An Object-Orient Designed FDTD simulator - applications to high field systems

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Synopsis

An finite-difference time-domain (FDTD) simulator has been developed for electromagnetic analysis and design applications in MRI. It is intended to be a complete FDTD model of an MRI system including all RF and low-frequency field generating units and electrical models of the patient. The program has been constructed in an object-oriented framework. The design procedure is described and MRI-based numerical examples are provided to illustrate the utility of the numerical solver, particular emphasis is placed on high field examples.

Introduction

Numerical modeling of electromagnetic fields (EMFs) generated by MRI coils presents a difficult computational problem. The FDTD method has been used extensively for MRI applications [1,2]. This is because FDTD method has distinct advantages in the analyses of field-sample interactions. We have developed a series of FDTD schemes [3-6], which can be used to analyze gradient as well as RF field interactions. We are attempting to generate an entire FDTD model of an MRI system with all field generating units and biological models. This might lead to a better understanding of the fields within patients and general temporal field behavior during an MRI scan, thus offering insight into coil design. To this end, we have designed a 3D FDTD simulator which integrates our algorithms and includes several improvements such as better boundary condition and source modeling. We have architected this simulator using Object-oriented Design (OOD) techniques and philosophies. In this work, the design procedure is described and demonstrates how OOD can lead to a well-organized field calculation tool. The numerical scheme has been employed to both gradient and RF field analyses.

Method

In our simulator, the field calculation problem is handled through class construction. In FDTD analysis, the *yee*-cell analysis is the key point, and hence a *CELL* class is identified to be the base class. In each cell, three E-field components, three H-field components, and constitutive electromagnetic parameters are the basic member variables; the six EMF-update operations are the essential methods. In MRI engineering, a typical computational domain can be represented by Fig.1. The main domain can be split into several sub-domains: *CAIR* is defined for the free space; *CSOURCE* relates to input source; *CLOAD* handles the imaged sample/load; *CCIRCUIT* considers the RF circuits and dielectrics; CPML and *CPEC* are basic boundary conditions. All of these can be treated as sub-class of *CELL*. The FDTD simulator is coded using C++ language with the capability of upgrade and expansion. The class hierarchy design heavily relies on Inheritance and Polymorphism by means of virtual methods. To accelerate the update procedure, frequently used coefficients are pre-computed and stored as local private variables in each cell. In the implementation, before using FDTD solver, all the system parameters such as the human model and source data are obtained from files and/or through a dedicated user interface, which provides a wizard for assisting users to input their own system data/parameters. The output data is organized and analyzed in post-processing. The visualization of the output data is handled using openGL® codes.

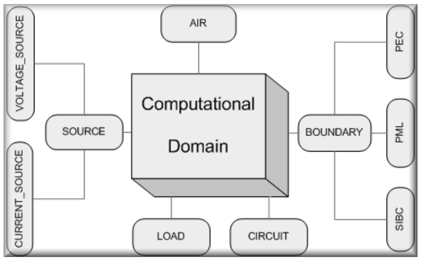

Fig.1 The configuration of the FDTD computational domain in MRI. (PEC: perfect conductor; PML: perfect matched layer; SIBC: surface impedance boundary condition)

Simulations

To show the capability of the proposed simulator, several new RF coil/load interaction cases (see Fig. 2) have been investigated. Before these simulations, we have also validated the embedded FDTD kernel with a debye-potential-based solution of the eddy currents inside a multi-layered spherical head phantom excited by a coil, the results corresponded well to those previously published [7].

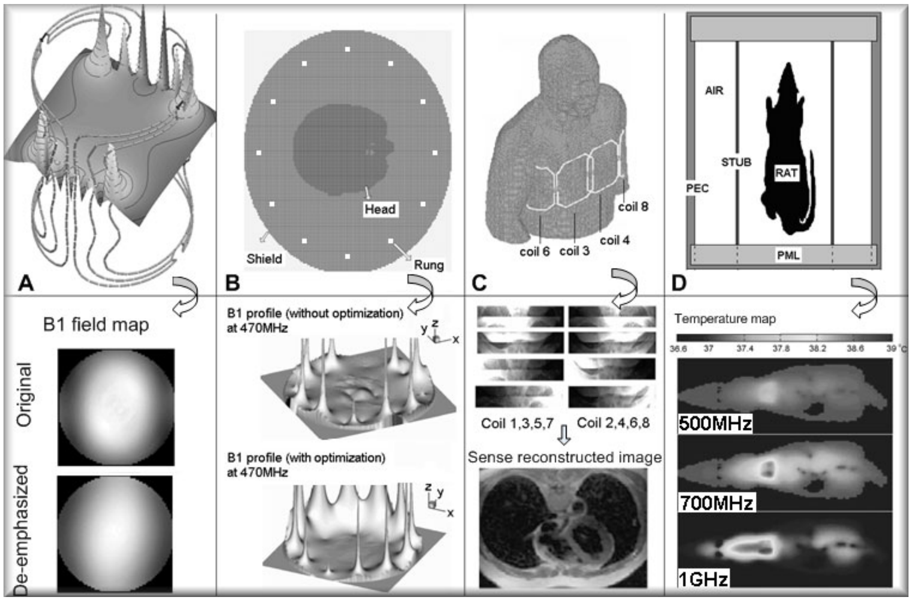

Fig.2 The applications of the FDTD simulator. A: The simulation of the inverse-method [8] designed RF coil at 4T. Top: the coil structure and the B_1 field map at empty case; Bottom: B_1 field loaded with cylindrical phantom with & without de-emphasis. B: Optimization of the source profile for a shielded birdcage resonator. Top: The coil-sample setup; Bottom: Comparisons of the field map before and after optimization at 470 MHz. C: The simulation of a transceive torso phased array coil at 2T. Top: The coil structure and the human model; Bottom: The simulated, aliased chest images and SENSE reconstructed chest image. D: Temperature map simulations from MRI induced fields inside a rat phantom at high frequencies.

Conclusion

By enabling an Object-Oriented designed FDTD simulator we are in a position to approach a complete model of an MRI system, including tissue-field interactions and the effect of EMFs on surrounding coils & conductors. In future we plan to design more novel MRI coils within this framework.

Acknowledgements

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