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Estimating separability of magnetisation signals by fast implementation of Bloch equation simulations across multiple tissues and distance correlation function

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Magnetic Resonance Fingerprinting (MRF) is an emerging field in Magnetic Resonance Imaging (MRI) where tissues to be identified are subjected to a series of magnetic pulses. The resulting magnetisation signal is governed by both the tissue properties as well as the chosen pulse acquisition parameters. By employing a suitable classifier, the tissue properties are recovered from the magnetisation signal in MRF. Depending on the chosen pulse acquisition parameters, the resulting magnetisation signals must be unique for different tissue properties for MRF to be effective. But the acquisition parameters of magnetic pulses in MRF are traditionally chosen in random. Hence, it is possible that the magnetic signals for tissues of concern may not be sufficiently distinguishable for efficient classification. Therefore, to explore the possibility of optimising the level of separability of magnetisation signals of different tissue types, optimal values of acquisition parameters of the pulse sequence must be carefully engineered. This task requires means of estimating the level of separability of magnetisation signals for different tissues. In this study, a fast simulation mechanism is implemented that estimates the level of separability of magnetisation signals generated in MRF for a chosen set of tissue properties and pulse acquisition parameters. An in-house built Bloch equations simulator was used to model nuclear magnetisation of atoms for both Balanced Steady State Free Precession (BSSFP) and Echo Planar Imaging (EPI) pulse sequences with variable pulse acquisition parameters. For the two pulse sequences chosen, calculating the magnetisation signal for a single tissue is sequential by nature. However, the calculations are parallel when repeated across multiple tissues. Therefore, the simulator was implemented on a Graphical Processing Unit (GPU) to exploit the parallel nature of the problem and to shorten execution time. To determine the level classification of magnetisation signals, distance correlation Function, which measures both linear and non-linear association between two signals was chosen. Since for N number of tissues, there are ${}^{N}C_{2}$ number of correlation computations, the computational demand will be prohibitively expensive with higher numbers of tissues. Therefore, the distance correlation which, given the parallel nature of calculations, was reformulated as a series of array operations to be able to execute in the GPU. It was observed that as compared to a CPU only implementation, GPU execution of Bloch equation calculations sped up significantly. Through reformulation as array operations, calculation of distance correlation, which computationally is more expensive than Bloch equation simulations, sped up roughly by a factor of 10,000 times. With the fast execution time through GPU, the implementation provides practical means of evaluating a vast number of tissues to indicate the level of separability for a chosen set of pulse acquisition parameters within a few seconds. Therefore, the system developed facilitates a designer to carefully engineer the optimal pulse sequence parameters to ensure that the magnetisation signals generated are efficiently classifiable prior to carrying out physical scans for MRF using the MRI machine.

Keywords: Bloch equations, Distance correlation, GPU, Pulse sequences