Hybrid Resolvent Kernel Calibration Technique for Microwave Imaging Systems

Original
Hybrid Resolvent Kernel Calibration Technique for Microwave Imaging Systems / Rodriguez-Duarte, D. O.; Origlia, C.; Tobon, Jorge; Vipiana, F.. - ELETTRONICO. - (2021), pp. 2014-2015. (Intervento presentato al convegno 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI) tenutosi a Singapore (Singapore) nel 4-10 Dec. 2021) [10.1109/APS/URSI47566.2021.9704044].

Availability:
This version is available at: 11583/2958716 since: 2022-03-17T17:52:33Z

Publisher:
IEEE

Published
DOI:10.1109/APS/URSI47566.2021.9704044

(Article begins on next page)

Hybrid Resolvent Kernel Calibration Technique for Microwave Imaging Systems

D. O. Rodriguez-Duarte*, C. Origlia, J. A. Tobon Vasquez, F. Vipiana
Dept. Electronics and Telecommunications, Politecnico di Torino, Torino, Italy,
{david.rodriguez, cristina.origlia, jorge.tobon, francesca.vipiana}@polito.it

***Abstract*—This work assesses a hybrid calibration technique that uses together measured and simulated data to compensate modeling errors such as fabrication tolerances and positioning inaccuracies. Here, as a proof-of-concept, it is considered a virtual microwave imaging experiment of a human brain stroke condition. The test involves a full-wave software based on the finite element method and 3-D highly realistic system models, including a set of 24 monopoles immersed in a solid brick-shaped matching medium and a single-cavity anthropomorphic head phantom. The studied case shows that under favorable assumptions, the calibration procedure improves the quality of the retrieved images compared to the non-calibrated-kernel approach.**

***Index Terms*—Measurements calibration, microwave imaging, numerical simulation, microwave antenna arrays, microwave propagation.**

I. Introduction

Microwave imaging (MWI) is an emerging technology in development with a high potential in the industry and the medical fields. It deals with applications where optically obscured targets, unreachable directly, present an unknown electrical contrast at microwave frequency. For instance, in the brain stroke case, the contrast is denoted by the difference of electrical properties of the stroke-affected area compared with the healthy tissues [1].

MWI is a nonlinear and ill-posed inverse scattering problem that maps the dielectric properties of a domain of interest (DOI) from a limited set of electromagnetic (EM) measurements taken outside of DOI. A general scheme of an MWI system consists of antennas around the DOI acting as transmitters and receivers, which sample the field in the antenna locations, and an inverse scattering algorithm that retrieves the contrast map (image) employing an inherently system-specific resolvent kernel. It gathers the particulars of the measurement setup by estimating the incident field distributions inside the DOI through analytical models or high-fidelity simulations.

However, achieving an accurate characterization of the incident field inside the imaging domain is challenging due to the harmful effects of non considered factors or incomplete representation of the acquisition setup. It leads to an approximation that contains modeling errors such as fabrication tolerances or positioning errors, which are unavoidable in real scenarios. These unwanted and non-modeled variations act on the inverse-problem solution similar to the noise in the measured data [2].

Hence, to improve the performance of a MWI system, both measuring and modeling errors should be calibrated. For instance, in [3], a full two-port calibration is applied to diminish error due to source match, cross-talk, among others. Other calibration approaches attempt to tune the measured scattering parameters with the assumed numerical model using a known scenario as a reference [4]–[6], compensating systematic measuring errors. Alternatively, [2] derives the resolvent kernel in the forward model from calibration measurements, preventing the approximation in the incident field, but requiring the measures of the system point-spread function.

This work considers a hybrid simulation-measurement (HS-M) that deals with the modeling errors. The method intends to calibrate the resolvent kernel, tuning the field distribution via a projection of measured scattering parameters on a custom set of basis functions obtained from multiple high-fidelity simulations. It is inspired in [7], where measurements and a-priori information are exploited for antenna testing, and posed and preliminary assessed in a single-antenna scenario in [8]. Here, the HS-M calibration is applied to a realistic scenario of hemorrhagic stroke imaging.

II. Methods

A. Imaging Algorithm and Study Case

A differential algorithm based on truncated singular value decomposition(TSVD) and the Born approximation is employed [1]. Besides, an intracranial hemorrhagic stroke condition, virtually mimicked, is selected to proof the calibration concept. The virtual setup consists of a single-cavity anthropomorphic head, filled up with average brain liquid ($\epsilon = 45.38$, $\sigma = 0.77\,\text{S/m}$) [1], and a conformal array of 24 brick-shaped antennas placed around the head [10]. The full-fledged system is 3-D modeled and full-wave simulated by an in-house finite element method solver [9].

Then, the experiment considers as a nominal case a healthy scenario (without stroke). It is simulated assuming the projected design (optimal positioning of the antennas) and non-manufacturing errors, i.e., the one typically used to build the imaging kernel. While an altered scenario with random variations of the placing and permittivity of all antennas, in comparison to the nominal case, mimics a realistic measurement setup.

This work was supported by the Italian Ministry of University and Research under the PRIN project "MiBraScan", and by the European Union's Horizon 2020 Research and Innovation Program under the EMERALD project, Marie Sklodowska-Curie grant agreement No. 764479.

B. HS-M Calibration

HS-M calibration aims to render the field employed for the imaging algorithm close to the real one, compensating the initial nominal field with information obtained from comparing the scattering parameters of multiple simulations and the measured ones. It comprises two main procedures, the basis function definition and the estimation of calibration coefficients.

The basis definition is the most computationally heavy part of the procedure, though it is performed once and off-line. It builds a basis applying the singular value decomposition (SVD) to simulated scattering parameters obtained via a systematic set of EM simulations considering the potential sources of error as variables. In this specific case, we select as variables the gap-distance between the head and the matching medium block and the permittivity of the matching medium, which are key factors in the antennas' performance [10]. The gap-distance varied from 0 mm to 10 mm, and the nominal permittivity scaled between 0.9 to 1.1, taking as reference the nominal value of the brick ($\epsilon = 18.5$, $\sigma = 0.012$ S/m).

Finally, the field radiated by the MWI system in DOI, not available by measurements, is estimated by applying the calibration coefficients on the simulated fields. The calibration computes the coefficients using the measured scattering parameters (the altered case here) and the ones from the systematic set of simulations. Details on the coefficients determination and mathematical framework can be found in [8].

III. Numerical Results

This section presents a preliminary validation of HS-M calibration scheme using a synthetic case. Then, the relative error between the target field and the calibrated and non-calibrated ones is compared. The "Target" refers to the field of the altered case (measured), the "non-Calibrated" to the nominal one, and the "Calibrated" to the one applying HS-M. Figure 1 shows a frontal-slice view of the error on the field produced by one of the antennas, evidencing the effect of the calibration.

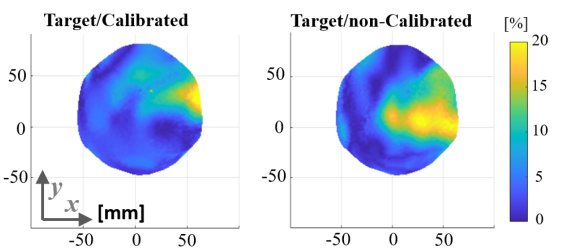

Fig. 1. Relative error of the electric field respect to the target one -Frontal view-. (left):Calibrated; (right):Non-calibrated.

The second result considers the effect of the calibration on the imaging reconstruction, taking as a reference scenario the reconstruction employing the non-altered setup for obtaining the fields and the parameters (best case), i.e., the kernel does not have modeling errors. Conversely, both test cases get the parameter from the altered setup, while the kernel is build

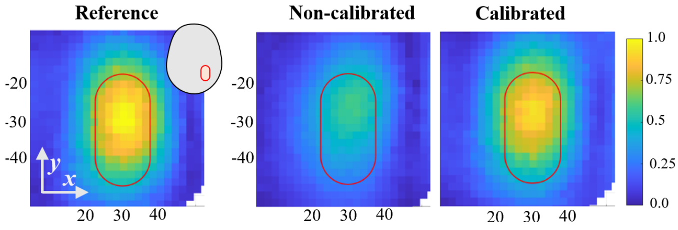

Fig. 2. Top view of reconstructed images. The red shape indicates the actual shape of the hemorrhagic stroke. Dimensions in [mm].

using calibrated and non-calibrated fields, respectively. Then, all the reconstructed images are normalized with the maximum of the reference and depicted in Fig.2, which reveals a clear improvement in the calibrated case.

IV. Conclusion and Perspectives

The HS-M calibration shows potential to improve the retrieved outcomes of a complex system for brain stroke imaging using both simulated and measured data, mitigating the effect of unavoidable modeling errors. For the next steps, we plan to apply it to actual measured data from the MWI system presented in [1].

References

[1] J. A. Tobon Vasquez et al., "A Prototype Microwave System for 3D Brain Stroke Imaging," in Sensors, vol.20, no. 9, May 2020, doi: 10.3390/s20092607

[2] S. Tu, J. J. McCombe, D. S. Shumakov and N. K. Nikolova, "Fast quantitative microwave imaging with resolvent kernel extracted from measurements," in Inverse Problems, vol. 31, 2015, doi: 10.1088/0266-5611/31/4/045007.

[3] J. A. Tobon Vasquez et al., "Design and Experimental Assessment of a 2D Microwave Imaging System for Brain Stroke Monitoring," in Int. Journal of Antennas and Propagation, vol.2019, 2019, doi: 10.1155/2019/8065036

[4] P. M. Meaney, K. D. Paulsen and J. T. Chang, "Near-field microwave imaging of biologically-based materials using a monopole transceiver system," in IEEE Transactions on Microwave Theory and Techniques, vol. 46, no. 1, pp. 31-45, Jan. 1998, doi: 10.1109/22.654920.

[5] M. Ostadrahimi et al., "Analysis of Incident Field Modeling and Incident/Scattered Field Calibration Techniques in Microwave Tomography," in IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 900-903, 2011, doi: 10.1109/LAWP.2011.2166849.

[6] O. Karadima, M. Rahman, J. Sotiriou, N. Ghavami, P. Lu, S. Ahsan, and P. Kosmas, "Experimental validation of microwave tomography with the DBIM-TwIST algorithm for brain stroke detection and classification," *SENSORS*, vol. 20, Feb. 2020.

[7] G. Giordanengo, M. Righero, F. Vipiana, G. Vecchi and M. Sabbadini, "Fast Antenna Testing With Reduced Near Field Sampling," in IEEE Transactions on Antennas and Propagation, vol. 62, no. 5, pp. 2501-2513, May 2014, doi: 10.1109/TAP.2014.2309338.

[8] D. O. Rodriguez-Duarte, J. A. Tobon Vasquez and F. Vipiana, "Hybrid Simulation-Measurement Calibration Technique for Microwave Imaging Systems," 2021 15th European Conference on Antennas and Propagation (EuCAP), 2021, pp. 1-5, doi: 10.23919/EuCAP51087.2021.9411459.

[9] D. O. Rodriguez-Duarte, J. A. Tobon Vasquez, R. Scapaticci, L. Crocco,and F. Vipiana, "Assessing a microwave imaging system for brain stroke monitoring via high fidelity numerical modelling," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, pp. 1–1, 2021, doi: 10.1109/JERM.2020.3049071, in press.

[10] D. O. Rodriguez-Duarte, J. A. Tobon Vasquez, R. Scapaticci, L. Crocco and F. Vipiana, "Brick Shaped Antenna Module for Microwave Brain Imaging Systems," in IEEE Antennas and Wireless Propagation Letters, doi: 10.1109/LAWP.2020.3022161.