Doctoral Dissertation

Doctoral Program in Electrical, Electronics and Communications Engineering
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EM Device for Cerebrovascular Diseases Imaging

Design, Implementation and Experimental Validation

By

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EM Device for Cerebrovascular Diseases Imaging

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This thesis deals with the application of microwave imaging technology to the medical diagnosis and therapeutic follow-up of cerebrovascular diseases, a subject of marked health impact worldwide. The work persuades to accelerate the technology translation from the research bench to the patient bedside, paving the way for future clinical studies with patients.

Crossing microwave engineering and medical imaging, hence, going beyond the strict electromagnetic aspects, the thesis presents the development and validation of a two-version innovative full-fledged in-laboratory prototype for imaging and monitoring cerebrovascular diseases. Specifically, the last version, consisting of a 22-antenna-array placed conformal to the upper head part, each being a flexible antenna with a custom-made matching medium.

The proposed system uses a differential imaging scheme based on a linear reconstruction algorithm, drastically reducing the computational burden while speeding the image reconstruction to a real-time operation. The algorithm then forms 3-D dielectric contrast maps by employing the online measured scattering matrices and exploiting the distorted Born approximation and the truncated singular value decomposition (TSVD), where the operator is advantageously off-line computed via accurate numerical models and an in-house Finite Element Method (FEM) Solver. Additionally, the imaging procedure includes pre-calibration and post-calibration techniques performed at the hardware and software level that compensate for drifts or uncertainties in system components and noise propagated through the operator.

The experimental validation subjects the system to emulated hemorrhagic and ischemic stroke conditions using anthropomorphic phantoms filled with liquids, mimicking their dielectric properties. The results verify the system's capabilities to live-track the continuous evolution of the stroke, indicating its location, approximated shape, and clinical state change. Overall, the work validates the proof-of-concept of brain stroke follow-up using microwave imaging in non-trivial conditions moving from the design problem to experimental validation, while applying an iterative problem-center methodology with inputs and feedback from both the technical and clinical sides.

The work results thus in a preliminary pre-clinical prototype that brings closer the trials on volunteers and patients. Even if the next step in clinical translation of the microwave-based imaging system will not be straightforward, the knowledge gained thanks to this thesis constitutes a solid and precious basement for continuing.