PhD Thesis Proposal

Biophysical Modeling of Electrical Properties of the Human Brain

Candidate Profile: Scientist or engineer with a strong background in physics. The candidate should also possess skills in scientific programming.

Background: Bioengineering advancements revolutionize neurological disorder management with precise diagnosis, continuous monitoring, and personalized treatment. Techniques include advanced MRI, high density EEG, brain implants and Transcranial magnetic stimulation (TMS).

To maximize efficiency and minimize risks associated with these technologies, it is essential to understand in detail the interactions between electromagnetic fields and biological tissues. By employing numerical methods coupled with biophysical models, it is possible to account for the electrical properties of biological tissues to solve Maxwell's equations. Such modeling, for instance, is used to predict the effects of TMS.

However, a major challenge of these approaches is the lack of precise data on the electrical properties of the human brain. These properties depend on tissue structure and composition and may be altered by neurological diseases or normal aging. To overcome this limitation, methodologies such as mapping the brain's electrical conductivity using MRI (MR-EPT) are under development, enabling a more accurate and personalized assessment of the brain's electrical properties [1-5].

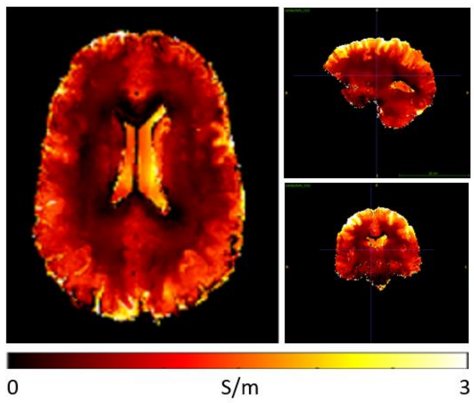

Figure 1 - Orthogonal views of an electrical conductivity map of a human brain (ICube laboratory).

Although the MR-EPT method holds considerable potential, it currently provides only values of electrical properties at the frequency used in MRI (128 MHz at 3 T). In contrast, techniques such as TMS and EEG operate at much lower frequencies, typically in the range of Hz to kHz. Recent research suggests the possibility of estimating low-frequency conductivity values based on measurements at high frequencies, considering their anisotropy [6, 7]. These efforts rely on empirical or physical relationships between electrical properties and brain structure or composition, although further validation for the human brain is still required.

Within the scope of this thesis project, the objective is to theoretically and experimentally evaluate these relationships, using calibrated phantoms to validate the proposed models. The dielectric spectrum profile of these phantoms will be characterized, along with their structural properties (organization, orientation, density, composition, etc.) and their electrical properties derived from MR-EPT. By combining these data with our quantitative MRI database of healthy subjects from different age groups, **the aim is to establish a biophysical model derived from effective medium theory, linking tissue structure to electrical conductivity**.

Host laboratory: This PhD thesis will be carried out at the ICube laboratory, on the Hôpital Civil site in Strasbourg, France. The PhD student involved will actively participate in all stages of the project, including data acquisition and analysis, in close collaboration with a post-doc funded by the ELECTRA project ("Electrical property imaging by MRI: Application to the MR-compatibility of medical devices". P. L. de Sousa is scientific manager in Strasbourg for the MRI physics and modeling task).

How to apply: Email a CV, grades and rank of Master's degree, and a motivation letter to the two supervisors Dr. Paulo Loureiro de Sousa (ploureiro@unistra.fr) and Dr. Julien Lamy (lamy@unistra.fr). Interviews of the selected applicants will be done on an ongoing basis. Applications will be accepted until end of April.

Expected starting date: October 2024.

References:

1. Voigt, T., Katscher, U., & Doessel, O. (2011). Quantitative conductivity and permittivity imaging of the human brain using electric properties tomography. Magnetic Resonance in Medicine, 66(2), 456-466.
2. Katscher, U., Kim, D. H., & Seo, J. K. (2013). Recent progress and future challenges in MR electric properties tomography. Computational and mathematical methods in medicine, 2013.
3. Zhang, X., Liu, J., & He, B. (2014). Magnetic-resonance-based electrical properties tomography: a review. IEEE reviews in biomedical engineering, 7, 87-96.
4. Katscher, U., & van den Berg, C. A. (2017). Electric properties tomography: Biochemical, physical and technical background, evaluation and clinical applications. NMR in Biomedicine, 30(8), e3729
5. F. Savigny, J. Lamy & P. L. de Sousa, "Robust reconstruction of electrical conductivity using anatomically-informed quadratic fit", in 32th ISMRM meeting, Toronto, Canada, June 2023.
6. Wu, Zhanxiong, et al. "A review of anisotropic conductivity models of brain white matter based on diffusion tensor imaging." Medical & Biological Engineering & Computing 56 (2018): 1325-1332.
7. Katoch, Nitish, et al. "Comparison of five conductivity tensor models and image reconstruction methods using MRI." Molecules 26.18 (2021): 5499.
8. Foucher, J. R., Mainberger, O., Lamy, J., Santin, M. D., Vignaud, A., Roser, M. M., & de Sousa, P. L. (2018). Multi-parametric quantitative MRI reveals three different white matter subtypes. Plos one, 13(6), e0196297.