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MRiLab: Performing Fast 3D Parallel MRI Numerical Simulation on A Simple PC

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Introduction

Digital simulation can dramatically speed the understanding and development of new MR imaging methods. To numerically simulate spin evolution for large spin system, current available simulation packages typically employ dedicated computation architecture (e.g. computer grid and cluster) which is expensive and thus limited for convenient use [1-2].

We have developed a new and practical simulation package named 'MRiLab' for performing fast 3D parallel MRI numerical simulation on a simple desktop computer. 'MRiLab' features:

- Highly interactive program-free graphic user-interface
- RF and gradient modules for B1 and B0 field analysis
- Graphical pulse sequences design and analysis
- Fast parallelized simulation for tissue response in 3D
- Low computation power requirement

Our simulation package is aimed to provide a fast, comprehensive and effective numerical MRI simulation solution with minimum computation hardware requirement for the MRI community.

Methods

Based on Matlab GUI developing environment, MRiLab is composed of

1) A main simulation panel

The main simulation panel functions like a scanner console for graphically adjusting imaging setup and conducting simulation control. Simulation feedbacks are dynamically reflected on corresponding information windows based on simulation process.

2) A function panel unit

The function unit provides independent panels for designing RF pulse (e.g. SLR, non-adiabatic and adiabatic pulse etc.), for constructing arbitrary pulse sequence (e.g. SPGR, SSFP and FSE etc.), and for configuring RF coil profile and main magnet field (i.e. B1 and B0 field).

3) A discrete Bloch-equation solving kernel

The solving kernel simulates spin evolution in tissue with small discrete steps for accurately capturing spin behavior given the running pulse sequence, followed by virtual signal acquisition and image reconstruction with saved k-space in the reconstruction module.

MRiLab is accelerated using Matlab MEX functions that are optimized for running GPU and multi-threaded CPU parallel computation. To maximize computational efficiency and guarantee simulation accuracy, the parallelization is performed by incorporating latest NVIDIA CUDA technique [3] and OpenMP technique [4].

To extend functionality, MRiLab provides graphical tools for analyzing simulated 3D image, visualizing multiple spin evolution behavior, and analyzing local SAR distribution. MRiLab uses XML files for storing simulation information, which simplifies simulation transition across different studies. MRiLab also supports external plugins written with either Matlab or C language for creating extendible simulation system. The precompiled Matlab function library in each panel contains programming-free modules that can facilitate simulation design without requiring efforts for extra coding, although build-in plugins also exist for specifying customized modules.

Main simulation panel

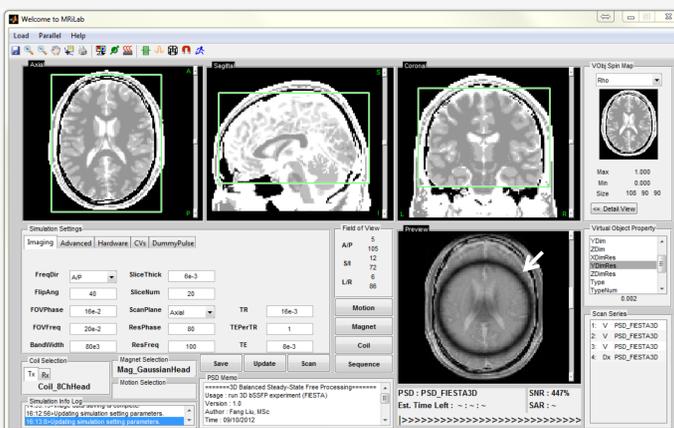


Figure 1. The simulation panel of 3D bSSFP brain imaging with a designed Gaussian B0 field profile. Note the signal drop-off circle (arrow) caused by the B0 inhomogeneity.

RF pulse design

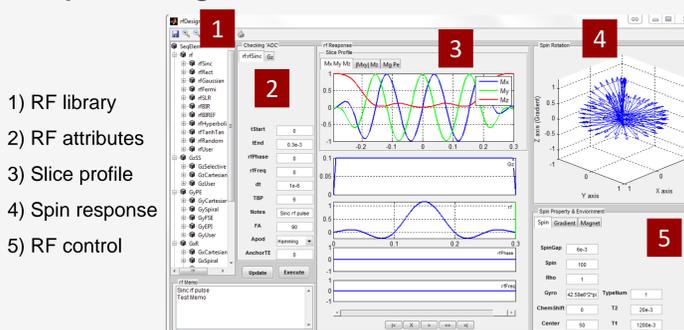


Figure 2. The RF pulse design and analysis. The transverse and longitudinal magnetization response of a 5-lob Sinc pulse is shown. A variety of predefined pulse and gradient (in the left tree) can be modified and analyzed. Any arbitrary RF and gradient also can be imported and analyzed in MRiLab.

Pulse sequence design

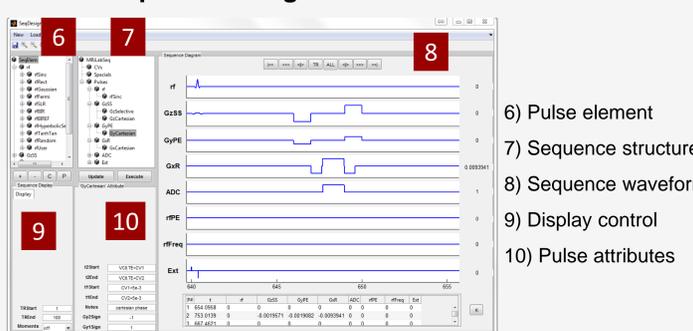


Figure 3. The pulse sequence design and analysis. A 3D bSSFP sequence diagram is graphically designed and analyzed. A sequence element library is provided on the left tree in which each node is a sequence element (i.e. RF, Gx, Gy, Gz etc) that can be added and modified to construct specific sequence. Any new designed RF pulse also can be used.

RF Coil design

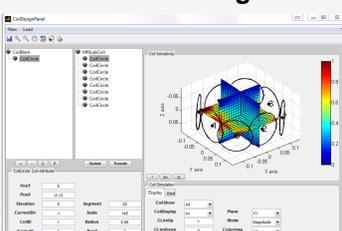


Figure 4. A B1 field created using 8 Bio-Savart circles.

B0 Field design

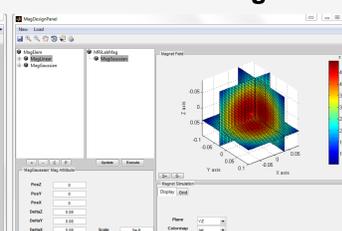


Figure 5. A B0 field of 3D Gaussian profile

Results

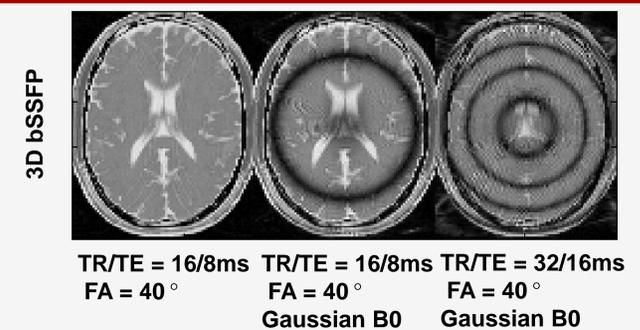


Figure 6. Simulated 3D bSSFP brain image of matrix size of 80x100x20. The circular banding artifact is due to added Gaussian field simulating the main magnet field inhomogeneity.

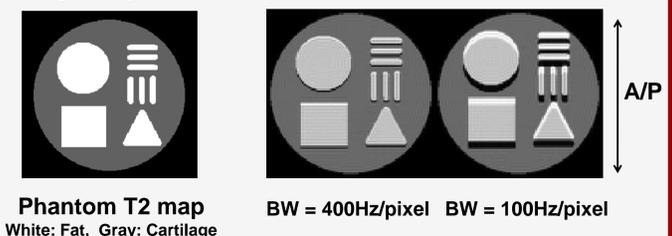


Figure 7. Simulated 3D gradient echo image at 3.0T using cartilage-fat phantom showing water fat chemical shift at different readout bandwidth. The phantom size is 256x256x32x2, simulated in-plane matrix size is 100x100, TR/TE = 10s/50ms, Axial plane, A/P readout.

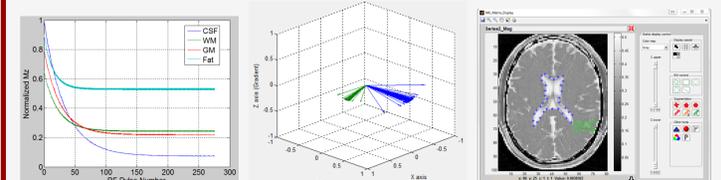


Figure 8. Catalyzing transient response in SPGR sequence for different tissue. **Figure 9.** An animation of spin evolution in rotating frame for fat and water. **Figure 10.** Handy GUI tools for performing image analysis

All the simulation were performed using NVIDIA Quadro 4000 500MHz GPU and/or using Intel Xeon W3530 2.80GHz CPU on a desktop computer. The simulation speed depends on the simulated matrix size and step size. For example, using a 90x108x90 virtual brain phantom (McGill University BrainWeb), the simulation in **Figure 6** takes average 30s per slice using GPU and 2min per slice using multi-threaded CPU.

Conclusions & Discussion

In this work, we demonstrated that, simply using a low-cost PC setup, the MRiLab is able to perform fast, comprehensive and effective MRI simulation including intensive numerical computation.

The MRiLab holds great potentials as a research tool for MRI technique developers to instantly test new MRI ideas and also as an educational tool running on ordinary computers. MRiLab also has the potential for providing accurate simulated MR data for open source reconstruction platforms like the Gadgetron [5].

Further improvement of MRiLab is undergoing for simulating multi-pool water exchange, parallel excitation, real-time imaging.

References

- 1) Stocker T. MRM, 2010
- 2) Benoit-Cattin H. JMR, 2005
- 3) www.nvidia.com
- 4) <http://openmp.org/wp/>
- 5) Hansen M. S. MRM, 2012

MRiLab will be published online for free download soon, or contact Fang Liu (fliu37@wisc.edu) if interested.