Accuracy investigation of an ultra-wideband time domain microwave imaging system

ACCURACY INVESTIGATION OF AN ULTRA-WIDEBAND TIME DOMAIN MICROWAVE IMAGING SYSTEM.

X. Zeng[1, 2], A. Fhager[1], P. Linner[2], M. Persson[1], and H. Zirath[2]
[1]Division of Biomedical Engineering, Chalmers University of Technology, Gothenburg, Sweden, [2]Microwave Electronics Laboratory, Chalmers University of Technology, Gothenburg, Sweden.

Introduction: As a potential imaging modality for biomedical applications, active microwave imaging has attracted considerable interest in the past few decades [1-3]. With active microwave imaging, biological tissues are differentiated based on differences in dielectric properties. A lot of studies have been carried out on measuring the dielectric properties of different types of biological tissues and the results have shown that their values vary a lot depending on the tissue water content [4-6].

Microwave tomography is a classical approach to active microwave imaging which poses an inverse scattering problem. In a typical microwave tomography system, an antenna array is used to transmit microwave signals into an object-under-test and acquire scattered signals. By iteratively solving a nonlinear inverse problem, the dielectric properties of the object are quantitatively reconstructed from the scattered signals. Reconstructions based on mono-frequency data, multiple frequency data or time domain data have been theoretically and experimentally investigated [7-9]. It has been shown that the reconstruction quality can benefit from the use of ultra-wideband (UWB) data [9].

Measurement speed is crucial for a clinical imaging system, while our current UWB microwave tomography system works in frequency domain, which is time consuming [9]. With this measurement strategy, scattering parameters at many discrete frequencies are measured by means of a commercial vector network analyzer (VNA). The obtained data are then utilized to synthesize time domain signals for image reconstructions. In comparison with a UWB frequency domain system (e.g, a VNA), a UWB time domain system has the advantage of fast acquisition of UWB data and low cost, which is preferable for the clinical applications of microwave tomography.

Microwave measurements are subject to unavoidable errors, which may degrade the quality of the reconstructed images depending on the size of error [10]. Compared to a frequency domain system, a time domain system has relatively poor signal to noise ratio, therefore there is a need to investigate if it is accurate enough for microwave imaging.

In this paper, an investigation on the measurement accuracy of a UWB time domain microwave tomography system is carried out. In order to investigate if the system is accurate enough for microwave tomography, a phantom is tested with the system and the reconstructed images are compared to those obtained by using a UWB frequency domain system.

Experimental System: Fig. 1 shows the system block diagram of the UWB time domain microwave tomography system. The UWB time domain experimental system mainly consists of a transmitter module, a data acquisition module, an antenna array, and a switching matrix. The transmitter module is an impulse generator and the data acquisition module consists of a digitizing oscilloscope mainframe and a wideband two channel test set. The antenna array consists of twenty monopole antennas, which are evenly distributed on a circle with radius of ten centimeters. The mechanical switching matrix is used for changing the transmitting and receiving antenna pairs.

Results: A plastic cup of oil is put in the center of the antenna array for testing. No averaging is applied in the measurements. The dielectric properties of the phantom are reconstructed from the measured data by the use of a time domain inversion algorithm [9].

The phantom's permittivity and conductivity profiles reconstructed from the time domain measurements are shown in Fig. 2 and Fig. 3 respectively in comparison with those obtained by using a VNA. The reconstructions are made in two dimensions and the reconstructed region is a circle with radius of 90 mm, with its center coinciding with the center of the antenna array. The color bars on the right of each image give the reconstructed permittivity and conductivity values.

It is shown that the permittivity profiles reconstructed from time domain measurements and frequency domain measurements are very similar to each other. Both the location and size of the cup are well reconstructed in the permittivity profiles. The conductivity profiles obtained from both time domain and frequency domain measurements have poorer quality than the reconstructed permittivity profiles. A hole occurs in both pictures and the conductivity reconstructed from time domain measurements shows more artifacts than that obtained from frequency domain measurements. Since the reconstructed conductivity profiles are not as reliable as those of the permittivity, we care more about the permittivity reconstructions.

Conclusion: The reconstructions of the phantom made from time domain measurements show very small difference from those obtained from frequency domain measurements. Therefore, it is concluded that the presented UWB time domain system is accurate enough for the reconstructions of the phantom while still sustaining the advantages of fast measurement and low cost. More complex phantoms will be tested in the next step in order to further evaluate the measurement accuracy of the UWB time domain system.

Acknowledgement: This work was supported in part by VINNOVA within the VINN Excellence Center Chase, and in part by SSF within the Strategic Research Center Charmant.

REFERENCES

[1] C. Pichot, L. Jofre, G. Peronnet, and J. C. Bolomey, ``Active microwave imaging of inhomogeneous bodies," IEEE Trans. Antennas Propagat., vol. AP-33, no. 4, pp. 416--425, Apr. 1985.

[2] J. C. Bolomey, A. Izadnegahdar, L. Jofre, C. Pichot, G. Peronnet, and M. Solaimani,"Microwave diffraction tomography for biomedical applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, no.11, pp. 1998-2000, Nov. 1982.

[3] L. Jofre, M. S. Hawley, A. Broquetas, E. de los Reyes, M. Ferrando, and A. R. Elias-Fuste, "Medical imaging with a microwave tomographic scanner," *IEEE Trans. Biomed. Eng.*, vol. 37, no. 3, pp. 303-312, Mar.1990.

[4] T. S. England and N. A. Sharples, "Dielectric properties of the human body in the microwave region of the spectrum," *Nature*, vol. 163, pp. 487–488, Mar. 1949.

[5] K. R. Foster and H. P. Schwan, "Dielectric properties of tissues and biological materials: A critical review," *Crit. Rev. Biomed. Eng.*, vol. 17, pp. 25–104, 1989.

[6] M. Lazebnik, D. Popovic, L. McCartney, C. Watkins, and etc., "A large scale study of the ultrawideband microwave dielectric properties of normal, benign and malignant breast tissues obtained from cancer surgeries," *Phys. Med. Biol.*, vol. 52, pp. 6093-6115, 2007.

[7] Q. H. Liu, Z. Q. Zhang, T. T. Wang, J. A. Bryan, G. A. Yabbara, L. W. Nolte, and W. T. Jones, "Active microwave imaging I - 2-D forward and inverse scattering methods," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 1, pp. 123-133, Jan. 2002.

[8] Q. Fang, P. M. Meaney, and K. D. Paulsen, "Microwave image reconstruction of tissue property dispersion characteristics utilizing multiple frequency information," IEEE Trans. Microwave Theory Tech., vol. 52, no. 8, pp. 1866–1875, Aug. 2004.

[9] 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.

[10] Z. Wu, ``Effects of noise and system parameters on the tomographic image reconstruction of ground surfaces," IEEE Trans. Antennas Propagat., vol. 51, no. 6, pp. 1401-1403, 2003.

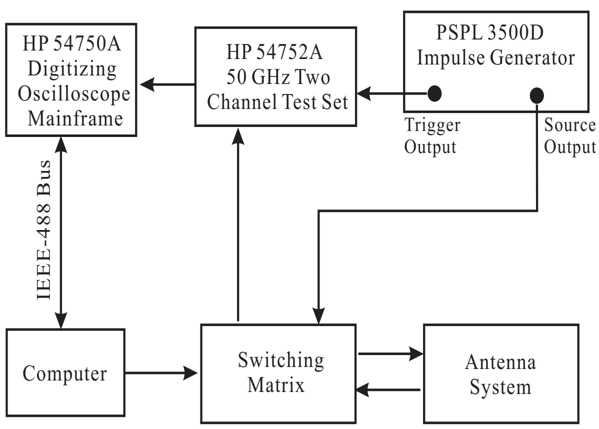
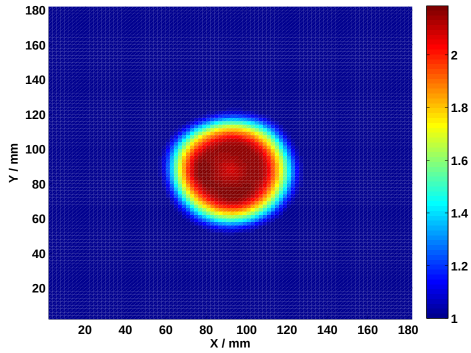
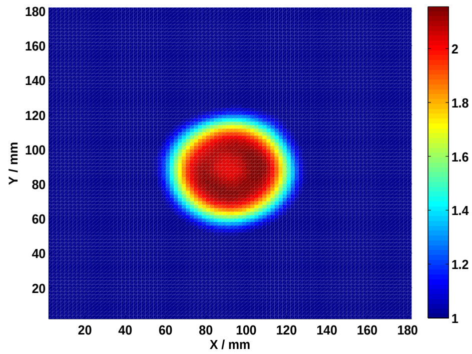


Fig.1. The block diagram of the UWB time domain microwave tomography system.

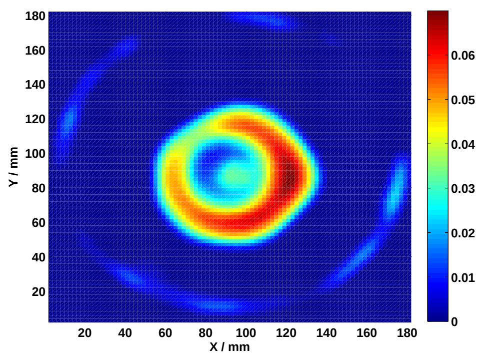


(a)

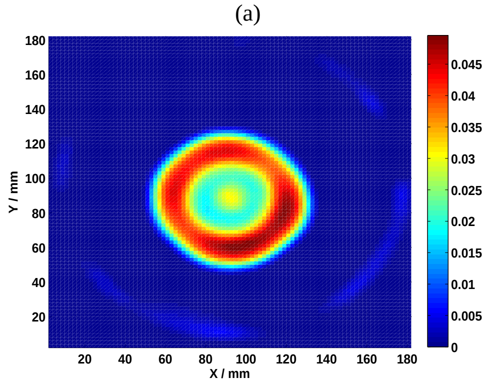


(b)

Fig. 2 The permittivity profiles of the phantom reconstructed from (a) time domain measurements and (b) frequency domain measurements.



(a)



(b)

Fig. 3 The conductivity profiles of the phantom reconstructed from (a) time domain measurements and (b) frequency domain measurements.