Realistic Numerical Modelling for 3-D brain stroke monitoring

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***Abstract*— This paper aims to provide a realistic 3-D modelling framework of a real-world microwave imaging system for brain monitoring that mimics pre-assessment experimental clinical scenarios and lab setups. The model considers an anthropomorphic adult head with multiple tissues, a hemorrhagic brain stroke and a detailed prototype of a modular microwave antennas helmet. The set of antennas detect changes in the permittivity of biological tissues and then imaging reconstruction algorithms generates a 3-D representation of stroke using EM fields and scattering data generated by a full-wave numerical simulation. As results, it is presented a reconstruction of onset stroke in the white matter area of the brain using a TSVD algorithm and the born approximation for imaging.**

Keywords—Numerical modelling; Microwave imaging; stroke; inverse problem; TSVD

I. Introduction

Stroke is a severe neurological disease that triggers brain cell death due to the lack of the normal supply of oxygen-rich blood and nutrients to part of the brain when a blood vessel is either blocked by a clot or bursts (or ruptures). It is major cause of death and collateral disabilities worldwide, and its promptly and correct diagnostic is still a paradigm in the medical community. Currently, clinicians support the diagnostic and treatment employing traditional imaging-based technologies as Magnetic Resonance Imaging (MRI) or X-ray based Computerized Tomography (CT). However, traditional techniques present limitations in either prehospital environments and post-acute stage follow-up (monitoring on patient bed), encouraging recently an intense interest and research on alternative and complementary technologies based on microwave imaging (MWI). These as options of system less bulky, more cost-effective and that uses low-intensity power [1]-[2].

MWI techniques allow to map the structure of the brain zone and distinguish between healthy and stroke-affected regions relying on the contrast of the electrical properties (permittivity and conductivity) that exhibit the human tissues and pathological status under an electromagnetic field in the microwave frequency. In the last years, several MWI devices and prototypes have been proposed [3]-[7]. Among them, the two most prominent examples are the Strokefinder developed by Medfield Diagnostics [3], and the EMTensor BrainScanner [4]. The Strokefinder is a device which aims at discriminating between ischemic and hemorrhagic strokes in the early stage of patient rescue and The EMTensor BrainScanner aims at brain stroke tomography. Also, Politecnico di Torino [5]-[6] and University of Queensland [7] present examples of systems of low-complexity under development.

This paper aims modelling a realistic digital twin of a real MWI system for brain stroke monitoring, and it has a double purpose. First, the model allows to forecast and analyze the outcomes of lab experiments and test. Second, it generates the EM fields used to build the imaging kernel, and the differential scattering parameters used by the reconstruction imaging algorithms.

II. Numerical Modelling and Imaging

A. Microwave imaging system

The modeled MWI device is a system designed adopting the theorical and rigorous process presented by [5]. This is a system of 24 printed monopoles immersed each one in a brick of matching medium, working at 1 GHz and placed conformally on a human head. The model uses a reliable and detailed full-wave simulation that employs a commercial computer-aided design (CAD) and EM simulation software. The numerical solver used is based on Method of Moments applied to surface integral equations employing higher-order basis functions and a quadrilateral mesh.

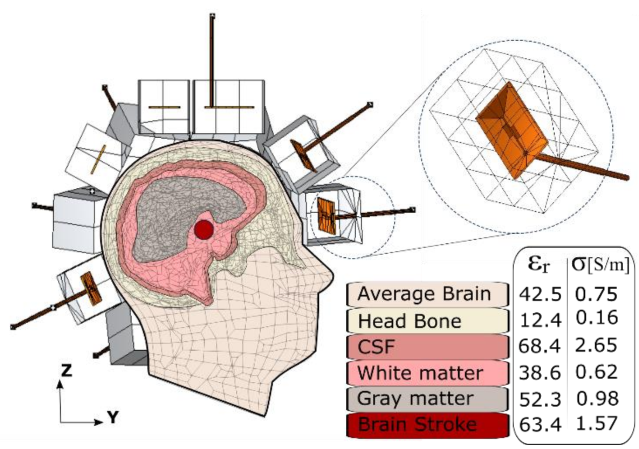

Fig 1. Realistic model of a microwave imaging system with a table of permittivity a conductivity of the used head's tissues at 1GHz.

Figure 1 represents a middle cut of the CAD model of the antennas' helmet and the anthropomorphic head, and a summing up brick antenna. The head model contains five different tissues and spherical-shaped hemorrhagic stroke with 10mm of radius. Each antenna brick represents a TX/RX one. The antenna is

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modeled using conventional FR4, the dielectric brick mimics a mixture of urethane rubber and graphite powder designed to minimize the losses, and the antenna ports are placed at the end of the coaxial cables outgoing from the bricks. The dielectric characteristics of the bricks are ε_r = 18.5 and σ = 0.2 S/m at 1 GHz.

B. *Imaging algorith and validation test*

Considering the approached application is in the frame of stroke monitoring, we aim imaging "small" variation of the brain and not the overall structures and features. Hence, we select a differential method for testing and rely on the distorted Born approximation, which leads to a strong simplification of the mathematical problem underlying MWI, allowing a real time and reliable imaging of the stroke variation. The imaging reconstruction algorithm has as input data the scattering matrices measured in two instants of time, denoted as ΔS in the following, while the output is a 3-D representation of the possible variation of the electric contrast of the brain tissues, say Δ_χ. Then, linearizing the problem the relationship holds between ΔS and Δ_χ:

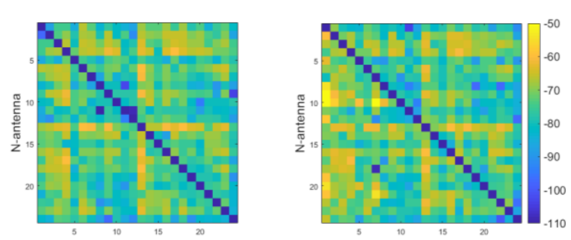
$$\Delta S(r_p\,, r_q) = \mathbf{S}(\Delta_\chi), \qquad (1)$$

where $\mathbf{S}$ is a linear and compact integral operator, whose kernel is $-\frac{j\omega\varepsilon_b}{4}\boldsymbol{E}_b(r_m, r_p)\cdot\boldsymbol{E}_b(r_m, r_q)$, with r_m as the positions of the points in which the imaging domain is discretized, and r_p and r_q denoting the positions of the transmitting and receiving antennas. $\boldsymbol{E}_b$ is the background field in the unperturbed scenario, which employed a single tissue head with average brain dielectric considering the operator works with different kind of heads in real scenarios. Then, the well-established method, represented by the truncated singular value decomposition (TSVD) scheme, is used to invert (1). It allows us to obtain the unknown differential contrast function through the inversion formula:

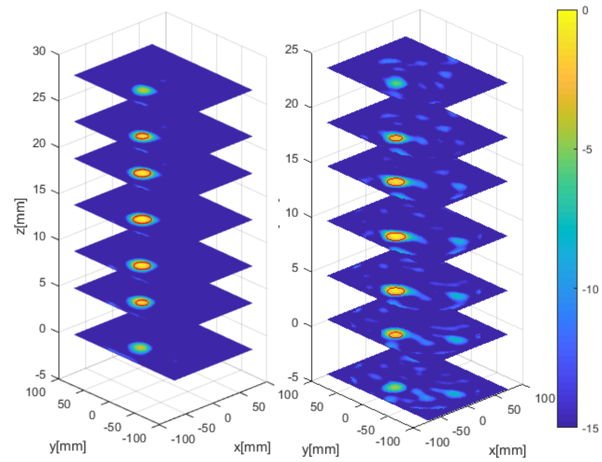
$$\Delta_\chi = \sum_{n=1}^{L_t} \frac{1}{\sigma_n}\langle \Delta S, [u_n]\rangle [v_n], \qquad (2)$$

where $\langle |u||\sigma||v|\rangle$ is the SVD of the discretized scattering operator $\mathbf{S}$. L_t is the truncation index of the SVD acting a regularization parameter.

For testing two scenarios were tried. First, mimicking a lab setup, the model uses a single material head filled with a average brain dielectric. Then, a multi-tissues head model is modeled to mimic more realistic clinical scenarios. Figure 2 depicts the respective scattering matrix for both cases and the 3-D reconstructed images, where the red circles refer to the expected stroke shape, obtaining in both cases a very good reconstruction.



(a) (b)



(c) (d)

Fig 2. Evaluation cases of the numerical model using imaging reconstruction algorithm. (a)-(b) Differential scattering matrix at the antenna ports scaled in dB for the case with average head and multi-tissues head respectively. (c)-(d) Reconstruction image of a hemorrhagic stroke for the cases (a) and (b).

III. Conclusion

We presented a description and validation of a full-wave numerical model of a brain stroke monitoring system generating reliable 3-D imaging reconstruction of likely clinical condition and lab setup.

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