Experimental Comparison of Two Printed Monopole Antenna Designs for Microwave Tomography

1st Syed Ahsan  
Department of Informatics  
King’s College London  
London, UK  
syed.s.ahsan@kcl.ac.uk

2nd Wei Guo  
Department of Informatics  
King’s College London  
London, UK  
wei.guo@kcl.ac.uk

3rd Olympia Karadima  
Department of Informatics  
King’s College London  
London, UK  
olympia.karadima@kcl.ac.uk

4th Panagiotis Kosmas  
Department of Informatics  
King’s College London  
London, UK  
panagiotis.kosmas@kcl.ac.uk

Abstract—This paper presents an initial experimental comparison of two custom-made printed monopole antenna arrays for microwave imaging (MWI). Data is obtained by using the MWI system in the presence of regularly shaped gel phantoms mimicking the dielectric properties of average brain and blood. The antenna array and phantom are immersed inside a 90% glycerol, 10% water mixture. Our in-house two-dimensional (2D) imaging algorithm is applied to the acquired data to test and validate the sensitivity of the system, and the value of using multiple frequency reconstructions enabled by wideband antenna operation is demonstrated.

Index Terms—printed monopole antennas, microwave tomography, brain stroke detection, microwave imaging

I. INTRODUCTION

Microwaves have been studied for medical diagnostics in the past couple of decades (see for example [1] for a recent special issue on this topic). Microwave imaging (MWI) technology promises to lower significantly the cost of developing and maintaining a medical imaging device, and at the same time make it possible to realize safe and portable scanning devices.

Microwave tomography (MWT) is currently investigated for brain stroke detection as there is potentially enough dielectric contrast between the affected region and the surrounding healthy area [2]. The task of developing a MWT scanner for brain stroke detection involves various parameters, and the design of a suitable antenna and its incorporation in an array formation is among the most critical ones.

Several antennas for MWT have been reported in the literature, for example [3]–[6]. Theoretical studies on a simplified brain model [7] have argued that the optimum frequency of operation for a head imaging scanner ranges between 0.6 to 1.5 GHz and the matching medium’s dielectric constant should be between 10 and 40. Studies with our algorithm [8], [9] have shown that low frequencies can increase the algorithm’s stability, while high frequency operation can potentially yield higher resolution.

To satisfy the required characteristics of the antenna element, we have designed and fabricated spear-shaped and triangular patch printed monopole antennas that operate in 0.5-2.5 GHz frequency range when immersed in a 90% glycerol, 10% water mixture. This paper studies the imaging performance of both antennas by testing them under similar experimental conditions and applying the same algorithm to reconstruct gel-based regularly shaped phantoms. Reconstruction results demonstrate the value of using multiple frequency information enabled by wideband antenna operation, which is achieved particularly for the spear-shaped antenna.

II. EXPERIMENTAL SETUP AND DATA ACQUISITION

A. The Measurement System

Our system is comprised of the two types of printed monopole antennas shown in Fig. 1(a), with details on their exact design and geometrical features reported in [10]. We construct an array of eight individual antenna elements in an elliptical form surrounding the region of interest (ROI). Measured reflection parameters ($S_{11}$) of both antennas are shown in Fig. 1(b). We use Keysight’s PXI vector network analyser modules (M9370A) for our measurements. We calibrate the system with a two-port electronic calibration (Ecal) unit where we choose 201 points with an intermediate frequency (IF) of 200 Hz. Moreover, we also enable averaging with an averaging factor of 5 for these measurements.

The mechanical part of our MWT system is comprised of an imaging chamber and fixtures to mount the antennas...
and regulate their positioning. The imaging chamber is a large acrylic cylinder of 300 mm diameter, surrounded by an absorber (ECCSORB MCS) which is also covered with a metallic sheet to prevent any surface waves around the tank periphery and external interference. The imaging tank is filled with 90% glycerol water mixture and the phantom is inserted concentrically with the tank. The antennas are mounted at the bottom of the vertical supports using a 3D printed bracket.

The antennas are distributed elliptically around a 3D printed acrylic ellipsoid, and are numbered in clockwise direction. The distance between antennas and the plastic core of the phantom is kept at 10 mm. We have constructed gel-based average brain and blood phantoms specifically to mimic the properties of these media in the desired frequency range of 0.5 to 2.5 GHz.

We carry out two sets of measurements, firstly we fill up the ellipsoid with average brain material and record the data. This data is treated as a data with no inclusion (no target case), subsequently, we insert a cylindrical gel phantom mimicking blood into the average brain phantom at (-30, 30) with respect to the centre of the chamber (“with target case”) as shown in Fig. 2.

B. Transmission Signals

To quantify the impact of the target on the array signals, we have calculated signal differences between transmitted signals in the presence of the target (blood) and the no-target case. The magnitude of these signals (in dB) scattered from the target are plotted for the two arrays of different antennas as function of receiver locations at 1.0, 1.5 and 2.0 GHz in Fig. 3.

3. These plots show that both antennas have quite similar levels of signal differences recorded at lower frequencies (1.0 GHz), whereas at 2.0 GHz the spear patch antenna is more sensitive to the scattered signals relative to the triangular patch. For the triangular patch antenna, we observe the signal level approaching -100 dB, which is comparable to the noise floor for the given settings, suggesting that we do not have reliable data for this antenna for frequencies equal or higher than 2.0 GHz. As we will see in the next section, this observation has a direct consequence on our attempted reconstructions, which cannot be successful when the triangular patch operates above 1.5 GHz.

III. RECONSTRUCTION RESULTS

We have applied our 2D DBIM-TwIST algorithm [8], [9] to the acquired data to perform image reconstructions. We carried out two sets of reconstructions 1) single frequency and 2) multifrequency (frequency hopping). Details of how the algorithm is applied can be found in our previous work [8], [9], [11]. Reconstruction results obtained by applying a single frequency DBIM-TwIST algorithm are shown in Fig. 4, where we reconstruct epsilon infinity ($\epsilon_\infty$) of the imaging domain.
The spear patch antenna array yields good reconstruction results both at high and low frequencies. However, as inferred from the signal differences plot, the triangular patch array doesn’t yield successful reconstructions at 2 GHz and beyond.

We then continue our evaluation of the performance of our two antennas under study by applying our algorithm for multiple frequencies by frequency hopping on the same dataset as before. Frequency hopping reconstruction results are shown in Fig. 5 and 6. We studied two different bands of frequency hopping reconstructions to evaluate the performance of the antennas at low and high frequencies. We consider the 0.9-1.5 GHz band as a representative of low frequency and 0.9-2.2 GHz as a high frequency band, and performed reconstructions every 0.2 GHz. We selected these bands of operation to demonstrate our initial claim that the high frequency data reconstructions are not likely to work with the triangular patch antenna due to low level of signal transmissions.

IV. CONCLUSION

In this paper we have compared the performance of our two custom made printed monopole antennas designed for brain stroke imaging system. We studied the impact of a strong scatterer on the signals produced and recorded by these antennas, by configuring them in the form of an elliptical array around a gel-based average brain phantom. We have also applied our 2D DBIM-TwIST imaging algorithm on these experimental datasets. We have shown that the triangular patch shows good performance up to 1.5 GHz, while the spear patch printed monopole yields good results at higher frequencies as high as 2.2 GHz.

REFERENCES

[1] P. Kosmas and L. Crocco, “Introduction to Special Issue, Electromagnetic Technologies for Medical Diagnostics: Fundamental Issues, Clinical Applications and Perspectives,” Diagnostics, vol. 9, 19, Mar. 2019.
[2] M. Hopfer, R. Planas, A. Hamidipour, T. Henriksson, and S. Semenov, “Electromagnetic tomography for detection, differentiation, and monitoring of brain stroke: A virtual data and human head phantom study,” IEEE Antennas and Propag. Mag., vol. 59, no. 5, pp. 86–97, 2017.
[3] P. M. Meaney, M. W. Fanning, D. Li, S. P. Poplack, and K. D. Paulsen, “A clinical prototype for active microwave imaging of the breast,” IEEE Trans. on Microw. Theory and Tech., vol. 48, no. 11, pp. 1841–1853, 2000.
[4] C. Gilmore, P. Mojabi, A. Zakaria, M. Ostadrahimi, C. Kaye, S. Noghanian, L. Shafai, S. Pistorius, and J. LoVerdi, “A wideband microwave tomography system with a novel frequency selective structure,” IEEE Trans. Biomed. Eng., vol. 57, pp. 894–904, April 2010.
[5] B. J. Mohammed, A. M. Abbosh, S. Mustafa, and D. Ireland, “Microwave system for head imaging,” IEEE Trans. Instrum. Meas., vol. 63, pp. 117–123, Jan 2014.
[6] S. Y. Semenov, R. H. Svensson, A. E. Boulyshev, A. E. Souvorov, V. Y. Borisov, Y. Sizov, A. N. Starostin, K. R. Dezer, G. P. Tatsis, and V. Y. Baranov, “Microwave tomography: two-dimensional system for biological imaging,” IEEE Trans. Biomed. Eng., vol. 43, pp. 869–877, Sept 1996.
[7] R. Scapaticci, L. Di Donato, I. Catapano, and L. Crocco, “A feasibility study on microwave imaging for brain stroke monitoring,” Progress In Electromagnetics Research, vol. 40, pp. 305–324, 2012.
[8] Z. Miao and P. Kosmas, “Microwave breast imaging based on an optimized two-step iterative shrinkage/thresholding method,” in Proc. 2015 9th European Conf. Antennas and Propag. (EuCAP), pp. 1–4, May 2015.
[9] Z. Miao and P. Kosmas, “Multiple-frequency DBIM-TwIST algorithm for microwave breast imaging,” IEEE Trans. Antennas Propag., vol. 65, pp. 2507–2516, May 2017.
[10] W. Guo, S. Ahsan, M. He, M. Koutsoupidou, and P. Kosmas, “Printed monopole antenna designs for a microwave head scanner,” in 2018 8th Mediterranean Microwave Symposium (MMS), pp. 384–386, Oct 2018.
[11] S. Ahsan, Z. Guo, Z. Miao, I. Sotiropou, M. Koutsoupidou, E. Kallos, G. Palikaras, and P. Kosmas, “Design and experimental validation of a multiple-frequency microwave tomography system employing the dbim-twist algorithm,” Sensors, vol. 18, no. 10, 2018.