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Computer Simulation of Space Configuration of Low Frequency Magnetic Field in Magnetotherapy

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Introduction

Recently, numerous experiments confirm invitro biologic effects of the extremely low-frequency and low-amplitude magnetic fields. These effects can be evaluated as beneficial, as adverse, or with no impact on living organisms (animals and humans). In spite of the different opinions, an increasing number of therapeutical applications of very weak magnetic fields are discovered. One of the most popular applications is the use of such a field to assist fractured bone repairing and healing. There is some experimental evidence that electric and magnetic systems can aid nerve regeneration and peripheral circulation as well as blood vessels regeneration and soft tissue healing. Magnetotherapy is used also as an alternative treatment of pain and swelling associated with muscle strains, sprains, carpal tunnel syndrome and other types of injuries. Biomagnetism is proved to be non-invasive and non-harmful form of treatment. So, there are many methods of magnetotherapy currently available. However, the way the magnets or coils in these products re configured internally to promote maximum therapeutic benefits, is not explained. So, it is necessary to supply software solutions to assist in electromagnetic devices design and manufacture. The common goal of this software is to give the abilities to quickly enter a variety of magnetic models, calculate the field and visualize the obtained numerical solutions in a number of different ways to assist in understanding and determining the field's biological impact. The output must supply enough information to design and develop electromagnetic devices with predefined therapeutic possibilities.

The existing electromagnetic software [1–4], which unfortunately is not intended for biomagnetism problems solving, can be evaluated using the following basic characteristics:

- the computation methods used;
- the visualization techniques used;
- level of interactivity supplied;
- visualization mode (2D or 3D);
- possibilities to export numerical and graphical results.

All studied by the author electromagnetic software packages have the following common features that make it impossible or ineffective their use in biomagnetism:

- They do not permit to create magnetic field configuration on-line and from scratch;
- Only little part of them work with irregular meshes and no one permits additional subdividing of the mesh;
- They support only one viewport: orthogonal – for 2D simulators and perspective – for 3D simulators;
- They don't permit to interactively change the view point.

This article presents a prototype of 3D simulation program especially developed for the case of low-amplitude static magnetic field and its impact over the human body.

The main objective is to provide the user with the tool for intuitive and rapid creation of the current contours configuration as a source of the therapeutic magnetic field, for evaluation and visualization of the field distortion and for obtaining the needed information for electromagnetic device design and manufacture. The goals of the simulation program set out the following requirements to the developer:

- Supply the ability to create a configuration of current contours from scratch by adding and removing contours in contrast to the existing packages that allow only to choose among the predefined configurations;
- Supply the ability to position and reorient individual contours in 3D space freely and precisely in order to achieve the maximum therapeutic effect;
- Supply the ability to change the parameters of the contours interactively in the course of the program and what is different from another existing packages – additionally to turn on/off selected contours during the time;
- Supply a calculation method that allows to obtain the magnetic induction vector in each 3D point with enough precision;
- Supply the ability to visualize the magnetic field distribution over the human body parts in different ways with different level of mesh tessellation;

- Supply an application database that contains all the needed geometric and non geometric information for modeling and optimizing current contours configuration.

In order to satisfy the above listed requirements the presented program is designed and implemented in such a way that:

- Performs all calculation and visualization tasks in 3D;
- Supports on-line creation of the contours configuration;
- Supports interactive changes of the contours' parameters as well as the ability to turn on/off contours to enable/disable their impact on the net magnetic field;
- Supports 4 viewports on the screen that makes it possible to easy position and reorients contours against each other as well as against the human body;
- Supports interactive change of the view point to obtain the most appropriate pictures of magnetic field distortion;
- Supports an application model database that allows: rapid and easy update; dynamic changes in the level of mesh tessellation; dynamic selection of different sets of points.
- Supports an output that includes the rendered images of the magnetic field as well as plain text files with numerical data.

The user of the simulation program starts with a blank screen, chooses the type of human body surface, defines the number, parameters and initial positions of the individual current contours, reorients contours in 3d space if necessary, calculates the local and the net magnetic fields and obtains the pictures of the fields. If during the first construction and visualization stage the user finds out that the field influence is not enough strong or is not precisely directed, he or she must return to the initial contours configuration layout and redesign the model to achieve the desired therapeutical effect.

The presented 3d simulation program is written on MAX Script language, supplied by the 3ds max. The choice of the graphics package is determined by the fact that 3ds max is one of the most powerful desktop 3d graphics programs available today. It is used for a wide variety of commercial and artistic applications, including medical visualizations and scientific visualizations. MAX Script language is an object-oriented language with a rich library of build-in functions, large variety of built-in classes for geometric objects, and a support for a creation of user-defined functions.

As the users of the presented simulation program are not computer programmers, the user interface was designed to satisfy two basic requirements: to be easy-to-use and to hide the complexities of the implementation. All commands are accessible through a set of buttons with self-explanatory captions and corresponding tool tips. The buttons are arranged together into a named roll-out, positioned at the command panel in the right side of the program window. To prevent the corrupting of the geometric model database during the iterative process of redefining parameters and repositioning the contours, simple but effective synchronization technique is implemented. All user actions are based on click-and drag and drag-and drop technologies and in such a way the keyboard input is fully avoided.

Program implementation

The presented 3d simulation program handles user input, creates the application model, traverses this model's database and passes to the underlying graphics package 3ds max series of graphics output commands. These commands contain both a detailed geometric description of what is to be viewed and the attributes describing how the objects should appear.

The source of the magnetic field is a system of circular current contours each with a particular radius **R**, direct current **I** and number of turns **n** and with a particular position in 3D space. If the centre of the contour matches the origin of the coordinate system, then the area of interest has symmetry against the local Z axis. This permits to limit calculations only to the right upper quarter of the xOz plane.

For every point M lying in this xOz plane, the magnetic induction vector can be defined by the following two scalar components [1]:

$$\mathrm{B}\rho = \frac{\mu_0\, i}{2\pi\rho}\,\frac{z}{\sqrt{(R+\rho)^2+z^2}}\left[\frac{R^2+\rho^2+z^2}{(R-\rho)^2+z^2}L-K\right],(1)$$

$$Bz = \frac{\mu_0\, i}{2\pi}\,\frac{1}{\sqrt{(R+\rho)^2+z^2}}\left[\frac{R^2-\rho^2-z^2}{(R-\rho)^2+z^2}L+K\right];(2)$$

where $\mu_0 = 4\pi 10^{-7}$ for the air (the same value μ_0 has for the human skin); ρ and **z** are the cylindrical coordinates of the point M. Express-ions for **K** and **L** are full elliptic integrals of the first and the second kind as a function of **k**. For a given values of ρ and **z**, the value of **k** can be calculated from the following equation:

$$k^2 = \frac{4\,\rho\, R}{(R+\rho)^2+z^2}\,.$$

Then the corresponding values of **K** and **L** are obtained from the graphics **K** = $F_1(k)$ and **L** = $F_2(k)$.

Each contour has its own Local Coordinate System (LCS). At the time of creation this LCS has the same centre and orientation as the World Coordinate System (WCS) (fig. 1a). The magnetic field generated by the individual contour is evaluated in the contour's local coordinate system for a set of points that is calculated on fly and form a hemisphere oriented towards the human body. For each point the magnetic induction vector B is evaluated according to (1) and (2).

As the contour is translated and rotated to take its right place in the system (fig. 1b), the Transformation Matrix (TM) assigned to it is continuously updated. The resultant TM, called current TM is used during the total or net magnetic field evaluation.

The total magnetic field is evaluated for a set of points that includes all the vertices of the human body part.

For each vertex (3D point) the magnetic induction vector B is calculated. During the calculations each 3D point is transformed from WCS to LCS of the corresponding contour and vice versa:

$$P_{(LCS)} = P_{(WCS)} \bullet TM^{-1} \begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \bullet \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_x \\ R_{21} & R_{22} & R_{23} & T_y \\ R_{31} & R_{32} & R_{33} & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} .(3)$$

The principle of superposition applied to the magnetic field is used. According to this principle the net vector of the magnetic induction B is the sum of the individual B's.

The core of the computational module of the presented program is based on the algorithm shown in the fig. 2. The algorithm however does not involve the procedures for:

- Drawing vectors;
- Converting from decart to polar coordinate system;
- Mapping a color range.

The same algorithm is used for generating the colored map of the total magnetic field, but applied to a different set of points The magnetic field is visualized by plotting geometric objects (splines), one at each sample point with size and color that corresponds to the magnitude of the magnetic induction vector and with the geometry aligned with the vector direction at that point (Fig. 3). A color map of the field distribution over the human body is also supplied. The color of each triangular face in the mesh is determined on the base of the magnetic induction calculated into the center of the face.

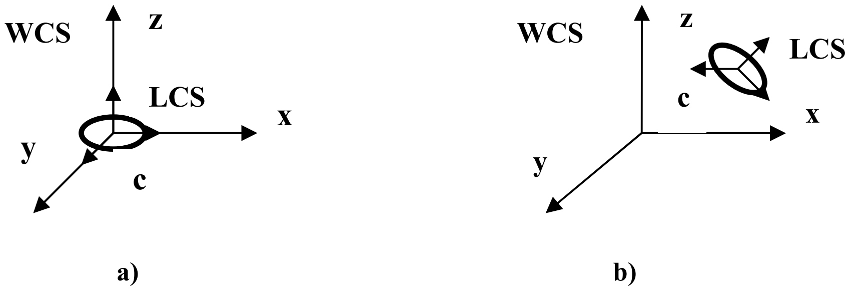

Fig. 1. Coordinate systems used: a) induction vector, b) system

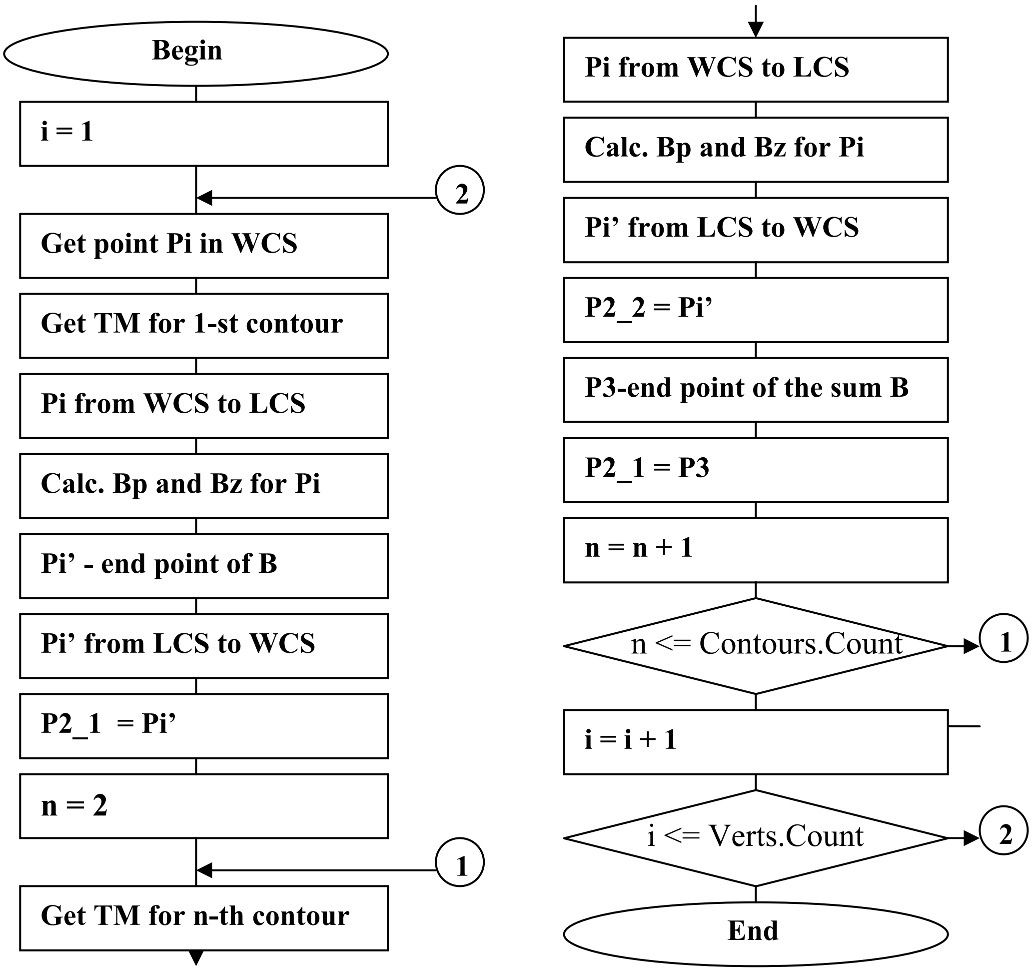

Fig. 2. Total magnetic field evaluation

Data acquisition and maintenance

The simulation program creates and maintains a geometric model database with a structure shown in Fig. 4. This database contains all the geometric and non-geometric information needed to construct and visualize the system of current contours as well as to generate a picture of both the local fields of the individual contours and the total field distribution over the human body.

Most of the information into the geometric model database (i.e. number of contours, their parameters and their 3d positions) comes from the user input. The program continuously updates the information into the geometric model database according to the user actions. The program then repeatedly traverses this database to extract the data needed for the magnetic induction calculation in order to supply dynamic update of the screen.

The other part of the information concerning the vertices, faces, normals of the human body mesh is acquired by direct access to the 3ds max internal database. The last part of the information, for example the points of interest in generating the local fields of the individual contours, is obtained on fly on the basis of calculations. The computational algorithms are stored as part of the geometric model. As the 3ds max provides an object-oriented environment, it is possible to store both data and computational algorithms as components of the geometric model.

Conclusion

The presented prototype of 3d simulation program is intended for calculation and visualization of a static magnetic field distribution over the human body. The purpose is to provide the user with an effective and easy-to-use tool for interactive design of a current contours system as a source of the therapeutic static magnetic field.

The program is written on object-oriented interpretative language MAXScript, supplied by 3ds max that is used as the underlying graphics package.

The magnetic field is generated by the system of circular current contours, which parameters as well as spatial placement are subject to design. All calculations are performed in 3D. For the purpose of the simulation program all anatomical tissues are treated as air, i.e. only the magnetic properties of the air are considered. The 3D models of the human body parts represented by irregular meshes and the green scale colors with 10 levels are used to display the field distribution.

The goal of the presented prototype is:

- to explore to what degree the interpretative language as MAXScript is appropriate for such a simulation program;

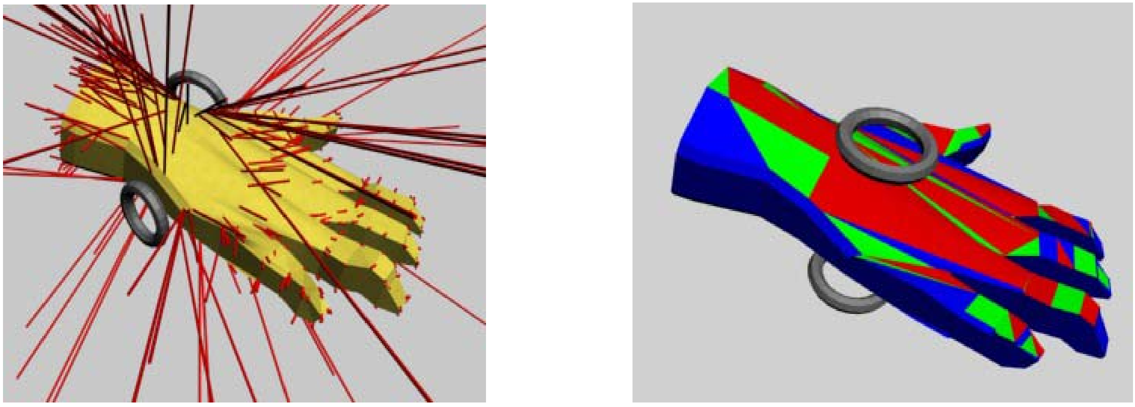
a) b)

Fig. 3. Vector field visualization: a) magnetic induction vectors, b) color map

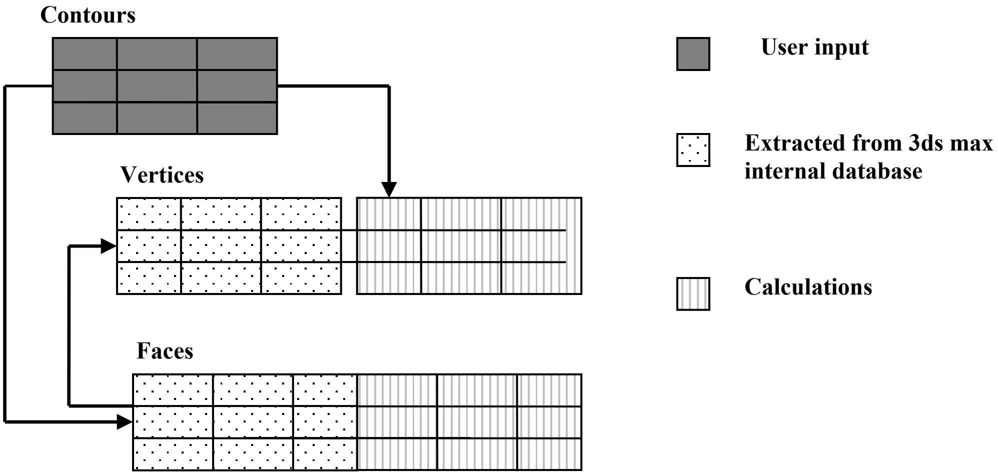

Fig. 4. Geometric model database structure

- to analyze the completeness of the application model and optimize the content and the structure of the model;
- to analyze the precision of the obtained numerical and visual results and to make decisions about possible changes into the computational algorithms;
- to analyze the effectiveness of the user interface in regard to the flexibility, completeness and convenience;
- to analyze the visualization techniques applied.

The future work will be concentrated in the following three areas:

- developing of the postprocessing modules for analyzing the accumulated data;
- increasing the quality and level of tessellation of the human body mesh models;
- exporting the graphics information about the human body model and the current contours configuration in XML for processing and visualization of another platforms.

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Pateikta spaudai 2005 02 28

D.T. Dimitrov. Žemadažnio magnetinio lauko erdvinės konfigūracijos magnetoterapijoje kompiuterinis modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 3(59). – P. 28–32.

Pateikiamas kompiuterinės programos prototipas, skirtas žemadažnio 3D magnetinio laiko ervdinei konfigūracijai magnetoterapijoje tirti. Pateikta 3D CAD programa skirta ne tik specialistams, bet ir tiems, kurie dirba magnetoterapijos srityje, kaip antai, gydytojams. Svarbiausias dėmesys skiriamas interaktyviam ričių sistemos magnetinio lauko modeliavimui. Be to, šį modelį galima panaudoti ričių savybių bei žemadažnio magnetinio lauko magnetoterapijoje tyrimui. 3D kompiuterinį modelį galima taikyti magnetinio lauko analizei bei magnetoterapijos prietaisų projektavimui. Il. 4, bibl. 14 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

D.T. Dimitrov. Computer Simulation of Space Configuration of Low Frequency Magnetic Field in Magnetotherapy // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 3(59). – P. 28–32.

The goal of this article is to present the prototype of the simulation program for investigation of space configuration of low-frequency magnetic 3d field used in magnetotherapy. The presented program is a 3D CAD program intended for non-professionals in electromagnetism. Therefore, the program can be used easy by physicians, also. The emphasis is on creating and interacting with a computer-based model of a system (configuration of coils). This model is being designed to test the magnetic properties of the coils and its influence on the human body in the process of magnetotherapy. The 3D simulation of the magnetic field, generated by the coil's system is used as a tool for analyzing the behaviour of the magnetic field and as a feedback for the further interactive design of apparatuses for magnetotherapy. Ill. 4, bibl. 14 (in English; summaries in Lithuanian, English, Russian).

Д. Ц. Димитров. Компъютерное моделирование пространственной конфигурации низкочастотного магнитного поля в магнитотерапии // Электроника и электротехника. – Каунас: Технология, 2005. – № 3(59). – С. 28–32.

Цель статьи – показать прототип компьютерной программы для исследования пространственной конфигурации низкочастотного 3D магнитного поля в магнитотерапии. Это 3D CAD программа, которая предназначена не только для специалистов, но тоже для неспециалистов в области электромагнитного поля как врачи, например. Создание новой компьютерной модели для интерактивного исследования магнитного поля систем катушек в магнитотерапии – это главное в статье. Эту модель можно использовать для исследования не только свойств катушки, но и влияния низкочастотного магнитного поля в магнитотерапии. 3D компьютерную модель низкочастотного магнитного поля можно тоже пользовать при анализе магнитного поля и проектировании аппаратов для магнитотерапии. Ил. 4, библ. 14 (на английском языке; резюме на литовском, английском и русском языках).