REALISTIC NUMERICAL MODELING OF HUMAN HEAD TISSUES EXPOSURE TO ELECTROMAGNETIC WAVES FROM MOBILES PHONES

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Abstract

The vast majority of numerical studies on possible consequences of electromagnetic radiation on human health have been conducted using the FDTD method, although strong limitations of its accuracy are due to heterogeneity, poor definition of detailed structures of head tissues (staircasing effects), etc. In order to propose numerical modeling using FETD or DGTD methods, reliable automated tools for the unstructured discretization of human heads are also needed. Results presented in this paper aim at filling the gap between human head MRI images and the accurate numerical modeling of wave propagation in biological tissues and their thermal effects.

Introduction

The diffusion of mobile phones has determined an increased concern for possible consequences of electromagnetic radiation on human health, in particular for children. In the last decade, several research projects have been conducted in order to evaluate the possible biological effects resulting from human exposure to such an electromagnetic radiation [1]. Thermal biological effects of microwave radiation have been investigated both from the experimental and numerical viewpoints. Concerning numerical modeling, the power absorption in a user head is generally computed using discretized models built from clinical Magnetic Resonance Imaging (MRI) data. The majority of such numerical studies have been conducted using the widely known Finite Difference Time Domain (FDTD) method for solving the time domain Maxwell equations. However, limitations are still seen, due to the rather difficult departure from the commonly used rectilinear grid and cell size limitations regarding very detailed structures of head tissues as well as of a handset which might be essential for reliable compliance testing. So far, little attention has been put to the application of numerical methods able to deal with unstructured grids, i.e. Finite Element, Finite Volume or Discontinuous Galerkin Time Domain (respectively FETD, FVTD, DGTD) methods. This situation is essentially due to the lack of reliable automated tools for the unstructured discretization of human heads.

The HEADEXP project at INRIA (see http://www-sop.inria.fr/caiman/personnel/Stephane.Lanteri/headexp/headexp.html) is aimed at filling the gap between human head MRI images and the efficient and accurate numerical modeling of the interaction of electromagnetic waves emitted by mobile phones on biological tissues. This requires the development of specific image analysis tools and automated unstructured mesh generation tools for the construction of realistic discretized human head models. Preliminary results for numerical dosimetry (Specific Absorption Rate – or SAR – distribution) are presented. An additional step is made towards biological effects simulation by computing the thermal response as a function of time, starting from the SAR distribution.

From images to numerical simulation

Segmentation tools

Starting from MRI data or the Visible Human 2.0 project, the head tissue has to be segmented. Each voxel of the Cartesian representation of MRI data is recognized as made (mainly) of a single material. After having decided the relevant number of different materials inside a head (see electromagnetic characteristics of tissues selected in Table 1; CSF stands for Cerebro-Spinal Fluid), the different tissues must be segmented and the interfaces have to be meshed, preferably using unstructured triangles, which will be used as inputs for volumic mesh generators.

Different strategies can be used in order to obtain a smooth and accurate segmentation of head tissues and interface triangulations as well. A first strategy consists in using a ”Marching Cube” algorithm [3] which leads to huge triangulations of interfaces between segmented subdomains. These triangulations can then be regularized,

Tissue	ε_r	μ_r	σ (S/m)	ρ (Kg/m^3)	λ (mm)
Skin	43.85	1	1.23	1100.	26.73
Skull	15.56	1	0.43	1200.	42.25
CSF	67.20	1	2.92	1000.	20.33
Brain	43.55	1	1.15	1050.	25.26

Table 1: Relative parameters ε_r and μ_r, conductivity σ, density ρ, and wavelength λ at 1800 MHz.

refined and decimated. Another strategy consists in using a variant of Chew's algorithm [4], based on Delaunay triangulation restricted to the interface, which allows to control the size and aspect ratio of interfacial triangles [5]. Examples of the skin and skull surfacic meshes are presented on Figure 1 ($\bar{h}$ denotes the average edge length). Bumps are artifacts due to the head positioning system in the MRI scanner. Finally, another very promising strategy deriving from a level-set approach has been tested [6].

Semi-automatic mesh generation

The volumic mesh generation is almost automatic. The mesh generator GHS3D [7] is used to mesh volumic domains between triangulated interfaces between materials. The mesh generated is fully unstructured and can lead to some small edges, which is a concern for the explicit leap-frog time-scheme used. The exterior of the head must also be meshed, up to a certain distance, where an artificial absorbing boundary condition has to be set (in practice, Γ_∞ is a sphere). For numerical simulations with a mobile phone model, the meshing process is a little more complex and requires the meshing of the phone and of the free space around the head and the phone.

Numerical methods

We have used a Finite Volume Time-Domain solver based on an explicit leap-frog time-scheme and totally centered numerical fluxes at element interfaces [8]. A $\mathbb{P}_1$-DGTD version of the software exists and a generic high-order capable version is under development, similar to other existing software [9]. The FVTD solver is quite fast and an interesting result of these preliminary study is the evaluation of the accuracy of numerical results obtained on automatically generated unstructured meshes, for highly heterogeneous materials.

Numerical results

The global mesh used consists of a little more than three millions of elements (over 18 millions of unknowns). The average edge length is 5.4mm (maximum length: 25mm, minimum length: 0.3mm). The temporal excitation is a Gaussian pulse modulated by a sinusoid

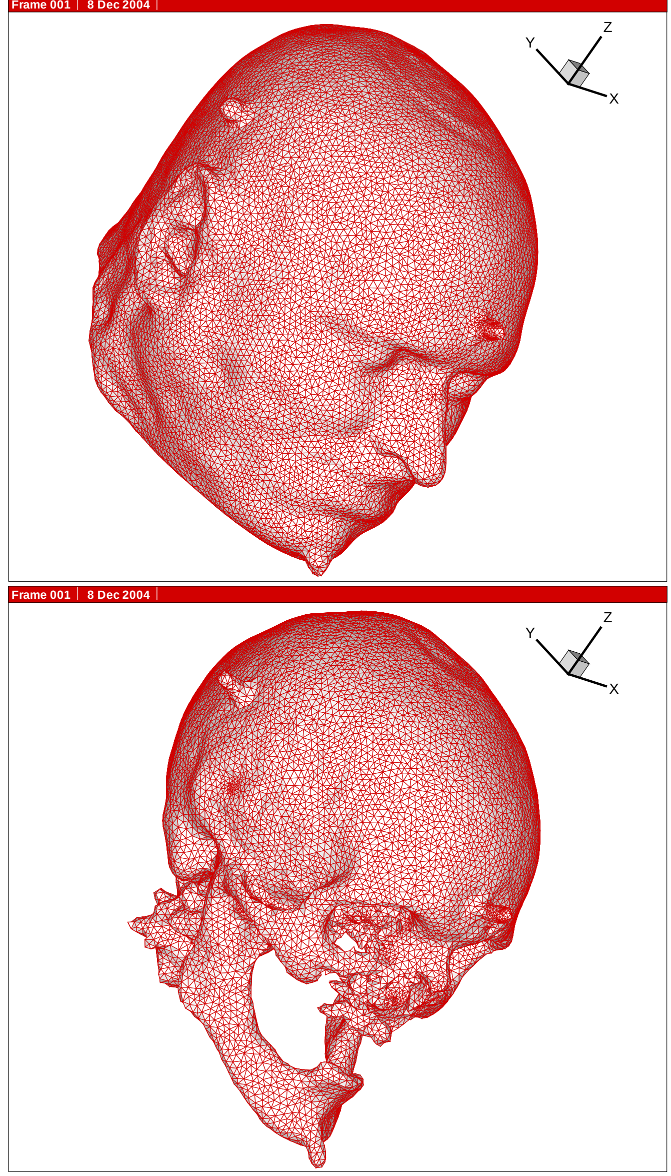

Figure 1: Triangulated skin (35k triangles, $\bar{h}$=3.2mm) and skull surface (57k triangles, $\bar{h}$=3mm).

with a central frequency of 1.8 Ghz (total emitted power equal to $1W$). Note that at this frequency, the minimal wavelength is obtained in the CSF (20.3mm) while the maximal wavelength is 166.7mm (in the air). The time $\Delta t = 0.091ps$ lead to a CPU time of 616mn on a 16 PC cluster (Pentium4@2GHz, Gigabit Ethernet).

SAR distributions

The quantity of interest involved in the definition of international norms for mobile phones is the Specific Absorption Rate (SAR), defined by $\text{SAR} = \sigma\,|\vec{E}|^2/\rho$. Its integral is somehow related to the total power absorbed by head tissues (here we found $P_{\text{abs}} = 0.795W$). Indeed, only average values of the SAR over tissue balls are used

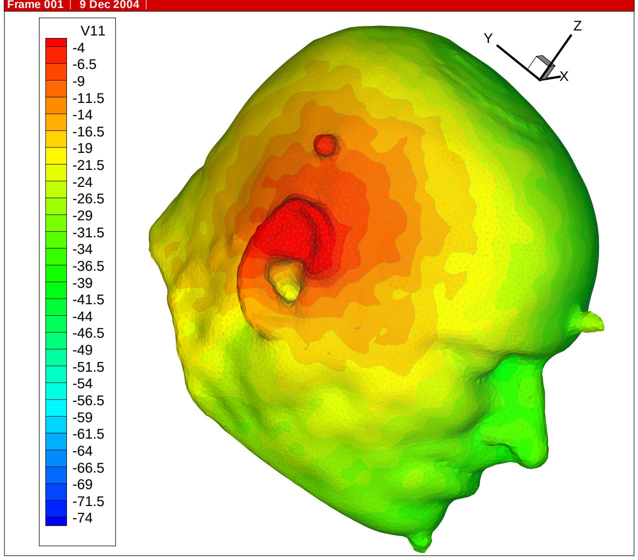

Figure 2: 5mm-sphere averaged normalized SAR in Db.

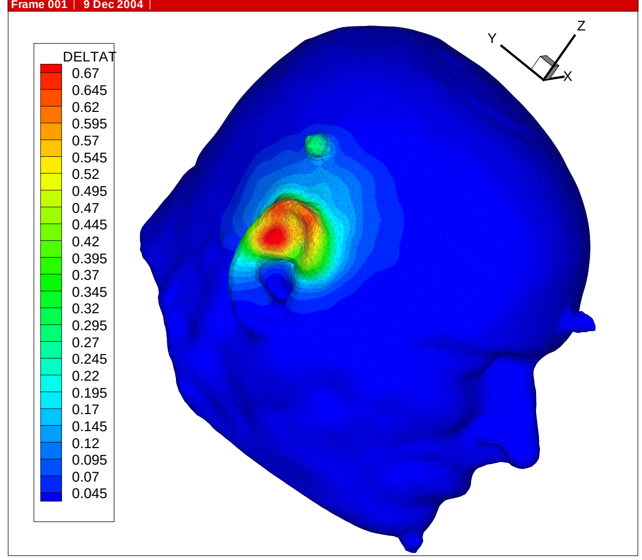

Figure 3: ΔT due to electromagnetic radiation.

in mobile phone norms. These quantities are less sensitive to FVTD inaccuracies due to heterogeneities in materials and elements. The normalized SAR distributions averaged over 5mm-radius spheres are shown on Figure 2.

Estimation of thermal increment

The SAR computed can be used as a source term in Pennes bioheat equation [2], modeling the evolution of the temperature in biological tissues. In the present computation, no convection has been considered and the steady solution is seeked for, using a classical P1 Lagrange finite element method. Starting from the averaged-SAR distribution, we compute here the temperature increment ΔT due to the electromagnetic radiation (see Figure 3). The maximum value of this increment, less than 1^oC, is in good agreement with other studies [1], [10].

Further works

These preliminary results will be completed in the future with locally-refined tetrahedral meshes, computations with the $\mathbb{P}_1$-DGTD method (at least) and more realistic mobile phone models. Concerning thermal effects, the thermal radiation of the phone and blood convection inside tissues should be taken into account.

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