Fast Subject-Specific SAR Calculation for Multi-Channel RF Transmission

Shumin Wang[1]
[1]Auburn University, Auburn, AL, United States

Introduction: Safety assessment for multi-channel RF transmission systems requires the analysis of specific absorption rate (SAR) in a subject-specific manner. Since SAR depends on individual subject anatomy and on the multi-channel excitation scheme, traditional approaches that rely on generic subject models and worst-case scenario evaluations may result in excessive overestimations and become practically meaningless. With the advancement of fast computational electromagnetics techniques, real-time full-wave simulations of actual subject models have been proposed. However, the accuracy, which is measured by comparing with conventional "gold standard" simulation approaches, is little unknown. In this study, we demonstrate that high accuracy can be achieved with careful modeling and simulation procedures.

Methods: An overview of the real-time simulation procedure is shown in Fig. 1. It starts from pre-scans that acquire scout images for subject model generation. Ideally, the transmit coil under investigation is better used as receive coil, i.e., by making it a transceiver coil. This is because we need to determine the part of the body that can be "illuminated" by the transmit coil in its safety study. Thus this procedure minimizes the uncertainties caused by possible misalignment of separate transmit and receive coils. Since surface models are required in following full-wave simulations, suboptimal image quality is tolerable as long as the skin-air interface can be preserved. An image processing program was then applied to extract subject surface model from scout images. It first applied an anisotropic diffusion filter that reduces image noise while preserving sharp edges. The processed images were then segmented slice-by-slice to extract the contour. A consistence check was run for each pair of extracted contour. If the area of neighboring contours changes by more than 15%, it is likely because of the finite coverage of the transmit coil. In this scenario, any slices beyond will be discarded. The retained contour is then connected to form the subject model.

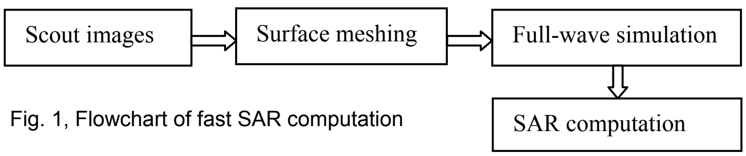

Fig. 1, Flowchart of fast SAR computation

The constructed surface model was passed to a fast Method of Moment (MoM) program [1]. The advantage of MoM is its superior computation speed. For a regular human head and eight-channel RF transmission system, typical CPU time on a single-core processor is less than 30 seconds. However, when it comes to highly inhomogeneous dielectric bodies, additional numerical techniques, such as the one proposed in Ref. [2], may be required to retain its computational efficiency. Once the electromagnetic fields are obtained, any SAR computation methods can ensure.

Total Power	FE/FDTD anatomically detailed "Duke"	FE/FDTD homogeneous (50 mM NaCl)	FE/FDTD homogeneous (42.5 mM NaCl)	MoM (42.5 mM NaCl)
Axial	5.2	6.7	5.3	5.2
Sagittal	4.9	6.6	4.8	5.0

Table 1 The total RF power required to generate a 90 degree flip angle at the peak B1+ location inside the "Duke" model.

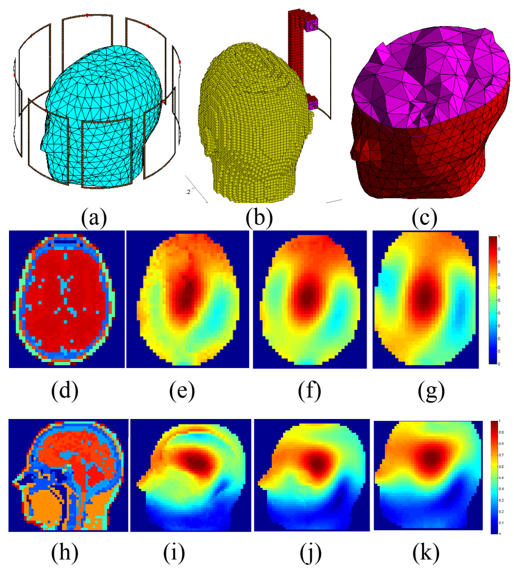

Fig.2 Numerical models and simulation results of the "Duke" phantom.

Results and Discussion: The accuracy of the proposed method was verified by comparing the MoM simulation results with the finite-element/finite-difference time-domain (FE/FDTD) method [3], which can accurately account for both material inhomogeneity and complex coil geometry. Eight transmit coils and the "Duke" head models are considered. The MoM model is shown in 2a. The FE/FDTD hybrid model of one coil element is in 2b. The anatomy of the axial slice and the sagittal slice are in 2d and 2h. B_1^+ maps simulated by the FE/FDTD hybrid method with anatomically detailed head model are in 2e and 2i. B_1^+ maps simulated by the FE/FDTD hybrid method with homogeneous head model filled with 42.5 mM NaCl are in 2f and 2j. B_1^+ maps simulated by fast MoM with the same homogeneous head model are shown in 2g and 2k. As can be seen, with 42.5 mM NaCl, the resulting B_1^+ field maps of the fast MoM match closely to those of the FE/FDTD. The total RF power required to generate a 90 degree flip angle at the peak B_1^+ location inside the "Duke" model was also calculated. The results in Table 1 show that 42.5 mM NaCl again provides very close results as compared to the FE/FDTD. Finally, an example of real subject is shown in Fig. 3. The entire CPU time, which includes image processing, automatic mesh generation and full-wave simulation, is less than 60s.

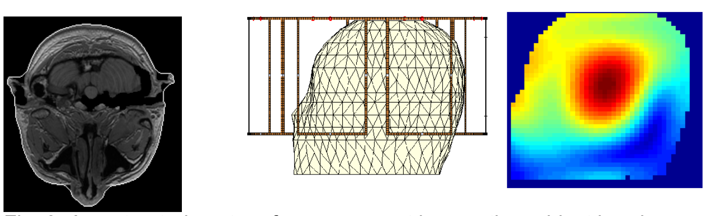

Fig. 3. An extracted contour from one scout image, the subject head model and the simulated B1+ map of the "birdcage" mode.

Conclusions: We have demonstrated that fast MoM can yield accurate subject-specific simulation results of both magnetic fields and total power deposition. Because electric fields and magnetic fields are related by Ampere's law, we expect that accurate electric fields in anatomically detailed human models can also be obtained via fast MoM and post-processing. This will be subject to our future research.

References: 1) PMB, 56:2779-2789, May, 2011, 2) Proc. ISMRM, 2010, p. 1448. 3) PMB, 53:2677–2692, May, 2008.