Accelerating MRI physics simulations using GPU computing: comparison with other computer configurations

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Background

MRI physics simulators may be used both for optimizing imaging protocols and for training purposes. Since the introduction of the first nuclear magnetic resonance physics simulator by Summers, Axel and Israel in 1986, further research has been conducted on the development of various simulators serving different purposes. However, current MRI physics simulators are confined to few pulse sequences and compromises are made due to the high computational power needed.

A step-by-step comprehensive Bloch equation simulator, which allows for high performance parallelizable computations, without the aforementioned compromises, was designed and developed employing the CUDA-technology. In this study, the efficacy of GPU implementation was evaluated against other computer configurations.

Methods

A comprehensive computer simulation platform of MR physics was developed that integrates all the stages of MRI physics from signal generation to image reconstruction in a realistic manner. This simulation platform allowed the development of custom MRI pulse sequences and their application on computer models, including custom phantoms, a brain model and a detailed 3D model of the anatomy of the human heart and torso, previously developed in our lab.

The simulation platform was developed in MATLAB while the main computationally demanding services were written in CUDA-C and were executed in parallel within the GPU environment.

Execution times were recorded for the application of the simulator on three different computer configurations:

1. one single CPU computer (Intel Pentium D, 3.40GHz)
2. a 23 core computer cluster using MATLAB spmd constructs
3. one single CPU computer with one GPU Tesla c2070 of 448 GPU cores.

These simulations were based on a Gradient Echo pulse sequence applied on a cubic object of 21600 voxels (k-space 256x256).

Results

Conventional CPU-based calculations offered limited computing performance since the simulator involves multiplication/summation of large matrices whose values change in time and cannot be addressed by using sparse matrices. In addition to that, sometimes the size of the object being simulated prohibited the initialization of the simulator due to memory limits.

The setup of a computer cluster of 23 cores produced an increased computing efficiency, though the runtimes were still long for realistic MRI simulations.

On the other hand, the GPU-based simulation recorded a speedup of almost three orders of magnitude (x908) when compared to CPU-based and more than two orders of magnitude (x240) when compared to the cluster-based system (Table 1).

Computer Setup	Execution Time (sec)	Speedup
CPU-based	91950	1
Cluster (23-cores)	15843	≈ 4
GPU c2070	66	908

Table 1: Execution times for the application of a pulse sequence of 480000 time-steps on a cubic object of 21600 isochromats. Speedups are compared to the CPU-based setup.

Conclusion

The CUDA technology employed by this MRI simulator allows its application in large-scale analysis without model simplifications. The almost three orders of magnitude speedup obtained in MRI simulations with a single video card of 448 GPU cores is promising and reveals the potentials of such an MRI simulator in optimizing MRI protocols and for educational purposes.

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