6-month Master's internship (Stage de fin d'études)

Microwave-Induced Thermoacoustic Tomography for Electrical Properties Mapping

Keywords: microwave-induced thermoacoustic imaging, electrical properties tomography, coupled-physics inverse problems, hybrid imaging, quantitative tissue characterization

Context and challenges:

Microwave-induced thermoacoustic imaging (MITAT) [1] is a hybrid method that uses microwaves to excite tissues and ultrasound to read out the response. A short microwave pulse deposits power in tissues and causes a small, fast temperature rise. This thermoelastic rise creates an initial acoustic pressure $\boldsymbol{p_0}$. The pressure waves then travel through the tissues, are recorded by ultrasound transducers outside, and an image can be computed from the recorded signals. Compared with standard microwave imaging, MITAT uses ultrasound detection, so its MHz bandwidth and aperture set the resolution, often at the millimeter level. And compared with standard B-mode ultrasound, MITAT is more sensitive to differences in soft-tissue electrical properties (conductivity $\boldsymbol{\sigma}$ and permittivity $\boldsymbol{\varepsilon}$), and often exhibits a higher contrast in "functional hotspots" like tumors, inflammation, or regions with higher water content.

In short, MITAT combines high contrast of microwaves and high resolution of ultrasound. Most current works focus on the acoustic domain: reconstructing the initial pressure $\boldsymbol{p_0}$from measured pressure time series. Only a few studies probe further, i.e., using the absorbed energy or power density to recover the electrical parameters. If so doing, it can produce device-independent, physiologically meaningful maps of $\boldsymbol{\sigma}$ and $\boldsymbol{\varepsilon}$, supporting in particular quantitative biomarkers.

Research objectives:

The aim is to retrieve tissue electrical parameters within the MITAT framework. Unlike classical electromagnetic inverse scattering (ISP) [2], which collects only the scattered fields at the boundary, MITAT uses ultrasound to access an internal quantity: the absorbed power density ($\boldsymbol{q} \approx \boldsymbol{\sigma}|\mathbf{E}|^2$). This internal data adds constraints inside the object to diagnose and can improve the uniqueness and stability of the inversion. Yet a MITAT readout yields only the field magnitude ($|\mathbf{E}|^2$), and no phase, which does mix the effects of conductivity and permittivity. To separate them, one will vary frequency, polarization, and illumination angle to guide the solution. Overall, the goal is to map measured pressure time series back to ($\boldsymbol{\sigma}$ and $\boldsymbol{\varepsilon}$) [3,4], and to evaluate trade-offs between accuracy and robustness, as well as computational cost, benchmarking against a pure microwave ISP baseline under matched conditions.

Internship plan:

1. Literature review and setup of simulation tools; reproduce the forward EM model and the acoustic reconstruction baseline.
2. Perform acoustic retrieval and calibrate from initial pressure to absorbed power density.
3. Within multi-frequency, multi-illumination settings, conductivity ($\boldsymbol{\sigma}$) and permittivity ($\boldsymbol{\varepsilon}$) from the absorbed power density.
4. Benchmark against a pure microwave ISP baseline.

Candidate profile:
1. Master's student (M2) or final-year engineering student in applied physics, electrical engineering, or applied mathematics, with a strong interest in inverse problems and computational imaging.
2. Proficiency in MATLAB or Python for numerical simulation and data processing.
3. Background in electromagnetics and/or ultrasound physics would be an asset.

Practical information:

Duration and dates: 6 months in 2026

Remuneration: Approx. 600 € per month

Location: SATIE – UMR 8029, ENS Paris-Saclay, CNRS, Université Paris-Saclay, 4 avenue des Sciences, 91190 Gif-sur-Yvette, France.

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A PhD extension could be envisaged, depending on funding opportunities and the candidate's motivation.

References :

[1] Yao L, Guo G, Jiang H. Quantitative microwave-induced thermoacoustic tomography. Med Phys. 2010 Jul;37(7):3752-9. doi: 10.1118/1.3456926. PMID: 20831083.
[2] Chen, X. (2018). Computational Methods for Electromagnetic Inverse Scattering. John Wiley & Sons.
[3] Sahlström, T., Lähivaara, T., & Tarvainen, T. (2025). Simultaneous estimation of electrical conductivity and permittivity in quantitative thermoacoustic tomography. Inverse Problems, 41(3), 035015.
[4] Z. Luo et al., "Quantitative Reconstruction of Dielectric Properties Based on Deep-Learning-Enabled Microwave-Induced Thermoacoustic Tomography," in IEEE Transactions on Microwave Theory and Techniques, vol. 71, no. 6, pp. 2652-2663, June 2023.