CREATIS

Low energy RF pulse optimization for MRI: an optimal control approach

PhD position (3 years)
Starting October 2023

Overview

This PhD position will take place in CREATIS (`www.creatis.insa-lyon.fr`), a medical imaging laboratory located on the campus de la Doua, Villeurbanne. It will be supervised by E. VAN REETH (CPE Lyon, CREATIS) and H. RATINEY (CR CNRS, CREATIS), who both have been highly involved in optimal control pulse design since its introduction in 2015 as a hot research topic in CREATIS. The candidate will join a research team which expertise includes MRI sequence and methodological developments, and composed of 8 permanent staff, 4 radiologists, 5 postdoctoral fellows and 14 PhD students. More specifically, the team research interests focus on applied signal and image processing, optimization of acquisition strategies, sequence development and clinical applications.
The team works in close collaboration with the PILoT imaging platform, which hosts 2 preclinical high-field Bruker MRI (7T and 11.7T).

Scientific context

In Nuclear Magnetic Resonance (NMR), radiofrequency (RF) pulses are applied to modify the magnetization state of the system. They play a central role in the acquisition of MR images or spectrum. For instance, excitation pulses create a detectable tissue-specific signal that is measured by a dedicated receiver coil, while refocusing pulses flip the magnetization around the transverse plane to generate spin echoes. The application of RF pulses induces a certain amount of energy deposition that increases with

Figure 1: 11.7T Bruker MRI on which will be performed the various experiments of the PhD.

the pulse amplitude and duration, typically related to the targeted flip angle and pulse bandwidth. For both safety and hardware constraints, **the energy associated with RF pulses is carefully monitored**:

- **Clinical regulations impose limits on the Specific Absorption Rate (SAR)** - proportional to the pulse energy - over any 6 minutes period in the scanner to avoid temperature elevation and thus patient hazard.
- **Hardware constraints in the pulse transmission chain (from the amplifier to the coil itself) also limit the power and peak amplitude of the pulse**

Typical situations where pulse energy and/or peak amplitude is problematic are frequent repetitions of pulses with large flip angles (Turbo Spin Echo sequences), adiabatic RF pulses (inversion recovery, saturation-based sequences), or low gyromagnetic ratio nucleus excitation. When the desired pulse fails to comply with energy constraints, various strategies can be applied at the expense of signal-to-noise ratio (SNR), contrast, or scan duration:

- reduction of the flip angle
- increase of the pulse duration
- increase of the sequence repetition time (TR)

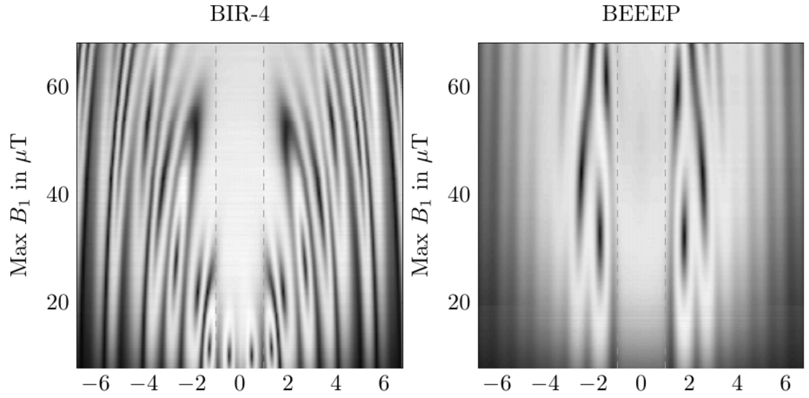
It is thus key to use RF pulses with low energy and low peak amplitude, to preserve optimal overall image quality (contrast-to-noise ratio, SNR), and scanning duration (patient comfort, scan availability).

Research hypothesis

Optimal control (OC) theory is a well-established mathematical methodology to determine the control (here, the RF pulse) that brings a dynamic system (here, the magnetization) in a user-defined state, while minimizing a cost functional (here, the pulse energy). It has been applied in various contexts in MRI and MR spectroscopy [3, 4, 5, 2, 8, 7]. The major strength of this approach is that it is able to compute, with a certain degree of optimality, the RF pulse that reaches a given target while:

- accounting for any phenomena that impact the magnetization trajectories (e.g. relaxation, B0 and B1 magnetic field inhomogeneities, chemical shift, . . .)
- specifying characteristics with respect to which the pulse must be optimal (e.g. energy deposition, control time, . . .).

On the other hand, other pulse design strategies (adiabatic, Shinnar-Le Roux) do not have such a direct and simultaneous control on the pulse characteristics, and guarantees on their optimality. **The first hypothesis considers that the flexibility and genericity of the OC pulse design framework will outperform standard design strategies for three targeted applications detailed later.** Preliminary results have been obtained for the design of low-energy B1-robust excitation pulses [6]. The energy deposition is reduced by a factor of 5 compared to a standard BIR-4 adiabatic pulse with similar bandwidth as can be observed on Figure 2.



(a) (b)

Figure 2: Excitation profiles as a function of pulse peak amplitude and resonance offset for (a) an adiabatic pulse, and (b) optimal control pulse.

A complementary approach called variable-rate selective excitation (VERSE [1]), achieves significant RF peak amplitude reduction by adapting the RF shape to the time-varying gradient while preserving the slice selection profile. **The second hypothesis considers that significant RF amplitude and energy reduction can also be obtained by incorporating the B0 gradient field as an additional optimization variable in the OC framework.** The additional degrees of freedom offered by the extra control field should lead to an advantageous compromise between the resulting pulses characteristics and the deposited energy.

Objectives

This PhD aims at obtaining decisive advances in **the design of low energy optimal pulses** for MR imaging and spectroscopy applications:

- As a first objective, **methodological aspects of the OC framework will be addressed** by considering simultaneous optimization of both RF and gradient fields, and adequate representation spaces to improve the convergence.
- As a second objective, specific optimal pulses will be developed to **tackle both standard (robust excitation and refocusing), and innovative (sodium MRI) applications, for which RF energy deposition currently acts as a bottleneck.**
- Finally, experiments will be carried out to validate the practical benefits of the computed pulses

Profile of the candidate

The candidate has validated a Master's degree (or engineer degree). His/her formation includes a solid background in image/signal processing, numerical optimization and/or applied mathematics. Experience in medical imaging is required, ideally in the field of MRI, as well as strong Matlab skills.
The candidate should be interested in both methodological and experimental aspects of the project, as well as subsequent medical applications. He/she is highly enthusiast to integrate a multi-disciplinary team, has a high level of autonomy, and a strong will to collaborate on related projects inside the team and with external collaborators.
Finally, the candidate is fluent in both oral and written English and has very good overall communication skills.

Contacts

Cover letter and resume should be addressed to:

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References

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