3-D Microwave Scanner for Biomedical Applications: A Preliminary Prototype

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Abstract— This paper introduces the prototype of a scanning system operating in the microwave range 0.5–4 GHz with strong potential for biomedical applications such as breast cancer detection or to assess shape-discontinuity in bones. A fully automated scanner was designed to reduce mechanical uncertainties and data acquisition time. Accurate positioning and synchronization with data acquisition enables a rigorous proof-of-concept for the microwave imaging procedure. The system can remotely control two printed antipodal Vivaldi antennas that scan a phantom across a set of positions arranged in cylindrical coordinates. For antenna miniaturization and improved coupling, the antennas and their interface and the phantom are immersed in a coupling medium that presents electric properties similar to adipose tissue. The system performs automatically both the antenna positioning and data acquisition and post-processing. In the current version the reflection coefficients are measured by a Vector Network Analyzer (VNA). But the integration of dedicated chipboard attached to each antenna to replace the VNA and speed up data acquisition is on process. Without any difficult *a priori* antenna characterization, the system is to detect, in the phantom, enclosed regions with distinctive dielectric contrast.

1. INTRODUCTION

Microwave medical imaging was presented as one as one of the most promising emerging imaging modalities of the last two decades. Although the most targeted application has been breast cancer imaging [1, 2], other biomedical diagnostic areas have also been proposed [3, 4]. Based fundamentally on the dielectric contrast between tissues, microwave medical imaging offers a low-cost, non-ionising and non-invasive method. From a practical perspective, the imaging process involves illuminating the tissue of interest with a wideband radar pulse and recording the reflected (and sometimes transmitted) signals from any dielectric boundaries present within the tissue. Several different mechanisms for combining these signals to create an image have been proposed. These algorithms can be divided into two broad categories: those that seek to identify the presence and location of significant dielectric scatterers in the tissue; and those whose aim is to reconstruct the entire dielectric profile of the tissue under examination.

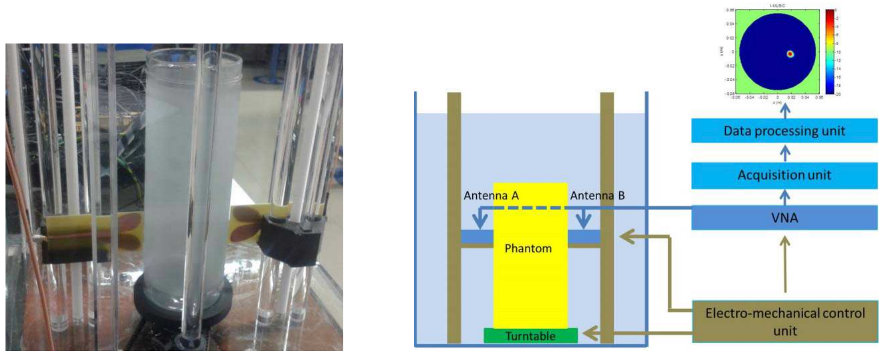
Besides, the choice of the most suitable imaging procedure, a very important role is played by the RF system and in particular by the antennas. Ultra-wideband (UWB) antennas have been largely used for microwave medical imaging as they can offer a very large operating band, stable radiation properties, and compact dimensions [5, 6]. In order to fully assess the achievable performance of a near-field microwave detection system, the presence of the antenna must be taken into account.

In this paper, we present a preliminary prototype of 3-D microwave scanner for medical applications. After a brief description of its functional parts, results are shown for the following scenarios: a metal scatterer in homogeneous background; skin-fat-muscle-bone phantom. Images are reconstructed by using three different methods: an interferometric version of the Multiple Signal Classification (MUSIC) algorithm [7], non-coherent migration [8] which is a particular version of beamforming, and the standard wideband MUSIC technique [9].

2. 3-D MICROWAVE SCANNER

The 3-D scanner here presented is meant to extend the investigation which was carried out in [7] in a more controlled environment. The prototype is made of the following parts:

- Two printed antipodal Vivaldi antennas that can be manoeuvred to adjust their height and distance from the phantom;
- A turntable that rotates the phantom with an accuracy of $+/-1°$;
- A tank that contains the measuring setup immersed in a coupling medium with permittivity equal to 12;



(a) (b)

Figure 1: (a) Detail of the scanner; (b) Functioning blocks of the scanner.

- A VNA to measure the S-parameters at terminals of the antennas;
- An acquisition unit to synchronize the antenna/phantom positioning with the data acquisition;
- A data processing unit to generate reconstructed images from the measured datasets.

The system records S_{11} and S_{22} of the antennas sampled across 801 equally sparse points in the frequency range 0.5–4 GHz.

The coupling medium was obtained with a mixture of a 50% kerosene-50% safflower oil solution and de-ionised water in the proportion of 80% and 20%, respectively, as in [7].

Although the measurements carried out in this investigation are based on a set of cylindrical positions of scanning position, the 3-D scanner can be adjusted for semi-spherical layouts as well.

3. RESULTS

The scanner was preliminary assessed for a very simple homogeneous scenario with the investigation imaged area totally filled with the coupling medium and an 8-mm thick cylindrical metal bar used as target. This test was performed in order to estimate the delocalization error due to the mismatch of the equivalent permittivity used by the algorithm to generate the image from the actual permittivity of the coupling medium. 10° rotations in 36 equally spaced measurements were taken at the same antenna height corresponding to 10° sectors.

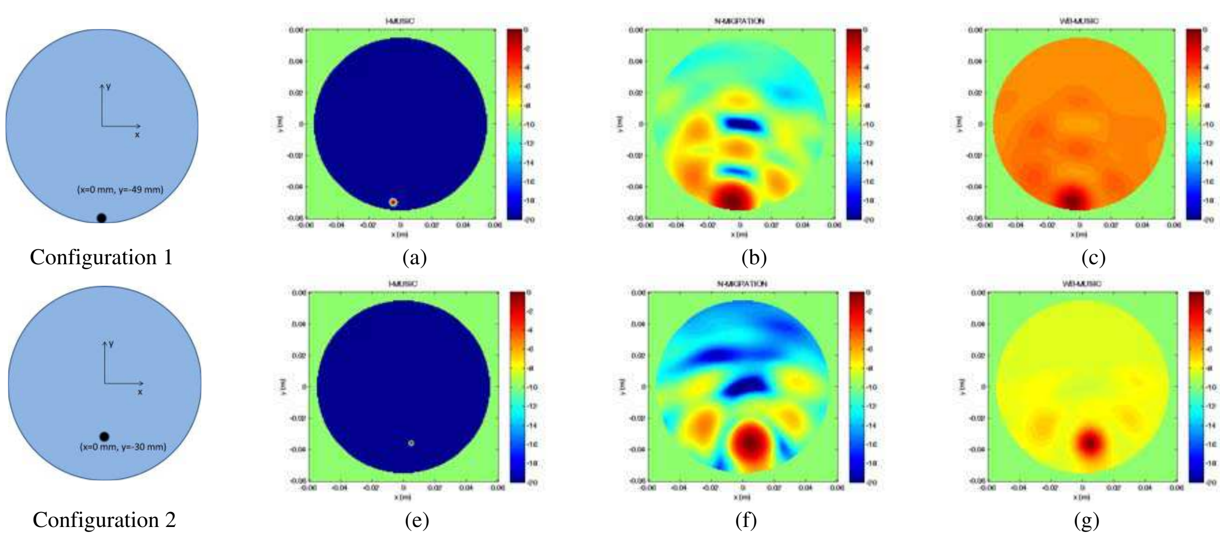


Figure 2: Image reconstructions in homogeneous scenario. (a), (e) I-MUSIC; (b), (f) non-coherent migration; (c), (g) wideband MUSIC.

A delocalization error occurs in the range of 1 mm for the configuration 1 and 5.9 mm for the configuration 2, respectively. Delocalization of the target in the reconstructed image is due to the losses of the coupling medium that are not taken into account in the Green's function of the imaging algorithms [10].

Finally a realistic phantom that mimics a cow's leg was prepared by using a bovine metacarpal bone section with muscle tissue attached and wrapped into pork fat and turkey skin for easier workability. The phantom has an overall diameter of approximately 100 mm and the length of 250 mm with the bone-section of an approximate diameter of 28 mm. Three slices spaced 10 mm were considered for the screening with 36 scans per each slice.

The dielectric properties of the corresponding human tissues in the phantom are listed in Table 1 at the centre frequency of 1.75 GHz [11–13].

Table 1: Dielectric properties of corresponding human tissues in phantom at 2.75 GHz.

	Conductivity [S/m]	**Relative permittivity**
Bone cortical	0.45429	11.207
Marrow	0.10877	5.2644
Muscle	1.9515	52.363
Fat	0.11809	5.2492
Skin	1.7802	42.442

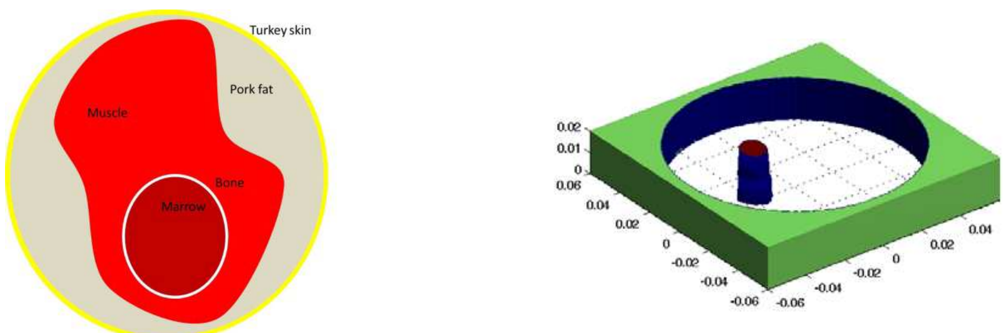


Figure 3: Sketch of the phantom cross-section. 3-D reconstruction performed with Non-coherent migration.

4. CONCLUSIONS

The prototyped 3-D scanner here presented showed significant potential in microwave medical imaging. An estimation of the delocalization error was achieved by using a metallic bar of diameter equal to 8 mm as a target in three different configurations. The measured reflection coefficients were processed with three linear non-coherent methods: an interferometric version of the Multiple Signal Classification (MUSIC) algorithm, non-coherent migration, and the standard wideband MUSIC technique. Reconstructions showed a delocalization error which is equal to 1 mm for the configuration 1 and 5.9 mm for the configuration 2, respectively.

From experimental results carried out on a multi-layer phantom including skin, fat, muscle and bone, successful reconstruction were achieved of the bone section. The phantom was scanned across three equally spaced slices to obtain a 3-D bone image reconstruction.

REFERENCES

1. Nikolova, N. K., "Microwave imaging for breast cancer," *IEEE Microwave Magazine*, Vol. 12, No. 7, 78–94, 2011.
2. Fear, E. C., P. M. Meaney, and M. A. Stuchly, "Microwaves for breast cancer detection?," *IEEE Potentials*, 12–18, Feb./Mar. 2003.
3. Fhager, A. and M. Persson, "A microwave measurement system for stroke detection," *7th Loughborough Antennas and Propagation Conference, LAPC 2011*, Loughborough, 14–15 Nov. 2011.
4. Tian, Z., P. M. Meaney, M. J. Pallone, S. Geimer, and K. D. Paulsen, "Microwave tomographic imaging for osteoporosis screening: A pilot clinical study," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, 1218–1221, 2010.

5. Jafari, H. M., M. J. Deen, S. Hranilovic, and N. K. Nikolova, "A study of ultrawideband antennas for near-field imaging," —it IEEE Trans. Antennas Propag., Vol. 55, No. 4, 1184–1188, 2007.
6. Flores-Tapia, D. and S. Pistorius, "Real time breast microwave radar image reconstruction using circular holography: A study of experimental feasibility," *Med. Phys.*, Vol. 38, 5420–5431, 2011.
7. Ruvio, G., R. Solimene, A. Cuccaro, D. Gaetano, J. E. Browne, and M. J. Ammann, "Breast cancer detection using interferometric MUSIC: Experimental and numerical assessment," *Medical Physics*, Vol. 41, No. 10, 103101/1–11, 2014.
8. Ahmad, F. and M. G. Amin, "Non-coherent approach to through-the-wall radar localization," *IEEE Trans. Aerosp. Electron. Syst.*, Vol. 42, No. 4, 1405–1419, 2006.
9. Yavuz, M. E. and F. L. Teixeira, "On the sensitivity of time-reversal imaging techniques to model perturbations," *IEEE Trans. Antennas Propag.*, Vol. 56, 834–843, 2008.
10. Solimene, R., G. Ruvio, A. Dell'Aversano, A. Cuccaro, M. J. Ammann, and R. Pierri, "Detecting point-like sources of unknown frequency spectra," *Progress In Electromagnetics Research*, Vol. B, No. 50, 347–364, 2013.
11. Gabriel, C., "Compilation of the dielectric properties of body tissues at RF and microwave frequencies," *Report N.AL/OE-TR- 1996-0037, Occupational and Environmental Health Directorate, Radiofrequency Radiation Division*, Brooks Air Force Base, Texas, USA, June 1996.
12. Gabriel, C., S. Gabriel and E. Corthout, "The dielectric properties of biological tissues: I. Literature survey," *Phys. Med. Biol.*, Vol. 41, 2231–2249, 1996.
13. Gabriel, S., R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Phys. Med. Biol.*, VOl. 41, 2251–2269, 1996.