

Performance of Multiple Types of Numerical MR Simulation using MRiLab

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Introduction: Digital simulation dramatically facilitates the understanding and development of new MR imaging methods. To numerically simulate spin evolution for large system, previous available simulation packages typically employ dedicated computation architecture (e.g. computer cluster) which is expensive and thus limited for convenient use [1-2]. In our previous work, we have developed a new simulation package for performing fast parallelized 3D MRI numerical simulation on a simple desktop computer [3-4]. Our simulation package 'MRiLab' features highly interactive graphic user-interface tailored for investigating RF pulse design, MR pulse design, B0 and B1 field analysis etc. For this new optimized and enhanced MRiLab version, we have engaged our efforts for incorporating many new challenging simulation features including multiple RF transmitting and receiving, motion simulation, etc. The spin model is also extended to include multiple exchanging spin compartments to create more realistic MR signal for certain types of tissues with, for instance, magnetization transfer (MT) modulation. This abstract was aimed to demonstrate the feasibility of using MRiLab for studying multiple types of MR experiments that remain challenging for numerical simulation.

Methods: MRiLab was developed with Matlab Graphical User Interface Developing Environment for user interface. Compute Unified Device Architecture (CUDA) and Open Multi-Processing (OpenMP) were used for GPU and multi-core CPU parallel simulation computation. The Java Swing, Open Graphics Library (OpenGL) and Visualization Toolkit (VTK) were used for 3D object rendering. The current version of MRiLab is composed of 1) a main simulation panel, 2) accessory function panels, 3) a discrete Bloch-equation solving kernel, 4) image reconstruction module and 5) image and signal analysis toolkit. The main simulation panel functions like a scanner console for configuring imaging parameters and conducting simulation workflow. Accessory function panels includes panels for designing RF pulse, constructing pulse sequence, investigating field inhomogeneity and configuring RF coil profile etc. The functions allowing individual RF source design combined with multiple channel RF coil tuning enables multiple RF transmitting and receiving simulation. The motion simulation panel is incorporated for designing motion trajectory and triggers motion according to coded time sequence for simulating 4D dynamic MRI experiment. The Bloch-equation solving kernel translates simulation input (i.e. MR pulse, digital tissue properties, B0, B1 and motion etc.) into discrete spin evolution steps in the rotating frame, followed by signal acquisition and image reconstruction in the reconstruction module. On top of standard Bloch-equation solving ability, a two-pool MT exchange model (5) has been incorporated to take into account MT effect modulation for more realistic approximation of MR signal from macromolecule enriched tissues such as brain white matter, muscle, and cartilage. At result section, three specific simulation cases in current challenging MR research topics was studied and demonstrated to unveil MRiLab's simulation power. These cases include multiple RF transmitting, 4D real time imaging and simulation of MT saturation effect.

Results: All the simulation work has been performed under a window 7 PC with a single nVidia Quadro 4000 GPU card and the MRiLab v1.0. Figure 1 shows the effect of the transmission RF phase on bSSFP image homogeneity at 7.0T. The imaging parameters are TR/TE = 16/8 ms, $\alpha_{\text{norm}} = 40^\circ$, FOV = 20x16 cm, axial in-plane, slice thickness = 6 mm. Part a shows a bSSFP image of a head phantom inside an eight channel Biot-Savart transmission only RF coil array. The loss of signal at the center of the head region is caused by the destructive interference of the individual B1+ field. The relative transmit phase of each coil element is labeled beside the coil element (indicated as a line). Part b shows by optimizing the relative transmit phase of the three coil elements on the left side via individual RF phase adjustment, the signal loss is largely reduced. Figure 2 simulates 2D 80x80 image acquisition for an oscillating sphere using a bSSFP sequence with continuous golden angle radial sampling for 4.5 s. Each image is reconstructed with 80 radial spokes. The imaging parameters are TE/TR/ $\alpha^\circ = 8\text{ms}/16\text{ms}/40^\circ$, continuous radial sampling at 111.246° golden angle increment with 80 samples per spoke. Figure 3 shows MT effect for a cartilage MT phantom. The imaging parameters are TR/TE = 60/8 ms, excitation flip angle $\alpha = 10^\circ$ with the 20 ms Fermi MT saturation pulse. Images are displayed for MT flip angle $\alpha_{\text{MT}} = 800^\circ$, offset frequency = 0.1, 1, 10 and 100 KHz. Z-Spectrum is measured for $\alpha_{\text{MT}} = 400^\circ$, 800° and 1600° , offset frequency range from 0.01 to 100 kHz.

Conclusion: In this abstract, we demonstrated MRiLab, a fast parallelized MRI numerical simulation package, is feasible and flexible for simulating multiple types of numerical MR experiment, including multiple RF transmitting, 4D real time imaging and two-pool modeling in the presence of magnetization exchange. A future work is targeted to incorporate different types of spin models, MR spectroscopy simulation and MR hardware simulation.

References: [1]Stocker T. MRM, 2010, [2] Benoit-Cattin H. JMR, 2005, [3] Liu F. ISMRM, 2013, [4] <http://mrilab.sourceforge.net/> [5] Henkelman R.M., NMR Biomed, 2001

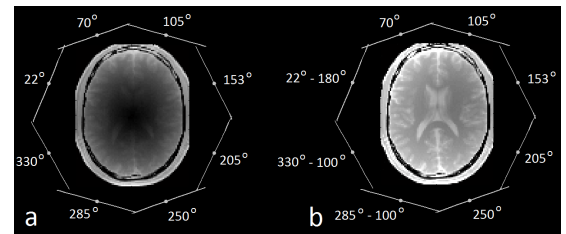


Figure 1. The effect of the transmission RF phase on bSSFP image homogeneity at 7.0T.

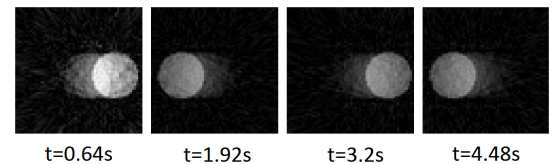


Figure 2. Simulation of 2D 80x80 image acquisition for an oscillating sphere using a bSSFP sequence with continuous golden angle radial sampling for 4.5 s.

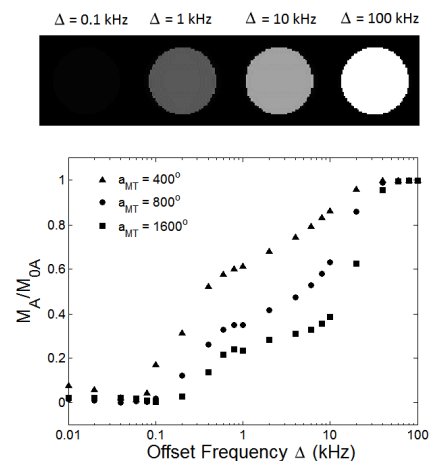


Figure 3. Measuring magnetization transfer Z-spectrum with a cartilage MT phantom.