Master's Internship – Opportunity to Continue with a PhD

Simulation-Based Evaluation of Gradient Imperfections in Flow MRI

CREATIS Laboratory · MYRIAD Team · Lyon, France

PROJECT SUMMARY

Investigate the effects of MRI gradient imperfections, particularly eddy currents, on phase-contrast velocity measurements using simplified numerical simulations. Building on existing open-source tools (PyPulseq[1], MRzero[2]), the methodological aims are to reproduce a published benchmark, evaluate selected MRI sequences, including 2D and 3D radial, using synthetic flow phantoms and explore sequence parameter optimization.

CONTEXT

Four-dimensional flow MRI (4D Flow MRI) enables non-invasive measurement of blood velocity fields throughout the cardiac cycle, providing valuable information for cardiovascular research and patient-specific modelling. However, its use remains limited by long acquisition times and measurement accuracy challenges [3].

Among the factors affecting measurement accuracy, eddy currents induced by rapidly switching magnetic field gradients can distort k-space trajectories and velocity encoding, leading to errors in velocity quantification. These effects can be characterized using gradient impulse response functions (GIRFs)[4]. Numerical simulations provide a controlled environment to investigate such errors. In particular, simplified models using prescribed velocity fields can help isolate individual sources of error, complementing more realistic approaches based on computational fluid dynamics (CFD)[5].

At CREATIS, we develop MRI acquisition and reconstruction methods for cardiovascular flow imaging. Within the ANR RAPIDFLOW project, we aim to build on this work to better understand gradient-related measurement errors and improve the accuracy of 4D Flow MRI.

INTERNSHIP OBJECTIVES

The internship will focus on the numerical evaluation of gradient-related errors in phase-contrast MRI, building on existing open-source tools, including PyPulseq and MRzero. The student will undertake the following tasks:

1. **Establish a simulation framework for phase-contrast MRI.** Become familiar with existing MRI simulation tools and reproduce a simplified published benchmark on GIRF-based prediction of background phase errors. Use PyPulseq to define phase-contrast MRI sequences and investigate how velocity-dependent phase can be incorporated into MRzero using simple 2D and 3D synthetic flow phantoms.
2. **Investigate the effects of gradient imperfections**. Introduce simplified gradient response models to simulate eddy-current effects. Evaluate selected phase-contrast MRI sequence by comparing nominal and effective gradient waveforms, k-space trajectories, encoding moments, and quantify the resulting errors in velocity.
3. **Explore optimization strategies.** Investigate the potential of optimizing selected sequence parameters to reduce measurement errors, using differentiable simulation and backpropagation (Pulseq-zero/MRzero).

PERSPECTIVES

This six-month internship offers research training in MRI physics, simplified numerical modelling, open-source sequence design and automatic differentiation. A successful student may have the opportunity to pursue a PhD, extending the methodology to realistic cardiovascular flow configurations, experimental validation and advanced 4D Flow MRI acquisition strategies.

CANDIDATE PROFILE

Master's or final-year engineering student in medical imaging, applied physics, biomedical engineering, signal processing, applied mathematics or a related field. Good Python programming skills are expected; familiarity with MATLAB is useful. Prior experience with MRI, numerical simulation, optimization or PyTorch is an advantage. A strong interest in research and potentially pursuing a PhD is welcome. Applications from students studying outside France are particularly encouraged.

PRACTICAL INFORMATION

Location: CREATIS Laboratory, INSA Lyon / Université Claude Bernard Lyon 1, Villeurbanne (Lyon), France. | **Duration:** 6 months. | **Allowance:** approximately €650/month. | **Supervisor and contact**: Monica Sigovan — monica.sigovan@creatis.insa-lyon.fr

SELECTED REFERENCES

1. Ravi KS, Geethanath S, Vaughan JT. PyPulseq: A Python Package for MRI Pulse Sequence Design. *J Open Source Softw*. 2019;4(42):1725. doi:10.21105/joss.01725

2. Loktyushin A, Herz K, Dang N, et al. MRzero - Automated discovery of MRI sequences using supervised learning. *Magn Reson Med*. 2021;86(2):709-724. doi:10.1002/mrm.28727

3. Bissell MM, Raimondi F, Ait Ali L, et al. 4D Flow cardiovascular magnetic resonance consensus statement: 2023 update. *J Cardiovasc Magn Reson*. 2023;25(1):40. doi:10.1186/s12968-023-00942-z

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5. Puiseux T, Sewonu A, Moreno R, Mendez S, Nicoud F. Numerical simulation of time-resolved 3D phase-contrast magnetic resonance imaging. Borazjani I, ed. *PLOS ONE*. 2021;16(3):e0248816. doi:10.1371/journal.pone.0248816