Abstract

This thesis contributes to the development of a microwave imaging (MWI) system aimed at continuous monitoring of stroke patients during hospitalization. The focus is on improving the robustness and accuracy of image reconstruction, tackling the challenges of solving the inverse scattering problem in complex and dynamically varying medical conditions. To this end, the work emphasizes calibration to align the actual measurement system with its digital twin, used to build the imaging operator and mitigate modelling errors that degrade image quality. The study begins by evaluating a compact MWI prototype, composed of a 2- port vector network analyzer (VNA), a switching matrix, and 24 printed monopole antennas embedded in a custom urethane rubber and graphite powder matching medium. High-fidelity numerical simulations using a finite element method (FEM)- based digital twin assess the performance of a standard imaging algorithm based on Born's approximation and truncated singular value decomposition (TSVD). Results demonstrate centimetric spatial resolution and meaningful recovery of dielectric contrast values, enabling differentiation between hemorrhagic (HS) and ischemic stroke (IS), as well as monitoring of hemorrhagic transformation (HT)—a critical condition during treatment. This distinction is crucial to provide clinicians with decision-making support for stroke management. Experimental tests on simplified phantoms confirm the system's ability to monitor stroke evolution by reconstructing the sign of the real part of the dielectric contrast, assuming stroke type is known. These tests also expose limitations of the imaging algorithm, especially its sensitivity to calibration and reduced quantitative accuracy in the presence of environmental noise. To address these limitations, the thesis introduces a novel calibration framework that accounts for discrepancies between the physical and modeled MWI systems, due to fabrication tolerances and assembly imperfections. The method enhances the numerical representation of the electromagnetic (EM) environment by combining synthetic data with a single scattering measurement. A wide set of full-wave EM simulations, covering possible physical and electrical variations, are precomputed offline. These responses are processed through singular value decomposition (SVD) to extract a compact and informative set of basis functions. Online, each antenna's response is projected onto this basis set, producing a refined estimate of the incident field that better reflects the real scenario. The method requires no dedicated calibration objects, is compatible with various imaging algorithms, and is adaptable to different perturbations that can be numerically modeled. Numerical analyses show improved accuracy in imaging operator reconstruction, particularly for IS and HS cases. Preliminary experiments with the prototype and phantoms show promising improvements in stroke localization, though further investigation is needed to assess quantitative performance. The study also underlines the importance of careful basis function selection and suggests extending the calibration approach to include patient-specific anatomical variability and system-level uncertainties. A final contribution of this work tackles the limits of conventional linear inversion methods, which often fail when Born's approximation is not valid. A novel imaging strategy is proposed, introducing a correction step based on a reformulated scattering model inspired by Rytov's approximation. This approach enables a direct, noniterative refinement of the dielectric contrast map, enhancing quantitative imaging

without additional computational cost. The method is validated through full 3D simulations in realistic brain imaging scenarios, confirming its potential for future experimental implementation and robust clinical use.