Master's Internship / Final Year Project

MRF Simulation for Quantitative MRI of Iron-Oxide Nanoparticle Contrast Agents

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Project Summary: Iron-oxide nanoparticles are powerful MRI contrast agents because their strong paramagnetic effects induce marked changes in T1, T2, and especially T2*. In ongoing collaborations, these nanoparticles are further functionalized with an activable fluorophore for visible or near-infrared phototherapy [1], [2]. In such a context, therapeutic efficacy depends on the local dose of nanoparticles delivered in tissue. However, MRI cannot provide absolute quantification; estimation of nanoparticle concentration remains challenging because uptake by cells, aggregation, and intracellular compartmentalization all modify the magnetic properties.

Traditional T1/T2/T2* mapping can be used to estimate nanoparticle concentrations, but is slow and sensitive to these micro-environmental effects. Magnetic Resonance Fingerprinting (MRF) offers a promising alternative owing to its ability to acquire rapid, multiparametric, highly specific signal fingerprints that can be matched to a dictionary incorporating the physical behavior of the contrast agent. Recent studies have shown the feasibility of adapting MRF to paramagnetic or superparamagnetic agents [3], [4], [5].

The long-term project, potentially extending to a PhD, aims to develop a multimodal approach combining MRI and confocal microscopy to study concentration, distribution, uptake, and phototherapy-induced changes of these multimodal nanoparticles.

Scope of the Master's Project: The internship is structured around two complementary axes, designed to establish the methodological foundations for future MRF-based studies of iron-oxide nanoparticles.

1. Simulation of an MRF acquisition adapted to iron-oxide nanoparticles:

The first axis focuses on the numerical prototyping of an MRF sequence using existing open-source simulation frameworks. The goal is to set up the complete workflow for MRF acquisition and analysis, including:

- **Prototyping an MRF pulse sequence** to the relaxation properties of iron-oxide nanoparticles (T1, T2, T2*),
- **generating a signal dictionary** covering the expected range of nanoparticle-induced relaxation variations,
- testing basic **dictionary matching reconstruction** to evaluate the sensitivity of estimated parameters to nanoparticle concentration and magnetic properties.

This axis will provide a fully functional simulation platform that can later be used to guide in-vitro and eventual in-vivo MRF acquisitions during a PhD project.

2. In-vitro characterization of nanoparticles using classical MRI relaxometry

The second axis consists of experimental measurements on phantoms (tubes) containing nanoparticles. Using standard relaxometry methods (T1, T2, and T2* mapping), these experiments will allow:

- characterization of the nanoparticles' magnetic behavior in solution at different concentrations,
- validation of the ranges used in the simulated MRF dictionary,
- assessment of reproducibility and sensitivity of standard relaxometry for iron-oxide nanoparticles.

The *in-vitro* experiments provide essential ground-truth data to inform both simulations and subsequent multimodal imaging studies. Implementation of the MRF acquisition on the scanner is planned for future PhD work.
These experimental and numerical developments will establish the methodological basis required for subsequent work on cell cultures, confocal microscopy, and phototherapy-related modifications—components envisioned for a potential continuation of the project at the PhD level.

Candidate Profile
Master student in biomedical engineering, physics, medical imaging, or a related field. Skills in Python/Matlab programming, signal modelling, or MRI physics are highly appreciated. Motivation to continue the work in a doctoral thesis would be an asset.

Stipend: ~650 euros/month
Duration: 4 to 6 months

Please send your CV, motivation letter, and academic transcripts (M1 and M2) to:
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References

[1] R. Lapusan, R. Borlan, and M. Focsan, "Advancing MRI with magnetic nanoparticles: a comprehensive review of translational research and clinical trials," *Nanoscale Adv.*, vol. 6, no. 9, pp. 2234–2259, Apr. 2024, doi: 10.1039/D3NA01064C.

[2] R. Lapusan *et al.*, "From fundamentals to applications: magnetic nanoparticles for MRI imaging and NIR-induced thermal activation in tissue-mimicking environments," *J. Mater. Chem. B*, vol. 13, no. 38, pp. 12056–12072, Oct. 2025, doi: 10.1039/D5TB01160D.

[3] A. Marriott, C. Bowen, J. Rioux, and K. Brewer, "Simultaneous quantification of SPIO and gadolinium contrast agents using MR fingerprinting," *Magn. Reson. Imaging*, vol. 79, pp. 121–129, June 2021, doi: 10.1016/j.mri.2021.03.017.

[4] C. E. Anderson *et al.*, "Dynamic, Simultaneous Concentration Mapping of Multiple MRI Contrast Agents with Dual Contrast - Magnetic Resonance Fingerprinting," *Sci. Rep.*, vol. 9, no. 1, p. 19888, Dec. 2019, doi: 10.1038/s41598-019-56531-7.

[5] S. Fujita *et al.*, "MR Fingerprinting for Contrast Agent–free and Quantitative Characterization of Focal Liver Lesions," *Radiol. Imaging Cancer*, vol. 5, no. 6, p. e230036, Nov. 2023, doi: 10.1148/rycan.230036.