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

Fang Liu[1], Richard Kijowski[2], and Walter F. Block[1,3]

[1]*Department of Medical Physics, University of Wisconsin-Madison, Madison, Wisconsin, United States,* [2]*Department of Radiology, University of Wisconsin-Madison, Madison, Wisconsin, United States,* [3]*Department of Biomedical Engineering, University of Wisconsin-Madison, Madison, Wisconsin, United States*

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]. In this work, we have developed a new and practical simulation package for performing fast 3D parallel MRI numerical simulation on a simple desktop computer. Our simulation package named 'MRiLab' features highly interactive graphic user-interface for various simulation functions. Using RF and gradient modules provided in MRiLab, pulse sequences can be designed graphically and simulated seamlessly using parallelized Bloch-equation kernel. RF pulse analysis, B0 and B1 field design are also available in MRiLab to provide multi-functional simulation environment. Our simulation package is aimed to provide a fast, comprehensive and effective numerical MRI simulation solution with minimum computation hardware requirement.

Methods: Based on Matlab developing environment, MRiLab is composed of 1) a main simulation panel, 2) a function panel unit and 3) a discrete Bloch-equation solving kernel. The main simulation panel (Figure 1) functions like a scanner console for graphically adjusting imaging setup (i.e. FOV, resolution, scan plane, etc.) and conducting simulation control. Function panel unit (Figure 2) includes independent panels for designing RF pulse (e.g. SLR, non-adiabatic and adiabatic pulse etc.), constructing pulse sequence (e.g. SPGR, SSFP and FSE etc.) and configuring RF coil profile and main magnet field (i.e. B1 and B0 field). 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. The Bloch-equation solving kernel translates simulation input into discrete spin evolution steps in the rotating frame, followed by signal acquisition and image reconstruction with saved k-space in the reconstruction module.

MRiLab simulation is accelerated using Matlab MEX functions that are optimized for running GPU and multi-threaded CPU parallel computation. The incorporation of GPU parallel computation using NVIDIA CUDA technique provides fast simulation speed comparable to those high-cost computer gird and cluster. MRiLab also exploits GPU acceleration for simulating complex spin evolution (e.g. spin exchange, bulk-motion, and diffusion, etc) in feasible simulation time. Additional multi-threaded CPU parallel computation using OpenMP is also provided as an alternative to GPU.

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.

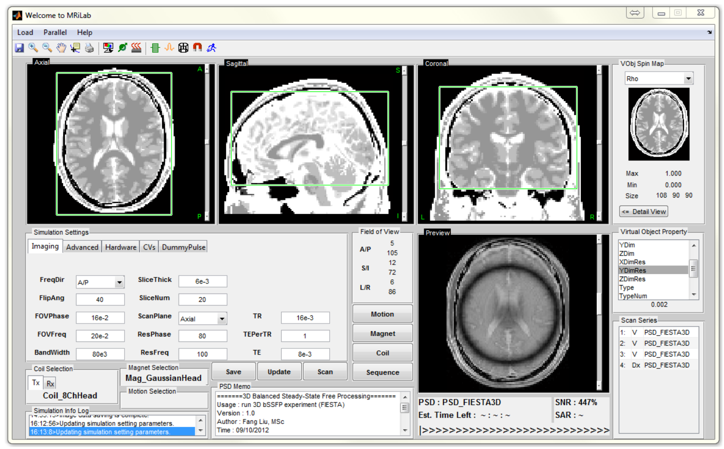
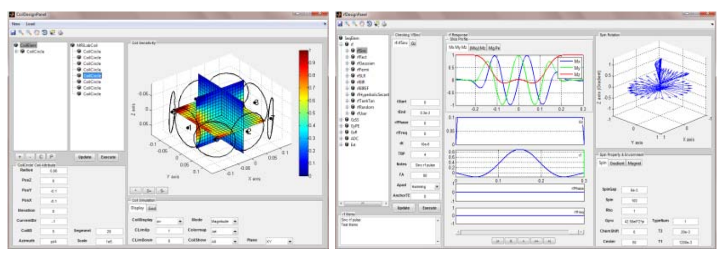


Figure 1. 3D-bSSFP simulation at 3.0T using MRiLab. Figure shows the main simulation panel and one axial slice of simulated bSSFP image. Note banding artifact is caused by added field variation.



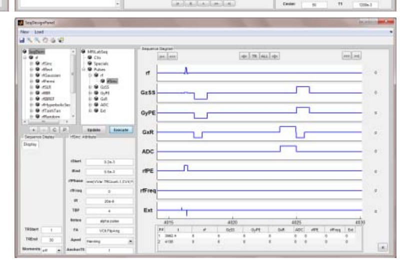


Figure 2. RF coil design panel (top left), RF pulse analysis (top right) and MR sequence design panel (bottom), the tree library on left side of each panel contains modules that can be used in designing.

Results: Figure 1 shows the main simulation panel and simulated image using a 3D balanced steady-state free precession sequence (bSSFP) with image matrix size of 80×100×20, TR/TE=16/8ms, FA=40°. The circular banding artifact is due to added Gaussian field variation simulating the main magnet field inhomogeneity. This simulation was performed using a 90×108×90 virtual brain phantom (McGill University BrainWeb) with 30s per slice simulation time using NVIDIA Quadro 4000 500MHz GPU and 2min per slice using Intel Xeon W3530 2.80GHz CPU on a single desktop computer. The top left panel in Figure 2 shows design interface for B1 field of a 8-channel Biot-Savart coil. The top right panel demonstrates RF pulse analysis for a 3-lob Sinc pulse with associated RF slice-selective profile and resultant spatial spin distribution. The bottom panel gives an example for graphically bSSFP sequence design where many aspects of the pulse diagram can be adjusted for specific simulation purpose.

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[3]. 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] Hansen M. S. MRM, 2012