COMPUTER ASSISTED MR IMAGING SIMULATION FOR GUIDANCE OF GRADIENT COIL DEVELOPMENT DURING DESIGN PHASE

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Introduction:

In magnetic resonance (MR), fast sequences and high-resolution imaging require fast switching and strong gradients. The fabrication process of new gradient coils relies on iterative trial-and-error prototyping, which is very time consuming and hence expensive. The introduction of assisting design and development tools is of great importance. For this reason, computer assisted MR imaging simulation on the basis of MR system components has been recently introduced[1]. The presented concept integrates and extends existing techniques from hardware and pulse sequence design to a flexible and modular problem solving simulation environment. This way the developer can combine multiple hardware components with various pulse sequences in order to obtain forecasts about the usefulness of the developed design and the impact on image quality prior building the hardware. To demonstrate the capabilities of this new environment, a three-axis uniplanar flat gradient set is modeled [2]. Symmetry boundary conditions are applied to enhance simulation speed and magnetostatic evaluations and first application simulations are presented to verify the modeling.

Materials and Methods: The whole simulation software is realized in Matlab with interfaces to the MR system, image reconstruction routines, finite element method (FEM) simulation software and graphics-processing unit (GPU). The MR application simulation is enabled by the import functionality of different shaped pulse sequences. This technique allows existing clinical applications and self-designed sequences to be loaded and utilizes FEM simulations for the hardware modeling. We integrated the commercial software Maxwell3D[3], where design files can be imported automatically. Maxwell3D performs both, static and time dependent simulations. The one-by-one transfer of the gradient waveform into the current pulse, which drives the coil, realizes this transient simulation. The simulated field data is exported and replaces the ideal field and gradient waveform information in the Bloch equation simulation. Computation speed and memory availability are causing the largest influence on the simulation time. Hence, we realized the parallelization of the Bloch equation simulation code on a GPU[4].

The planar gradient set incorporates two sets of boards for each axis. Extensive cooling capacity is added in order to minimize surface temperatures. The planar gradient set model was built from existing CAD design files. As model complexity is a limiting factor in terms of simulation performance, the model was simplified by representing each axis by one, instead of two coil plates. Exciting with a double amplitude current can compensate for this. As each axis is simulated individually, symmetry boundary conditions are utilized to further minimize model complexity so that all simulations are performed on ¼ of the setup.

Results:

We compared the simulated field profiles and strengths produced by the gradient coil with actual design simulations based on spherical harmonics and the results agreed to within 1% (Table 1). The model was additionally analyzed for correctness using linear regression and using this method, cross-terms as well as field intensity values were evaluated. The high-resolution phantom of the Alzheimer's disease neuroimaging initiative (ADNI) [5,6] is imaged in reality and also defines the spin density input into our simulation software. The top row in Fig.1 shows gradient echo simulated images from the central slide of the ADNI phantom enabled with the presented simulation technique, where Fig.1a shows the simulated image by running ideal gradients, and Fig.1b shows the simulated image based on the electromagnetic field simulations of the uniplanar gradient set. For illustration, the bottom row in Fig.1 shows real spin echo acquired images of a slightly different slice of the ADNI phantom using cylindrical gradients (Fig.1c) and the planar gradient system (Fig.1d). Because the gradient strength fades with distance from the planar gradient, the images show brighter and squeezed areas close to the boards, and weaker and blurred areas further away from the boards. The plotted lines in Fig.2 show the slice profiles indicated with the dashed lines in Fig.1. The phantom diameter calculations resulted to be 18.05cm and hence differ by 2.93% from real diameter.

Discussion and Conclusion: With the presented work, images simulated on the basis of electromagnetic fields generated from a finite element solving method were simulated. The presented concept and implementation can be utilized to predict image quality prior building the hardware. The first realistic simulations are shown and they include similar geometric distortions compared to acquired images. Model and evaluation procedure complexity are a limiting factor for this kind of simulation so simplifications to the model cannot be avoided. Model symmetry and simplification of hardware modeling, as well as parallelization help to save computational time and to optimize the simulation workflow. In electromagnetic field simulation, the accuracy of predicted fields is a measure of mesh discretization. Hence, utilizing adaptive meshing procedures or guiding mesh refinement through the help of skin depth further improves simulation quality. Future work will concentrate on the quantification of induced eddy currents in cryostat and gradient coil cooling tubes and their impact on image quality.

References: [1] Lechner et al, 17th ISMRM, Honolulu, 2009 #3047, [2] Aksel et al, Magn, Reson. Med. 58:134-43 (2007), [3] Maxwell3D12.0.1, Ansoft Corporation (LLC,2008), [4] Lechner et al, 17th ISMRM, Honolulu, 2009 #2695, [5] Mallozzi et al, 14th ISMRM, Seattle, 2006 #1364, [6] Mallozzi, et al., 13th ISMRM, Seattle, 2005, #1246

	Reference [mT]	FEM simulation [mT]	Rel. Error over 3D volume [%]
Gx	161.4537	174.99	0.91
Gy	234.5340	235.03	0.0014
Gy	341.3000	348.25	0.0035

Table1: summarizes the gradient field strength at 6.5cm underneath the bore iso-center[2].

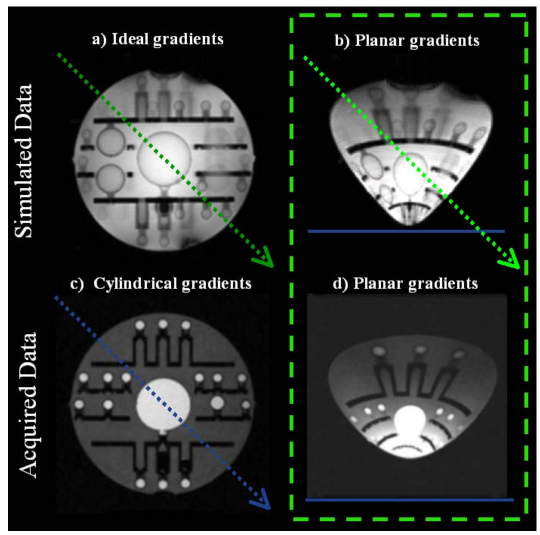

Figure 1: The top row shows the simulated images of one slice of the ADNI phantom for ideal (a) and the planar gradient field data (b). For illustration, a real data set acquired with cylindrical and planar gradients are shown in c) and d) [2]. The blue lines indicate the positioning of the phantom on top of the uniplanar gradient.

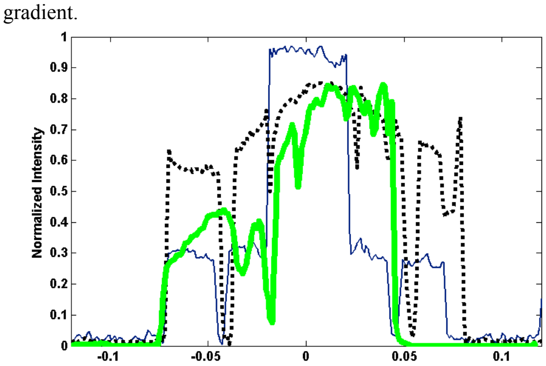

Figure 2: As depicted with the dashed lines in Fig.1, the slice profiles along the diagonal element are shown for the simulated image and the real acquired data set.