Оригинален научен труд/Original scientific paper

Visualization of Electromagnetic Fields in Individuals Exposed to Radio Frequency Electromagnetic Fields

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***Abstract*—Visualization of EMF effects in individual human bodies is described in the paper. To calculate EMF parameters in the region of interest, two-step computational method is applies. A partly automatic procedure has been developed to generate surface boundary model of tissues in the human body. All phases from obtaining models for visualization from MRI scans, field calculation and visualization using obtained models are presented.**

***Index Terms*— high frequency electromagnetic fields, modeling human body, visualization.**

I. Introduction

STUDIES concerned with biological effects of electromagnetic fields (EMF) on humans [1] are carried out to determine parameters useful for several different purposes. One goal of the studies is setting standards and developing protective procedures for human's health [2, 3] by monitoring negative outcomes and possible health problems of the human's exposure to residental EMF. Other studies are aiming to find out usability of EMF effects for medical treatments. These researches include determination of equipment configuration, and methods and techniques to achieve required effects [4].

However, to present complete picture about requested negative and positive EMF effects, several problems have to be solved. Problems include selection of representative parameters, development of a human model, approximation of electrical sources and environment, numerical calculation method and results presentation. In general, generalized specific absorption rate (SAR) values are calculated to represent tissues and EMF interaction in almost all studies. The SAR is the mass-normalized rate of EM energy absorbed by the body and not necessary gives the complete picture about possible problems. For example in MRI systems, used time varying magnetic fields induce currents in patients that can be associated with neuromuscular and peripheral nerve simulation. Even more, regions around peaked boundaries between tissues are places where electrical discharge in the surrounding because of EMF is very likely. Taking into account that the electric discharge can be more dangerous than thermal effects from increased hitting of the body, parameters as field distribution, induced charges and currents in human bodies are relevant in one study, too.

Another important part of the studies is selection an development of a human model used in numerical calculati procedure. Digital anatomical models of a human and anima are available for use in numerical calculations. To use the models, seems appropriate when systems calculate EM effects when setting standards and development of protecti procedures and individual differences can be neglected. many cases, the body model is usually modeled as a sphere as a spheroid, and the additional approximation is made th internal absorption is high enough for the rays not to internally reflected, but completely absorbed. This approa does not seem particularly suitable for individuals for medic purposes where exact values are required, due to t differences in physical dimensions and anatomical properti Therefore, when EMF effects are monitored for medic purposes, individual characteristic are important to obta accurate model.

We developed an integrated system for monitoring EM effects on humans [3, 5]. The purpose of development su system is to provide simulation tool for obtaining a detail estimate for the EMF effects in a human body individual. Tv steps procedure is used to optimize calculation process ar visualization engine is developed as the most appropria approach to present results. The paper describes the process visualization EMF distribution in individual human bodies.

II. Calculation Method

To determine electric and magnetic fields, human body divided in regions with the same electrical characteristi Regions are separated by boundary surfaces described wi triangles as most simple and suitable description form. T influence of the field within separated body regions calculated from electric and magnetic currents on the bounda surfaces. Mathematical models that determine equivale electric and magnetic current densities on boundary surfac are obtained from boundary surfaces conditions, where t tangential components of electric and magnetic fields, a normal components of electric and magnetic induction are t same. Knowing densities of equivalent electric and magne currents, the EMF distribution inside requested region a calculated with following formulas

$$\vec{E} = -j\frac{1}{\omega\underline{\varepsilon}\mu}\,grad\ div\,\vec{A} - j\omega\vec{A} - \frac{1}{\underline{\varepsilon}}rot\,\vec{F} \qquad ($$

$$\vec{H} = \frac{1}{\mu} rot \vec{A} - \frac{j}{\omega \varepsilon \mu} grad\ div \vec{F} - j\omega \vec{F} \qquad (2)$$

$$\vec{A} = \frac{\mu}{4\pi} \int_S \vec{J}_s \frac{e^{-\gamma r}}{r} dS \ , \qquad (3)$$

$$\vec{F} = \frac{\varepsilon}{4\pi} \int_S \vec{J}_{sm} \frac{e^{-\gamma r}}{r} dS \ , \qquad (4)$$

where

- ✓ $\vec{J}_s$ and $\vec{J}_{sm}$ are electric and magnetic current density,
- ✓ $\vec{A}$ is magnetic vector potential,
- ✓ $\vec{F}$ is electric vector potential,
- ✓ γ is propagation constant,
- ✓ ε is complex permittivity, and
- ✓ μ is permeability.

During calculation, the current density $\vec{J}_S$ is taken as constant on the triangle surface. Having the relation between magnetic vector potential and current density in (3) and because the assumption $\vec{J}_S = const$, the magnetic vector potential $\vec{A}$ is given by

$$\vec{A} = \frac{\mu \vec{J}_s}{4\pi} \int_s \frac{e^{-\gamma r}}{r} ds \qquad (5)$$

Distance r is defined from the point where $\vec{A}$ is calculated to the mass center of the correspondent triangle r_o. This point is treated as a center of the triangle surface. Therefore (5) can be written as

$$\vec{A} = \frac{\mu \vec{J}_s e^{-\gamma r_o}}{4\pi} \int_s \frac{e^{-\gamma (r - r_o)}}{r} ds \qquad (6)$$

Because dimensions of the triangles are small comparing to wavelength, the article $e^{-\gamma(r-r_o)}$ is developed in row (7) and only the first three articles are included in calculation process.

$$e^{-\gamma(r-r_o)} \approx 1 - \gamma(r - r_o) + \frac{\gamma^2 (r - r_o)^2}{2} \qquad (7)$$

On the same way, similar equations are determined for the electric vector potential, too.

To qualify the biological effects of EMF fields, two-step numerical procedure is developed. During the first step, boundary current densities are calculated for human body roughly divided on regions with the same electric characteristics. In the second step, requested monitoring parameters are calculated for refined models of regions of special interests. In this step, previously calculated boundary currents are used as EMF sources.

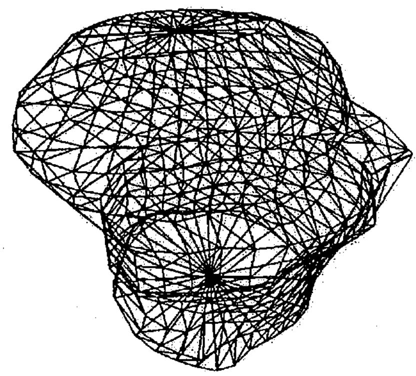
III. Human Model

There exists several ways how to select human model for calculation. However, a parallelepiped, a cylinder, a sphere or a combination of several of them, have been used to serve as a geometric model of a human form and its body tissues in several research areas [6]. On the other hand, three-dimensional geometric models of the human body that closely approximate actual body shapes have been developed, and their databases for various sizes of the human body have been disclosed. [6] Each of these models can be used for purpose of determining standards and protective procedures, but many of them are mostly non-usable for individuals.

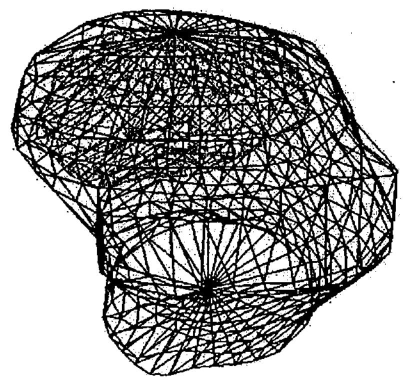
Our system offers semiautomatic procedure for development of individual human models. The system uses several consecutive MRI images to create 3D model of a specific person. User selects regions from a sequence of MRI images, defines spatial resolution for the parameters and participates in determining boundary surfaces. Having these parameters, system alone performs triangulation and generates surface models.

To increase the speed of making boundary models, the system generates data files that contain all points for boundaries between tissues in each slice. These data files are used as a source when determining surface models with different resolution (under resolution we understand a number of triangles used to approximate surface between two consecutive slices). The highest resolution of the generated model is determined with a number of triangles that can be formed for a slice with the maximal number of boundary points.

Fig. 1 shows models of a human head



a)



b)

Fig. 1. Boundary models of human head and brain

a) model of human head
b) model of human head and brain

. The a) part of the figure represents skin boundary model of the head where 60 triangles are used to approximate surface between two slices. The b) part of the picture shows the model that contains boundaries models for the brain and human head.

Fig. 2 presents developed boundary models of head and brain.

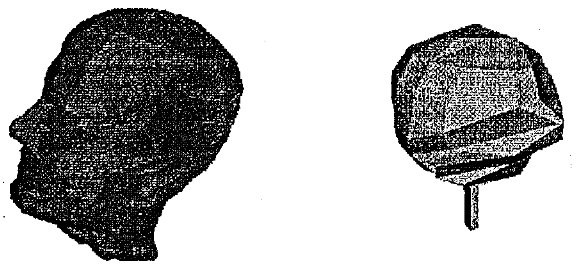


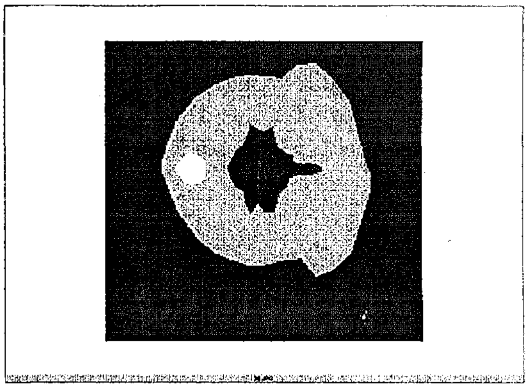
Fig. 2. Boundary models of human head and brain

IV. AN EXAMPLE

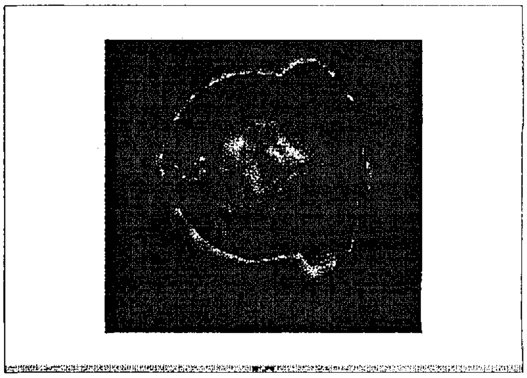
The system is used to calculate EMF effects in regions surrounding tissues with peaked surface boundaries in the human neck, when human head is exposed to radio frequency EMF generated by cellular antenna. Fig.3 and Fig.4 present calculated EMF distribution for two horizontal planes of the human neck. The a) parts of the pictures represent tissues considered during calculation, and The b) parts represent the results. Cellular antenna is approximated by half wave dipole that works on 1 GHz and the phone radiated a power of 1mW. The source is placed to be parallel to the vertical axis of the head, and the distance between the antenna and the head is 2 cm. The amplitude of induced electric fields is selected as most suitable parameter. The amplitude of induced electric fields is selected as most suitable parameter for visualization of EMF effects.

V. DISCUSSION

An advantage of the visualization using this system is to show how EMF is distributed to areas inside body. The results prove the model's usability for simulations in various conditions for different individual users. The developed algorithm provides reliable results and is usable for analysis effects of high frequency EMF. This model is based on assumption that wavelength is much greater than approximated triangles and is not appropriate for visualization effects by low frequencies EMF.



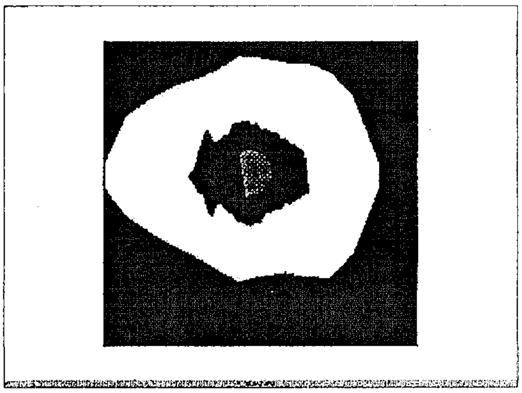
a)



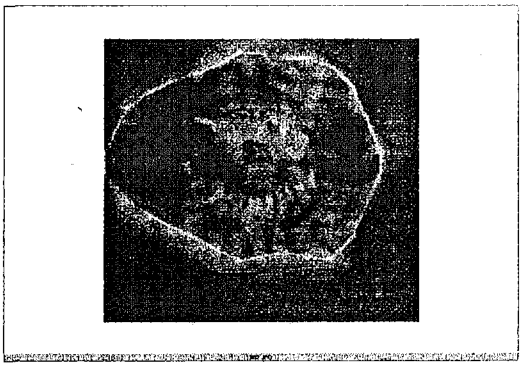
b)

Fig. 3. Regions and EMF distribution

a) regions
b) EMF distribution



a)



b)

Fig. 4. Regions and EMF distribution

a) regions
b) EMF distribution

The ultimate goal is to develop a simulation system that would quantify in detail the biological effects of EMF fields on humans in real time. That considers having a dynamic model of the human. For this aim, a procedure for developing human model should be optimized to decrease time necessary to develop surface model. Numerical calculation method should be modified to reduce time for obtaining results too. Finally, 3D visualization with easy navigation through data becomes also obvious requirement.

CONCLUSION

To provide detailed estimates of biological effects, an integrated system for monitoring EMF effects on humans is developed. The system provides a procedure for generating rough and refined human models. Two-step numerical method is developed to calculate EMF distribution. Advantages of the systems include considering influences of all tissues in EMF distribution in rough model, but values that are more specific are obtained for refined model.

Advantages of using this approach are several. There is no possibility of damage or health hazards on investigated individuals and the same model of the regions of interest can be used for different monitoring scenarios. Even more selected calculation method does not require powerful computer systems and enable system to be functional on standard personal computers. Finally, the procedure can be repeated on different human individuals, too.

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