Fast Local SAR Simulation by Domain-Decomposition

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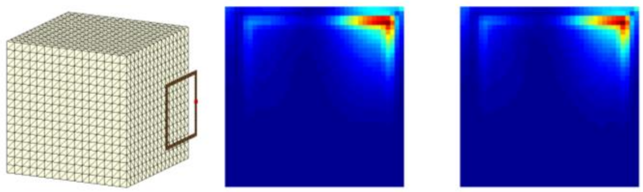
Introduction: Real-time Local SAR simulation is critical to the success of multi-channel RF transmission at high fields. The speed of conventional electromagnetic simulation methods is insufficient even on parallel computation platforms. We propose a novel domain-decomposition method that applies different numerical algorithms in the interior and the exterior of a human body model. These different methods then interface on the surface of the human body model. Preliminary studies show that on a single-core CPU, simulating an eight-channel brain imaging array only takes around 30 seconds.



(a) (b) (c)

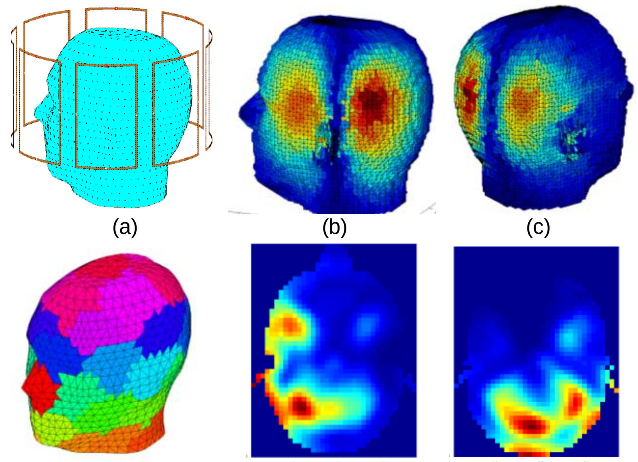
Figure 1. Layered cubic phantom model and a loop coil (a), local SAR maps computed by the conventional FDTD (b) and our proposed method (c).

Model	Proposed	Conventional FDTD	Relative Error
Layered Cube	1.80	1.83	1.67 %
Human Head	0.8	0.88	10 %

Table 1. The peak local SAR (Watt/kg/Watt) in different models computed by the proposed method and the conventional FDTD.

	The fast SIE method	Tetrahedral mesh generation	Finite-difference method	Total
CPU time (s)	20	5	8	33

Table 2. Simulation time of the proposed method on a single-core CPU for the eight-channel array.



(a) (b) (c)

(d) (e) (f)

Figure 2. (a) The eight-channel loop array model with the "Duke" head. (d) The decomposed sub-domains in fast MoM simulation. (b,d) The induced equivalent currents on the head surface. (e,f) The associated peak local SAR in the head.

Methods: The proposed method divides the entire computational domain into the interior and the exterior sub-domains. In the exterior sub-domain, RF coils were modeled in their exact tuning condition by a fast Method of Moment (MoM) program1. In contrast, the human body is modeled as a uniform phantom without anatomical detail. This was inspired by a common practice which applies saline water phantoms for tuning and matching RF coils. RF coils tuned in this way will perform well if the electric property of the saline phantom is close to that of the human body. By surface equivalence theorem, RF coils produce equivalent currents on the surface of the human body, which are solely responsible for the electromagnetic fields inside the human body. This implies that the effect of RF coils can be well described by equivalent surface currents without modeling them explicitly. In the proposed methods, the finite-difference method was applied in the interior sub-domain in order to model anatomical details. The benefit of the domain-decomposition method relies on its separate modeling of RF coils and the human anatomy. It is well understood that the finite-difference time-domain (FDTD) method is ideal for modeling human anatomy. On the other hand, the MoM is ideal for modeling RF coils but incapable of modeling the human anatomy. The domain-decomposition method applies each method in its suitable sub-domain and combines their results on the body surface. Optimal computational efficiency was achieved in this way.

Results and Discussion: We first simulated a 20-cm^3 layered cubic phantom, which consists of skin, fat, and white matter, by the proposed method and the conventional FDTD method. As shown in Fig. 1 and Table 1, the value and the location of the peak local SARs predicted by both methods are nearly identical. Since the surface equivalent currents are not identical when the interior of the phantom is modeled differently, a relative difference of 1.67% was observed. In the second example, a realistic human head model, i.e., the "Duke" model was simulated with a generic eight-channel loop array. Figure 2 shows the equivalent currents generated by two different coils on the head surface computed by the MoM. The peak local SAR *of each coil* computed by the finite-difference method was also shown in Fig. 2. The electromagnetic fields generated by the eight coils were combined in the birdcage mode and the overall 10-g averaged local SAR is listed in Table 1 together with that computed by the conventional FDTD method. It was found that the difference is larger than in the previous example. This was mainly attributed to the fact that the body surface was modeled in the MoM and the FDTD differently. Finally, Table 2 breaks down the run-time on a single-core CPU for the "Duke" example. The total simulation time is about 33 seconds (wall-clock time).

Conclusions: A domain-decomposition method was developed for real-time simulation of the electromagnetic fields inside the human body. It was found that for realistic brain imaging problems, the total simulation time is around 30 seconds and the relative error is about 10%.

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