Stochastic Online Magnetic Resonance Image Reconstruction in the Compressed Sensing Framework

Research theme: Large scale inverse problems. MR Image reconstruction at 7 Tesla.

Duration/Salary: 5 to 6 months, starting on April 2020.

Teams: CentraleSupélec/CVN and Inria/CEA Parietal team at NeuroSpin.

Advisors: Emilie Chouzenoux (emilie.chouzenoux@univ-mlv.fr) and Philippe Ciuciu (philippe.ciuciu@cea.fr, +33 1 6908 7785).

Localization: The successful candidate will be based at CVN (CentraleSupélec) and NeuroSpin.

Application: Interested candidates should send their CV and motivation letter to the supervisors.

Research topic: Magnetic resonance imaging (MRI) is one of the most powerful imaging modalities for examining the human brain. High isotropic resolution (UHR: 500 μm in 3D) MRI substantially facilitates the early diagnosis of neurodegenerative diseases. Although ultra-high magnetic field systems ($\geq$ 7 Tesla) enable increased spatial resolution, long scan times (i.e. 8 h for UHR imaging) and motion sensitivity continue to impede the exploitation of UHR-MRI. The recent theory of compressed sensing (CS) has offered a solution for reducing the MRI scan time. This breakthrough has been accomplished by combining three key ingredients: (i) variable density sampling, (ii) image representation using sparse decomposition (e.g., wavelets) and (iii) nonlinear image reconstruction. However, CS image reconstruction is an iterative and time consuming process, which makes the time saved at acquisition lost during reconstruction. For that reason, although all vendors (GE, Siemens, Philips) have released CS solutions in their MR systems, its application is unfortunately limited to Cartesian under-sampling.

To alleviate this issue, we have recently introduced an online image reconstruction framework that interleaves partial acquisition and reconstruction steps [1]. The immediate benefit is to get a decent image quality by the end of acquisition, which may be critical to prescribe which next MR sequence must be run during the exam. This approach is based on a mini-batch formulation of the original offline reconstruction problem so as to transform it into a realistic solution that fits the online timing constraints. Mathematically speaking, this solution relies on solving non-smooth convex problems of increasing size using a primal-dual optimization algorithm (i.e. Condat-Vu [2, 3]). The efficiency of online reconstruction setups relies on the assumption that the acquisition and reconstruction times of a given mini-batch are roughly the same. Although the proposed online algorithm fully solved image reconstruction for single channel acquisition, its extension to multi-channel imaging hits a computational barrier. The reconstruction time per iteration is actually too costly to fit the online constraints adequately.

The topic of the current internship thus consists in proposing a new acceleration scheme based on a stochastic version of the existing online implementation. For doing so, we will proceed in two separate steps:

- Develop a stochastic *offline* reconstruction algorithm by relying on recent works on randomized primal-dual algorithms for large-scale optimization [4]. Two instances of the problem will be considered, requiring or not the knowledge of the coil sensitivity maps.
- Integration of the aforementioned techniques to the *online* setting proposed by [1].

Implementation. All the software developments will be integrated into the open source `PySAP-MRI` plugin of the `PySAP` Python package.

Validation. The validation of these brand new algorithms will be performed on retrospective simulations from structural 2D MRI data already collected at 7 Tesla at NeuroSpin. Then, if time permits, prospective validation will be envisaged.

Skills. We look for candidates strongly motivated by challenging research topics in applied mathematics and medical imaging. The applicant should present a good background in signal processing including wavelet theory, optimization and computer science. Basic knowledge in MRI would be a plus. As regards software developments, proficiency in `Python` and `C` languages is expected and a preliminary experience in GPU programming will be desirable.

Keywords. Compressed Sensing, MRI, acquisition, reconstruction, optimization, primal-dual algorithms.

References

[1] L. El Gueddari, E. Chouzenoux, A. Vignaud, J.-C. Pesquet, and P. Ciuciu, “Online MR image reconstruction for compressed sensing acquisition in T_2^* imaging”, in *Wavelets and Sparsity XVIII*, San Diego, CA USA, 08 2019, vol. 11138, pp. 1–15, SPIE.

[2] L. Condat, “A primal–dual splitting method for convex optimization involving Lipschitzian, proximable and linear composite terms”, *Journal of Optimization Theory and Applications*, vol. 158, no. 2, pp. 460–479, 08 2013.

[3] B. Vũ, “A splitting algorithm for dual monotone inclusions involving cocoercive operators”, *Advances in Computational Mathematics*, vol. 38, no. 3, pp. 667–681, 04 2013.

[4] A. Repetti and J. Pesquet, “A class of randomized primal-dual algorithms for distributed optimization”, *Journal of Nonlinear and Convex Analysis*, vol. 16, no. 12, pp. 2453–2490, 2015.