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COMPARISON BETWEEN A 2.45 GHz PLANAR AND CIRCULAR SCANNERS FOR BIOMEDICAL APPLICATIONS

T. Gunnarsson, N. Joachimowicz, A. Joisel and J.Ch. Bolomey
SUPELEC, Département de Recherche en Electromagnétisme, Plateau de Moulon,
F-91192 Gif-sur-Yvette Cedex, France
E-mail: tommy.gunnarsson@lss.supelec.fr

Abstract. Microwave imaging is an efficient technique to non-invasively visualizing dielectric properties of non-metallic bodies. One potential of the technique is the high contrast in dielectric properties between biological tissues. In the 80's, Supélec developed a 2.45 GHz planar microwave camera, in the 90's the group developed algorithms for quantitative microwave imaging. The purpose of this study is to investigate the capability of these existing materials, or an extended version of them, in terms of quantitative imaging of high-contrast inhomogeneous object for application of breast cancer detection. A two-dimensional formalization is considered to be followed up with future three-dimensional investigations.

Keywords: Quantitative Microwave Imaging, Planar Microwave Camera, Breast Tumor Detection, Newton-Kantorovich

1 INTRODUCTION

Microwave imaging is recognized as an efficient diagnostic modality for non-invasively visualizing dielectric contrasts in non-metallic bodies. The usefulness of this modality results from the existing correlation between dielectric properties and quantities of practical relevance for industrial or biomedical applications. For example, during the last decade, many research efforts have been devoted to the early detection of breast cancer [1-6]. Indeed, a high dielectric contrast is expected between tumoral and healthy tissues. Various experimental setups have been considered [2,4-8], as well as different image formation algorithms [1,3,6,7,9]. Roughly speaking, microwave images can be derived from linear (Born approximation, confocal imaging, UWB techniques, etc) or non-linear (inverse scattering) data processing techniques. In the first case, the objective is only to detect the presence of the tumor, while the second approach aims to quantitatively estimate the dielectric contrast of the tumor.

During the earlier steps of microwave imaging developments, at the beginning of the 80's, Supélec developed a 2.45 GHz planar microwave camera for non-invasive thermometry during hyperthermia treatments. This camera, designed for operation at 2.45 GHz, can record the field scattered by a water immersed target over a 22 square centimeters area by means of an array of 32x32 sensors. This camera is using MST (Modulated Scattering Technique) technology [10], which allows a drastic simplification of the microwave circuitry used. After successive improvements, this camera was able to provide qualitative images from spectral processing at the rate of 25 images per second [7]. This system can be extended in view of full 3D polarimetric analysis of the scattered field. Until now, both a linear spectral algorithm and a non-linear iterative algorithm have been used to process single polarization scattered field data [11-12]. The purpose of this study is to investigate the capability of this existing equipment, (or an extended version of this equipment), in terms of breast cancer detection.

After a description of the experimental set-up, simulated results obtained with a 2D Newton-Kantorovich code for a multi-view planar configuration are presented and compared with two other multi-view circular scanner arrangements [2] and [8]. It is shown that satisfactory results can be obtained with a planar configuration as soon as the signal to noise ratio is larger than 40 dB.

2 THE PLANAR CAMERA

2.1 Description

The planar microwave camera operating at 2.45 GHz (Figure 1), used for providing the experimental data, has been developed at SUPELEC/DRE in the 80's and is already extensively described in previous papers [7,10,13]. The measured scattered field is provided by the retina of the camera, which is placed in front of the collector aperture as shown in Figure 1. It consists of a 32x32 dipole array, with a step size of 7.2 mm (half the wavelength in water) between each element, loaded by modulated PIN diodes modulated at 200 kHz. The array scanning is rapidly performed in a sequential way using the Modulated Scattering Technique [10]. The retina enables at the moment image reconstruction of the dielectric characteristics in horizontal cross-sections of the illuminated body, using all elements on the vertical plane could be a first intention for 3D reconstruction.

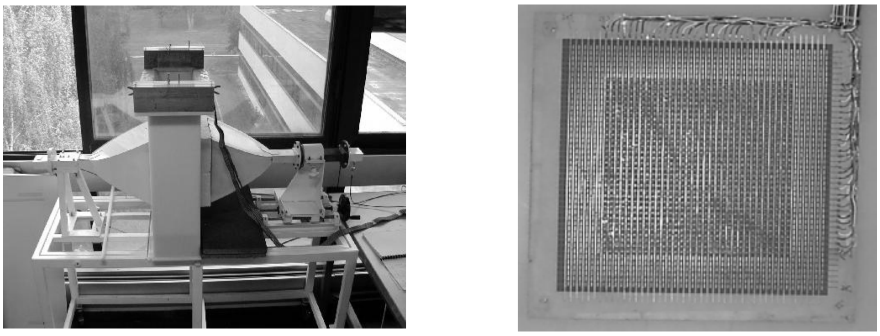

Figure 1: The 2.45 GHz microwave camera (left), the retina (right).

2.2 Real-time imaging capabilities

From the research in the 90's, it appeared a need of imaging systems able to provide images in real time of dynamic phenomena or at least with fast acquisitions. Benefiting from the spectacular rise of the microcomputer's power and after some transformations of the acquisition and control device, the camera was able by using a spectral method, to perform in real-time, reconstruction of the equivalent currents in cross sections [7]. In this real time mode the rate of qualitative acquisitions/reconstructions reaches 25 images/s.

2.3 Matching to the quantitative reconstruction

Quantitative reconstruction of low-contrast, cylindrical homogenous objects using the camera has already been achieved using a NKT method [11]. However, the intensive use of the algorithm by different groups [1,11,14-18], the characterization of its sensitivity to model errors and SNR [14], the use of information from qualitative real-time images, gives an opportunity to consider an improved system for the reconstruction of high-contrast inhomogeneous phantoms. Moreover, the technique can be used in view of 3D polarimetric analysis of the scattered field and some efforts have already been done for the generalization of the algorithm to 3D quantitative imaging [9]. In this context the following improvements have been performed. Modifications have been done in the matrix formalization of NKT process, in order to support any single-frequency experimental configuration. Furthermore, when symmetries of the system exist, they are used in order to save computation effort. In addition the formalism has been extended for taking into account possible interactions between the target and the measurement system [18]. Averaging is used in order to obtain higher SNR of the measured data. For example, the incident field, E_{inc}, in absence of object is systematically measured several times before any acquisition of the total field, $E_{tot}=E_{inc}+E_{scat,}$ radiates by the phantom. Furthermore, the general set-up has been improved in order to minimize the model's errors. The water temperature is regulated at 37°C (human body temperature). This induces a triple effect: 1) it reduces drastically the effects of the incident field drifts, 2) it improves the SNR by reducing the losses in water and 3) it decreases the model's error due to variation on the complex permittivity. Finally, a particular care was taken into the stabilization of the rotation axis of the phantom during the multi-view experiments. Note, for a 2D reconstruction purpose, only one line (or the average of several lines) of the retina is used, thus in the case of using 64 views (which corresponds to different orientations of the plane waves using the rotator) the data file contains 32 x 64 = 2048 complex values of the scattered field.

2.4 Calibration

In solving non-linear inverse scattering problems, the solution is found iteratively by minimizing the error between the measured scattered field and the scattered field estimated from a numerical model. Consequently, the convergence of such an iterative process requires, at least, the numerical model to reproduce as accurately as possible the experimental setup and thus the equipment has to be carefully calibrated. Figure 2 provides an example of calibrated results. It concerns a PVC circular cylinder whose diameter is 35 mm. While the phase shows a very good agreement, further studies are currently conducted to reduce the amplitude's errors.

3 SIMULATIONS

In order to investigate the planar geometry compared to the circular geometry with respect to topographic ability, a comparison with two circular multi-view systems is presented (Figure 3).

They differ from the repartition of the receiving antennas and from the nature, frequency and position of the incident wave.

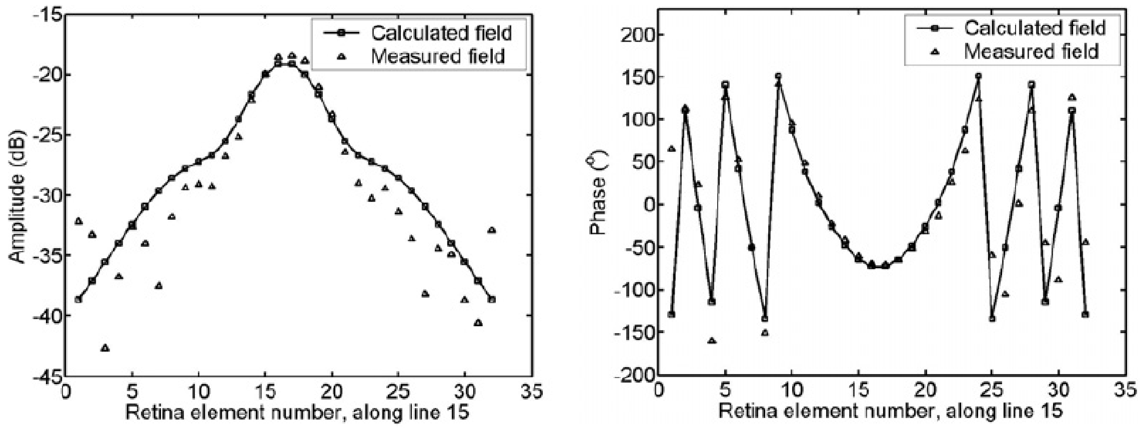

Figure 2 : Comparison between calculated and measured scattered field of a 35 mm PVC cylinder with a complex correction of the measured field.

Each system uses 64 views, one view consists of a set of M complex values of the scattered field at R_m (m=1,2 ….M) receivers positions. Each view changes with the transmitter's position or plane wave incidence, and is obtained by rotating the view axis represented by the dotted line in figure 3.

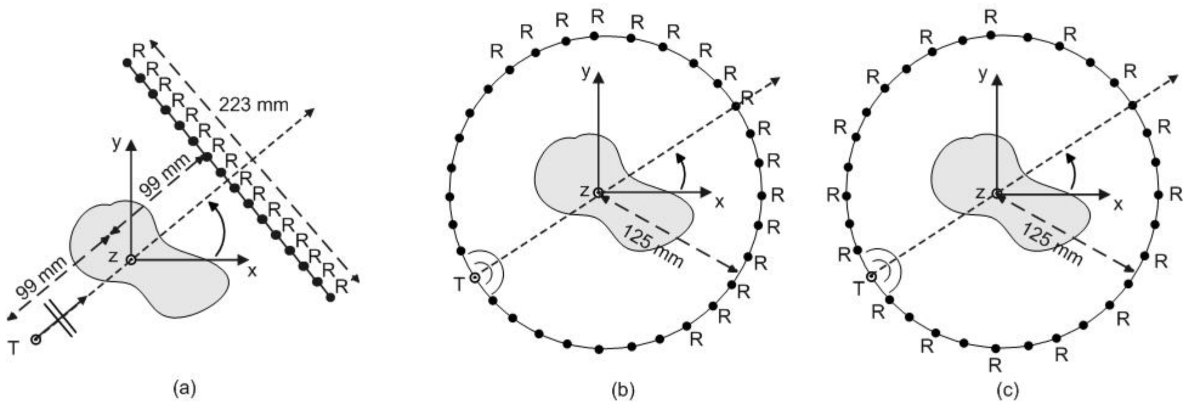

Figure 3 : The 3 different multi-view configurations. (a) Planar camera. (b) Barcelona camera. (c) Complete circular system

In the planar camera configuration (Figure 3a), a 2.45 GHz incident plane wave is considered. 32 receivers are located on a 22.3 cm straight measurement line, whose center is distant of 19.8 cm from the transmitter. In the two circular configurations, a 2.33 GHz cylindrical incident wave is used. 64 antennas on a circular array, whose diameter is 25 cm, can be operated in transmitting or receiving mode. When a given antenna T is transmitting, the other R ones are used as receiving antennas. As shown in Figure 3, the R positions (33) are located on a half circle in the opposite side of the transmitter T, for the Barcelona's configuration (Figure 3b), while 32 measurement positions located on the complete circle, are used in the configuration (Figure 3c).

As an example, an elliptical breast model whose dimensions are 100 x 76 mm, is used for the reconstruction. It contains a 15 mm diameter tumor and is surrounded by water. The values of the complex permittivity used come from a good compromise between measured values on existing phantoms materials and those found in the literature, shown in Table 1 [1,2,4,6,19].

Materials	ε_r’	ε_r”
Breast tissue	35	5
Tumor	65	14
Skin	37	8
Water	77.3	8.66

Table 1 : Complex permittivity used in the model [1,2,4,6,19].

Figure 4 shows the results obtained at iteration 3, for the three different multi-view systems, when a signal to noise ratio of 40 dB is considered. The initial guess and the exact complex permittivity distribution are also depicted in Figure 4 (d) and (e) respectively. It appears that similar successful quantitative results are obtained from the planar camera (Figure 4a) and the Barcelona system (Figure 4b).

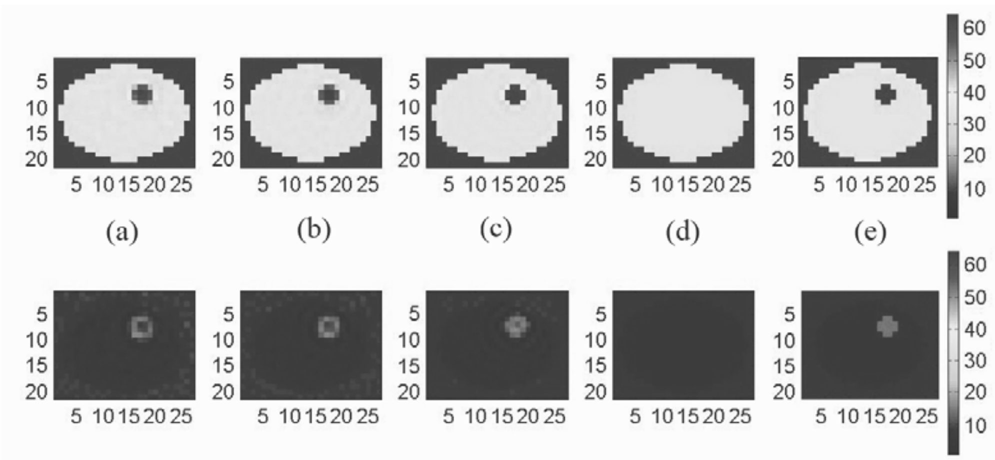

Figure 4 : Reconstructed complex permittivity after 3 iterations using noisy data for different multi-view systems
(a) Planar 2.45 GHz camera. (b) Barcelona 2.33GHz camera. (c) Complete 2.33GHz circular system.
(d) Initial guess. (e) Exact solution.

4 CONCLUSION

As compared to other existing systems, the major advantage of the microwave camera consists of its high data acquisition rate and its potential to perform rapid 3D reconstructions. It has been shown that its geometry allows obtaining reconstructed images similar to those provided by more popular circular scanners already considered for breast cancer detection. Further work will be focused on phantom experiments obtaining quantitative reconstruction on experimental data.

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