf{R}_n,t) - \mathbf{E}_m^m(\mathbf{R}_n,t)|^2 dt, \tag{1}$$

where $\mathbf{E}_m(\epsilon,\sigma,\mathbf{R}_n,t)$ is the calculated field from the computational model and $\mathbf{E}_m^m(\mathbf{R}_n,t)$ is the corresponding measured data when antenna number m has been used as transmitter. Here M is the number of transmitters, N is the number of receivers and $\mathbf{R}_n$ denotes the position of antenna number n. In Fig. 2 we can see an early example of a reconstruction as well as the original dielectric profile of a single target positioned in air. The configuration of the system is the same as in Fig. 1. The target can be clearly reconstructed. The extent in the xy-plane is reasonably well reconstructed whereas there is a bigger uncertainty in the z-direction and a slight discrepancy in the dielectric property values.



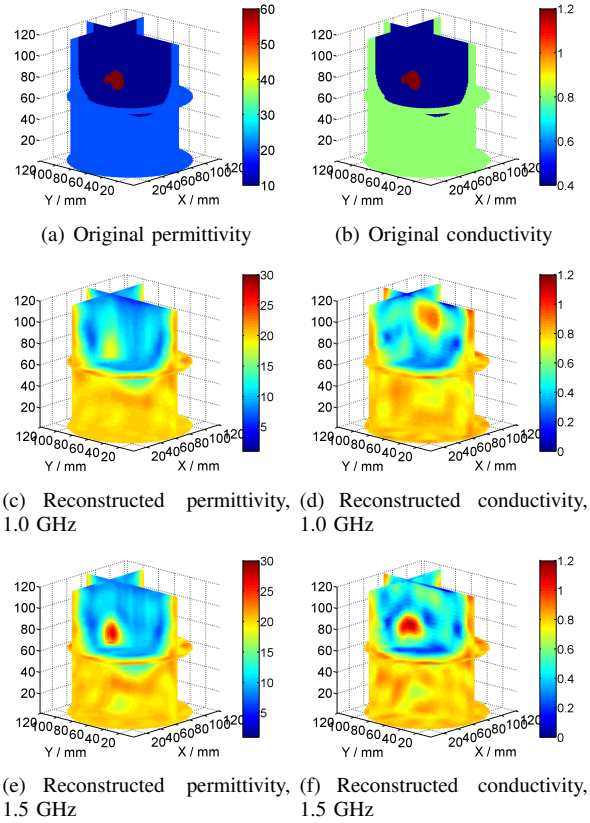
(a) Original permittivity (b) Original conductivity

(c) Reconstructed permittivity (d) Reconstructed conductivity

Fig. 2. (a) Original relative permittivity of the test object, (b) and original conductivity of the test object. (c) A reconstruction of the relative permittivity (d) and a reconstruction of the conductivity.

To further investigate the performance of the system we have made a reconstruction of a realistic breast phantom in the proposed antenna system. The radius of the antenna array for this test was 70 mm and the height of the antenna cylinder was 120 mm. The antennas were modeled as immersed in a coupling fluid with dielectric properties $\epsilon_r = 20$ and $\sigma = 0.8$S/m. Further a simple breast model used for imaging, the dielectric property for the healthy breast was set to $\epsilon_r = 10$ and $\sigma = 0.4$ S/m. A tumor with radius 10 mm and dielectric properties $\epsilon_r = 60$ and $\sigma = 1.2$ S/m was included in the breast model. In Fig. 3 (a) and (b) the original breast model is plotted. Scattering measurements were simulated with the FDTD algorithm on a 1 mm cubic grid. To avoid the inverse crime the image was then reconstructed on a coarser grid. As a start 10 iterations were made on a 4 mm grid and this was followed by 20 iterations on a 2 mm grid. An electromagnetic pulse having center frequency 1.0 GHz and FWHM bandwidth 1.0 GHz was used for the reconstructions. In Fig. 3 (c) and (d) the resulting images are plotted. The permittivity is approaching the original model but the conductivity shows significant artifacts. In an attempt to remedy these artifacts and obtain a better model these results were taken as the starting point for 20 additional iterations with a pulse having center frequency 1.5 GHz and FWHM bandwidth 1.0 GHz. This method of refining the reconstruction with increased frequency is referred to as frequency hopping and we have described a time domain version in [6]. The resulting image can be seen in Fig. 3 (e) and (f). These images show significant improvements, for example the artifact in the conductivity has more or less disappeared and the tumor is better reconstructed, however the dielectric values do not quite reach that of the

original model. On the other hand the background values of the healthy breast and the contours of the breast are well reconstructed.



(a) Original permittivity (b) Original conductivity

(c) Reconstructed permittivity, 1.0 GHz (d) Reconstructed conductivity, 1.0 GHz

(e) Reconstructed permittivity, 1.5 GHz (f) Reconstructed conductivity, 1.5 GHz

Fig. 3. (a) Original relative permittivity and (b) conductivity of the breast model. In (c) a reconstruction of the relative permittivity and in (d) the conductivity using a pulse with center frequency 1.0 GHz and FWHM bandwidth 1.0 GHz. In (e) and (f) the results from continued reconstruction using center frequency 1.5 GHz and FWHM bandwidth 1.0 GHz with the images from (c) and (d) as the starting point.

IV. Conclusions

There is a need for novel breast cancer detection systems to overcome the limitations with todays modalities. Microwave based system has the potential to become both sensitive and specific in this application. We have studied and evaluated a possible design for a clinical system as well as developed an accurate image reconstruction algorithm to work with this system.

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References

[1] Sweden's National Board of Health and Welfare: "Causes of death 2007", (Access at: `www.sos.se`).

[2] D. M. Parkin, F. Bray, J. Ferlay and P. Pisani: "Global cancer statistics, 2002," *CA: A Cancer Journal for Clinicians,* vol. 55, pp. 74–108, Mar. 2005.

[3] M. Lazebnik, D. Popovic, L. McCartney, C.B. Watkins, M.J. Lindstrom, J. Harter, S. Sewall, T. Ogilvie, A. Magliocco, T.M. Breslin, W. Temple, D. Mew, J.H. Booske, M. Okoniewski, and S.C. Hagness: "A large-scale study of the ultrawideband microwave dielectric properties of normal, benign, and malignant breast tissues obtained from cancer surgeries," *Physics in Medicine and Biology*, vol. 52, pp. 6093-6115, October 2007.

[4] S.P. Poplack, T.D. Tosteson, W.A. Wells, B.W Pogue, P.M. Meaney, A. Hartov, C.A. Kogel, S.K. Soho, J.J. Gibson, and K.D. Paulsen: "Electromagnetic Breast Imaging: Results of a Pilot Study in Women with Abnormal Mammograms," *Radiology*, vol. 243, pp. 350-359, 2007.

[5] P. Hashemzadeh, A. Fhager, and M. Persson, "Experimental investigation of an optimization approach to microwave tomography," *Electromagn. Biol. Med.*, vol. 25, no. 1, pp. 1–12, 2006.

[6] A. Fhager, P. Hashemzadeh and M. Persson, "Reconstruction quality and spectral content of an electromagnetic time-domain inversion algorithm," *IEEE Trans. Biomed. Eng.*, vol. 53, no. 8, pp. 1594–1604, Aug. 2006.

[7] A. Fhager, and M. Persson, "Using a priori Data to Improve the Reconstruction of Small Objects in Microwave Tomography," *IEEE Trans. Microwave Theory Tech.*, vol. 55, pp. 2452–2462, 2007.

[8] S. Nordebo, A. Fhager, M. Gustafsson and M. Persson, "A Systematic Approach to Robust Preconditioning for Gradient-Based Inverse Scattering Algorithms," *Inverse Prob.*, vol. 24, no. 2, art.no. 025027, April, 2008.

[9] S. K. Padhi, A. Fhager, M. Persson and J. Howard, "Measured Antenna Response of a Proposed Microwave Tomography System Using an Efficient 3D-FDTD Model," *IEEE Antennas Wirel. Propag. Lett.,* vol. 7, pp. 689–692, 2008.