3D RECONSTRUCTION OF THE HUMAN HEAD FOR FEMLAB ANALYSIS OF THE EXPOSURE OF MOBILE PHONE USERS TO MICROWAVES

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Abstract. *Potentially adverse health effects due to the exposure of living bodies to electromagnetic radiation is still a subject of debate. An engineering perspective on this issue deals with electromagnetic field parameters estimate by computation and measurement and with the certification of the electric and electronic equipment in compliance with exposure standards. The paper presented here describes a 3D computational model, based on the finite element method, for the study of microwaves penetration in the head exposed in the near field of a dipole antenna, in conditions similar to mobile telephony. The head is accurate in its external shape and has an equivalent homogeneous inner structure. The microwaves penetration in human tissue is superficial and the electric field distribution is less sensible to the accuracy of the inner anatomy, than to the body shape. Field parameters, like electric field strength and specific energy absorption rate, are evaluated in order to be compared to values stated in limiting exposure standards.*

INTRODUCTION

This paper presents a study of the electromagnetic field generated by a mobile phone and its distribution in the exposed human head.

The 3D reconstruction of the human head is accomplished with the aid of the MATLAB – FEMLAB software suite [1], after the preprocessing of the data with 3D Slicer [5]. FEMLAB is an interactive environment for modeling and solving problems based on the finite element method [6], while 3D Slicer is an image processor, capable of volumes reconstruction from 2D slices taken through them, like in tomographic techniques.

The human head is generated with accuracy, in order to guarantee the precision of the results. However, earlier studies [2] showed that in radio waves penetration, the internal anatomical structure is less important than the external shape.

The results for the computation of the electric field strength, *E* and the Specific energy Absorption Rate, *SAR* are presented.

THE GEOMETRY OF THE HUMAN HEAD

Data Preprocessing

The reconstruction of the human head is necessary for the numerical modeling. In order to be imported in this software, the three-dimensional object must comply with the following conditions:

- Simplicity – the object must be simple enough so that the numerical problem is solvable in a reasonable amount of time
- Complexity – the object must be complex enough so that the results are as close to reality as possible
- Adequate shape – the object must have a shape similar to the human head so that the results can be compared with results obtained from measurements

- "Solidity" – the object must be solid in the way compatible with FEMLAB's processing methods (it should be closed by a mesh)

The primary data used are CT images scanned from a patient (fig. 1), as a series of plane cross-sectional images made along an axis, a few millimeters one of another. The initial images are in shades of gray; a set of such images is called a *volume*.

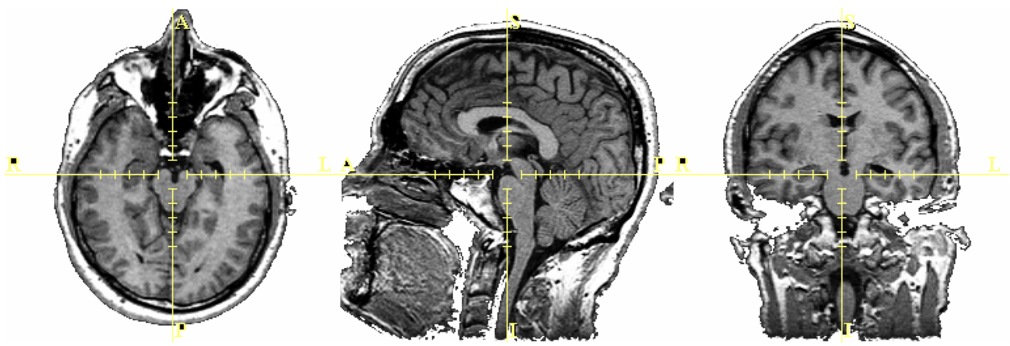


Fig. 1. Primary data (CT scans)

The images are segmented (the regions of interest are identified on the image – in our case the whole head) using a combination of manual and semiautomatic segmentation (the Threshold and Draw modules of 3D Slicer). The results of the segmentation are presented in the following image (fig. 2).

Fig. 2. The result of the segmentation in 3D Slicer

From these images the head is reconstructed in 3D Slicer as fig. 3 shows.

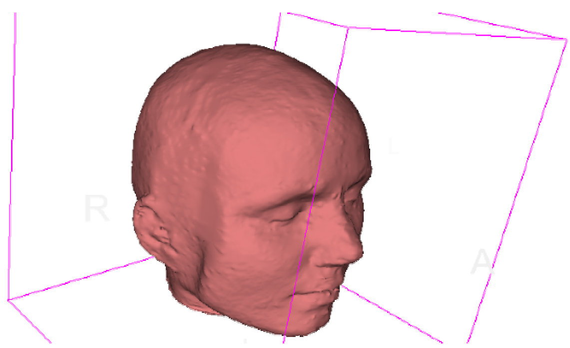


Fig. 3. The head, reconstructed in 3D Slicer

The reconstruction using the MATLAB – FEMLAB software suite

The images segmented in 3D Slicer were used as the basis of the reconstruction in MATLAB.

Each image from the segmented volume is saved in a separate file, the information in each one being coded as a string of two octets (raw image format). The images were imported in MATLAB using a custom script (to automate the process). An example of image displayed in MATLAB with the function *image* is shown in fig. 4.

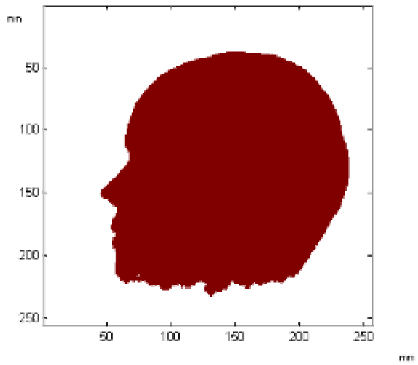


Fig. 4. Initial image shown with the *image* function in MATLAB

Using several MATLAB and FEMLAB functions [6] (flim2curve, solid2, geomdel, geomcomp, loft and other custom scripts), the final object was finally rendered in FEMLAB, along with the outer domain (the space around the head and antenna is limited with a spherical domain) and the antenna, located near the right ear:

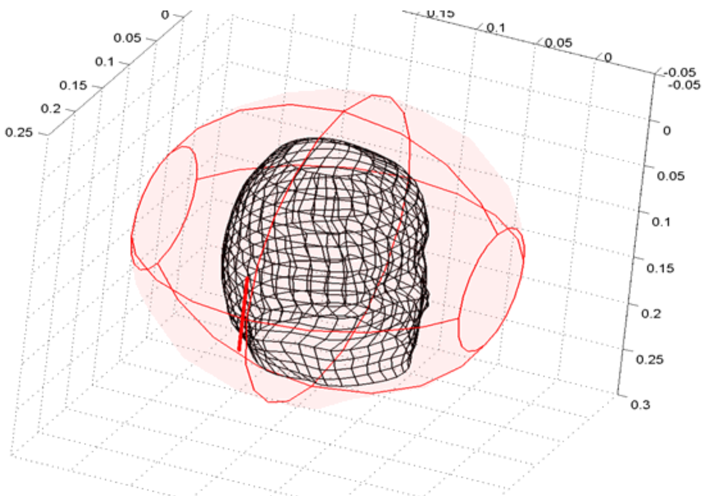


Fig. 5. Human head geometry, in FEMLAB

THE FEM MODELLING

The mathematical conditions on the external boundary are „low reflecting", which means that the result will be not influenced by the limitation of the computational domain with the sphere.

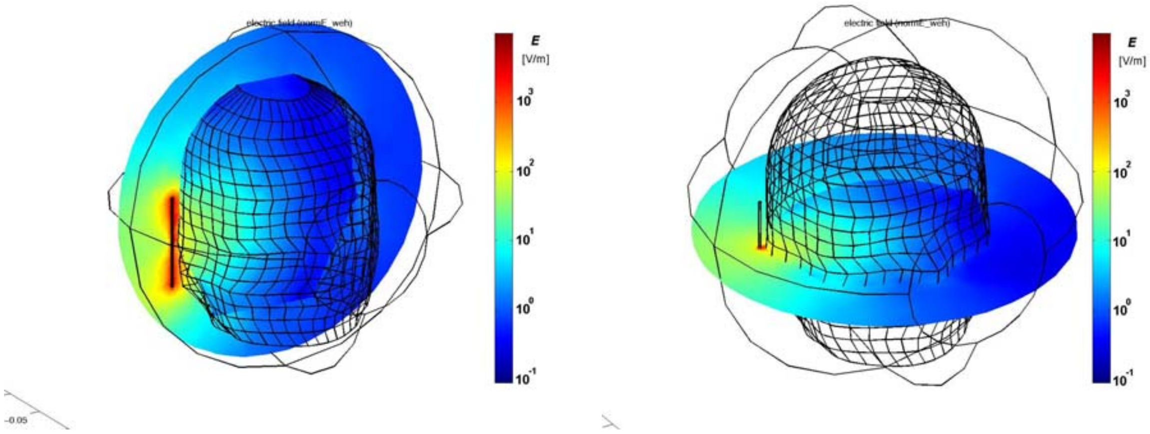
A center-fed half-wavelength dipole antenna that emits electromagnetic waves at the frequency of $1{,}8 \cdot 10^9$ Hz is considered as the electromagnetic field source. In order to get closer to the parameters of a mobile phone, the antenna is calibrated so that the power emitted is 0.125 W (the intensity of the magnetic field is specified on the antenna). The lateral surface of the antenna is considered to be a magnetic field emittor. The top and bottom of the antenna are considered perfect electric conductors, which means that their resistivity is null.

The head is considered a homogenous object with the electrical conductivity σ = 0,48 S/m and the relative permitivity ε_r = 17.84. A value of 1100 kg/m^3 is assigned to the equivalent mass density.

The generated mesh is composed of 6896 nodes and 38097 elements (tethraedra).

The FEMLAB selected solver is linear, stationary and of iterative type.

In the postprocessing step, the strength of the induced electric field, *E* and the specific energy absorption rate, *SAR* were calculated and displayed in two planes: the longitudinal section that includes the axis of the antenna and the transversal section, perpendicular to the antenna at its center. Fig. 6 shows the *E*-field colored maps (maximal values in the time harmonic mode) in the mentioned sections.

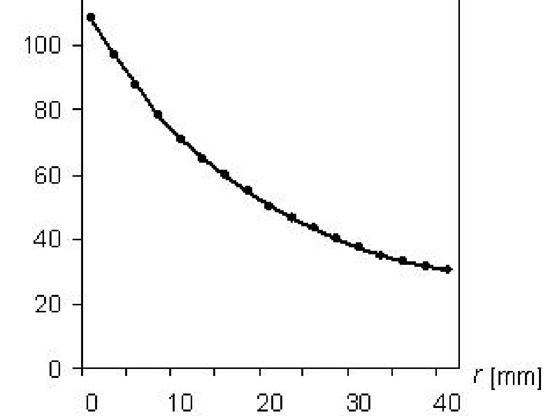


a. **b.**

Fig. 6. The electric field strength (maximal values) in section planes longitudinal (a) and transversal (b) with reference to the antenna

The variation of the electric field strength (maximal values in the time harmonic mode) in the head, along the direction of maximum values (perpendicular to the antenna at its center) is presented in fig. 7.

Fig. 7.
The strength of the electric field (maximal time harmonic value) in the head, along a direction of maximum values (perpendicular to the antenna)



Limiting exposure guidelines [3] state, as a reference level, the rms value of 58 V/m (respectivelly maximal time harmonic value of 82 V/m) as the maximum allowed electric field strength at 1.8 GHz.

SAR is calculated according to the following equation:

$$SAR = \sigma \frac{E^2}{2} \frac{1}{\rho},$$

where E is the maximal strength of the time harmonic electric field, σ is the electric conductivity of the medium where the evaluation is made (the human head) and ρ is its mass density.

The results of the *SAR* estimates are presented in fig. 8.

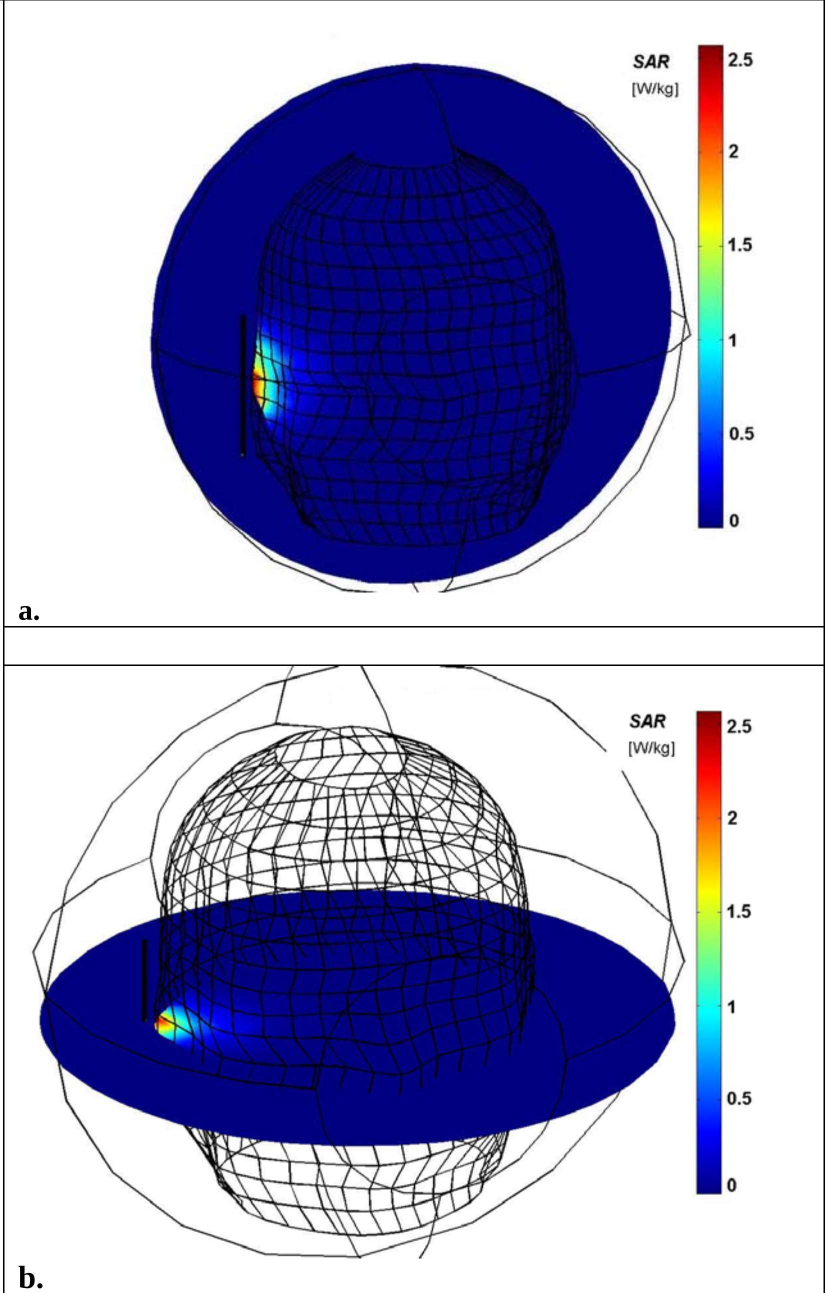


Fig. 8.
SAR spectra in section planes longitudinal (a) and transversal (b) with reference to the antenna

The guidelines that limit the human exposure to electromagnetic field in the GHz band [3] state, as the basic restriction for this type of exposure, the averaged value of *SAR* on a volume which corresponds to 10g of tissue ($SAR_{max\ 10g}$); this value should not exceed 2 W/kg (for the general public exposure). Results displayed in fig. 8 lead to $SAR_{max\ 10g}$ = 1.6 W/kg.

CONCLUSIONS

The 3D reconstruction of the human head is the first step towards the building of the numerical model:

- it is a semiautomatic process
- the results depend on the primary data used
- the results are comparable to data obtained with numerical simplified models, similar to those presented in [2]
- the *SAR* values obtained are close to the values measured on phantom models of the head and comply to the limiting exposure guidelines
- the advantages of the numerical modelling compared with experimental measurements are obvious: the anatomical data could be easily changed in numerical models and the required experimental conditions (anechoic chamber, adequate phantom model and sophisticated instruments) are seldomly accesible.

Future research directions may be followed on the basis of this study for the automatization of the process of three-dimensional reconstruction. Also, the neck, thorax and the hand that holds the mobile phone may be added to the numerical problem for the study of „hands free” devices.

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