A 3D approach to numerical dosimetry in quasi-static conditions: problems and examples of solutions

Nicola Zoppetti

IFAC-CNR - Italy

Main carachteristics of a computer application system for the resolution of 3D quasi-static dosimetric problems is presented. The system, currently under development, follows a standard approach, widely introduced in literature based on the Scalar Potential Finite Difference method (SPFD) [1]. The implementation aims to be modular so that every new feature could be added independently from the existing ones. Everything was developed from scratch, at low level, using C/C++ programming language; that characteristic emphasizes aspects that are hidden using higher-level tools.

The present network of applications uses voxel phantoms based on the body models developed in the "Visible Human Project" (VHP) and calculates the dielectric proprieties of tissues that compose human body using Gabriel's parametric model [2]. Currently only the magnetic problem is solved and field sources are represented by wired models. Successive Over Relaxation (SOR) is the numerical technique used to solve the finite difference equation given by SPFD method. Finally the 3D visualization system used for sources field intensity, body models, tissues characteristics and calculus results, developed in C++ either, uses the platform independent OpenGL graphic libraries.

Four different VHP body models are available: one head model of 178x235x211 cubic cells with size of $1mm^3$, and three entire body models: the biggest one of 586x340x1878 cells with size of $1mm^3$, another of 293x170x939 cells and resolution of 2mm and the last of 196x114x626 cells of 27 mm^3 (resolution 3 mm). The original data were elaborated and organized in files consisting in a heading carrying model resolution and dimensions and then a byte for every cell of the model. Each one of those bytes identifies one of the 58 recognized tissues. Each tissue can be characterized in terms of conductivity and permettivity in a frequency range that starts from few Hertz arriving to 100 Gigahertz, using a specific application that implements the Gabriel's parametric model.

The field sources modelling description can't be separated from the account of the numerical modelling method. According to quasi-static approximation, electric and magnetic problems can be considered separately. The SPFD method is usually applied with two other prerequisites beyond the condition that the wavelength has to be much longer than the dimensions of the considered problem. The first additional condition is that all tissues could be considered as good conductors. In that case the finite difference equation coefficients are real numbers, otherwise the coefficients are complex numbers. Complex arithmetic demands much more time and calculus resources than the real case given that one complex product entails four real products and two real sums while one complex quotient entails 8 real products, 4 real sums and 2 real quotients.

The second additional condition is that the magnetic field inside the body has not to be influenced by induced currents [3].

No supplementary boundary conditions on the body surface are needed for the magnetic problem, since the current continuity is guaranteed by the SPFD cell's equation itself. On the border of the considered volume the scalar potential is usually forced to be zero assuming the volume composed by the body model incorporated in a not-conductive shell of proper thickness. The charge density on body surface has to be considered in the electric problem only. The surface charge density must be calculated solving a Laplace problem before the SPFD method could be applied with the proper boundary conditions.

Considering magnetic problem only, every source is represented by one or more wire paths, each one with its current. Vector potential components used in the SPFD method can be computed with a numerical integration along the current paths [4]. In a multi-source environment, different cases arise if the source currents are or not characterized by equal time phases (different frequencies have to be taken into account into different problems). In the equal phase case the finite difference equation coefficients are real numbers otherwise are complex numbers. Rather than doing all the calculus in complex arithmetic, it is convenient to split the problem in two parts considering separately the real and imaginary part of source fields. The final result is obtained composing solutions of the two problems during post-processing [4]. One of the most used numerical techniques applied to finite difference problems is Successive Over Relaxation (SOR). Even if faster methods exist (multigrid methods for example) SOR has the great advantage to be really easy to code also in 3D case. It gives better result in conjunction with Chebyshev acceleration technique [5].

Different memory patterns can be adopted searching the best compromise between speed and demanded memory resources. The fastest approach consists in memorizing a 3D matrix for every coefficient and a matrix for the scalar potential. Given that a double precision number on 32 bit platforms is represented with 8 bytes, for every cell 64 bytes are needed (7x8 for coefficients, 1x8 for the scalar potential). In the case of VHP head model the demanded memory resources amount to more than 500 Mbytes while in the case of the VHP man's model with 1mm cell size, more than 22 Gigabytes are needed. In the latter case different approaches have to be used. The VHP models file structure inspires a more compact memory organization. A vector containing conductivities of all 58 recognized tissues is allocated and one byte for every cell is memorized. That byte identifies the tissue position in the array of double precision conductivity values that are then reachable with a fast single indirection. The same approach can be used for vector potential components, assuming to represent them with a discrete set of levels. Using two bytes for every component and a set of 2^{16} discrete equally spaced allowed values, the number of bytes needed for every cell can be decreased to 15.

This kind of representation is convenient both for saving data on files and for visualizing data. Color-index mode is more suited in those cases then standard RGB mode since indexes identifying tissues or subsets of discrete levels of potential, can be directly associated with a colour.

The described memory pattern allows to reduce to reasonable size the amount of memory needed to solve the SPFD problem in all the described cases except the one considering the entire body model with cell size of 1mm. In that case still 5,3 Gigabytes are needed and the problem cannot be solved with standard computer's configuration without having recourse to disk access, that dramatically reduces the computational process speed.

References

1. P.J.Dimbylow: "Induced current densities from low-frequency magnetic fields in a 2 mm resolution, anatomically realistic model of the body", Physics in Medicine and Biology, Vol.43 (1998), pp. 221-230.
2. C.Gabriel et al.: "The dielectric properties of biological tissues (part I, II and III)", Physics in Medicine & Biology, Vol.41 (1996), pages 2231-2293.
3. T.W.Dawson, M.A.Stuchly: "High-resolution organ dosimetry for human exposure to low-frequency magnetic fields", IEEE Transactions on Magnetics Vol.34, No.3 (May 1998), pp. 708-718.

4. T.W.Dawson, K.Caputa, M.A.Stuchly: "Numerical evaluation of 60 Hz magnetic induction in the human body in complex occupational environments", Physics in Medicine and Biology, Vol.44 (1999), pp. 1025-1040.
5. W.H.Press, S.A.Teukolsky, W.T.Vetterling, B.F.Flannery; "Numerical recipes in C: the art of scientific computing", Cambridge University Press, Second ediction, 1992, pp. 866-871.

Author

Nicola ZOPPETTI: born in 1974, graduated in electronic engineering in 2002. He is currently working at IFAC-CNR, toward the international PhD. degree on "RF, microwaves and electromagnetism" promoted by Florence University, developing the theme "numerical dosimetry in quasi static conditions". His past and current research interests include also low frequencies field sources numerical modeling.

contact: IFAC-CNR; via Panciatichi 64-I-50127 Firenze, Italy;

N.Zoppetti@ifac.cnr.it