High-accuracy electromagnetic field simulation using numerical human body models

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In this study, a high-accuracy analysis for the electromagnetic field based on the finite element method using numerical human body models is investigated. In this paper, we propose a mesh smoothing technique for reduction of noise caused by reflection and scattering of the electric fields in boundaries between different materials in the human body models.

***Index Terms*—Full-wave electromagnetic field analysis, Finite element method, Large-scale analysis, Mesh smoothing.**

I. INTRODUCTION

FOR A HIGH-ACCURACY analysis of the full-wave electromagnetic field using the numerical human models [1], [2] where the voxel discretization is employed, boundaries between different materials should be expressed by curved surfaces. In the case of direct use of the voxel base mesh model, the boundaries become stepped shape. This causes reflection and scattering of the electric fields, which in turn generate to noise in the numerical analysis. To reduce this noise, we developed a mesh smoother applied for smoothing the stepped shapes on the boundary of different materials. This smoother is featured by insertion of triangular prisms. In this method, boundaries between different materials are identified automatically. Then, trianglar prisms are placed on these boundaries to smooth boundary shapes. Hence the smoothing algorithm is relatively simple. The algorithm is robust for large-scale and complicate shape model.

II. MESH GENERATION AND SMOOTHING TECHNIQUE

A. Partition of a voxel into 5 tetrahedra

The NICT numerical human body models used in this research employ a binary data format where types of organs (including air area) are encoded using voxels with all sides of 2 mm. The size of the adult male model is 320 voxels width, 160 voxels depth and 866 voxels height. Represented as "char" type, it occupies 44,339,200 bytes of memory. The voxel partition types adopted in this paper are shown in Fig. 1. Two types of partitioning (Fig. 1) are alternated in order to maintain consistency between neighboring tetrahedral elements preventing to occur cross lines, as shown in Figs. 2 (a) and (b).

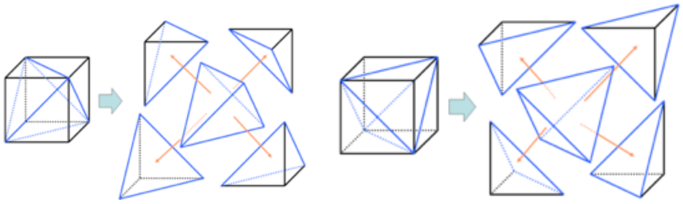

(a) Partition type 1 (b) Partition type 2

Fig. 1. Two types of partition of a voxel into 5 tetrahedral elements

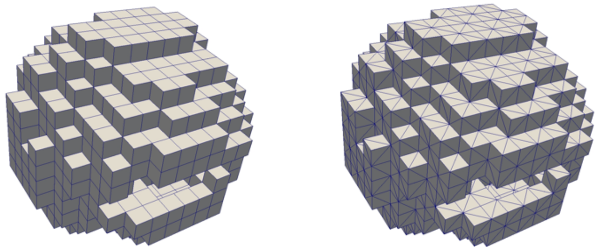

(a) Voxel mesh (b) Tetrahedral mesh

Fig. 2. Transformation of a voxel mesh to a tetrahedral mesh

B. Processing flow for the HDD mesh

Fig. 3 shows the procedure for generating the hierarchical domain decomposed (HDD) mesh. First, the file containing the numerical human body model, the only input file for this computation, is read. Next, ParMETIS [3] is used to partition the input voxel data into a number of "Parts". After this initial decomposition, all processing can be done independently in each node, without the need for communication between nodes. In each node, the voxel mesh is transformed to a tetrahedral mesh using the methods shown in Fig. 1.

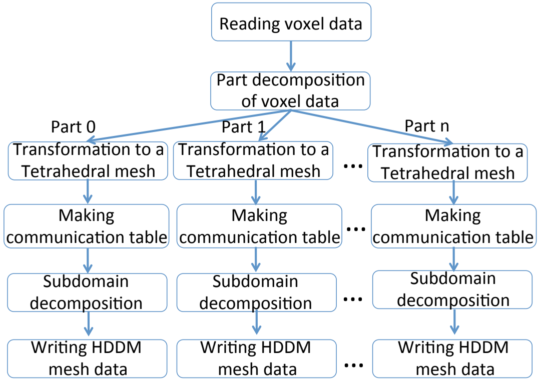


Fig. 3. Procedure for generation of the HDD mesh

C. Analysis conditions

Fig. 4 shows conditions of the analysis model. The dipole antenna is set above the breast. The distance between breast and antenna H is 0.06 m. The antenna length L is 0.5 m, which is same as half wavelength at 300 (MHz). All boundaries of the analysis domain Ω: $\partial\ \Omega$ is applied the absorbing boundary condition. Length of model sides are $x = 0.64$ m, $y = 0.32$ m, $z = 1.732$ m, respectively.

The parallel computer used in this paper is the Fujitsu

FX10 supercomputer at the Information Technology Center of the University of Tokyo. The processor of the FX10 is the SPARC64 IXfx. A node is powered by 16 cores running at a frequency of 1.848 GHz and has 32 GB memory.

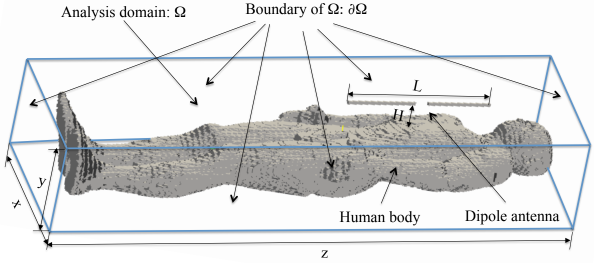
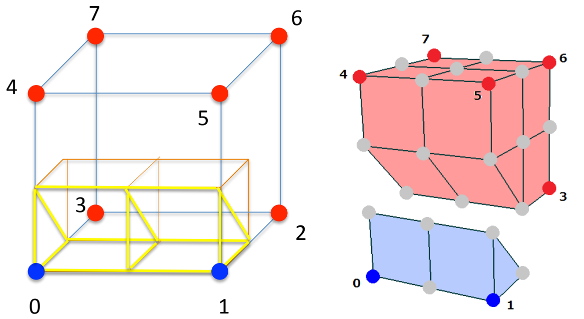


Fig. 4. Conditions of the analysis model.

D. Mesh smoothing

Boundaries between different materials in the human body should be expressed by free surfaces. In the case of the voxel base mesh model, the boundaries become of step shape. These cause reflection and scattering of the electric fields, which in turn contribute to noise in the numerical analysis. To reduce this noise, we developed a mesh smoother applied to smoothing step shapes between different materials. This smoother works by insertion of triangular prisms. In this method, boundaries between different materials are identified automatically. Then, triangle prisms are placed on these boundaries to smooth boundary shapes. The smoothing algorithm is relatively simple. The algorithm is robust for large-scale and complicate shape model.

Fig. 5 shows the concept of the smoothing. In the algorithm, eight center points 0, 1, 2, .. , 7 of voxels are considered as vertexes of a cube. These center points have a material ID. The cube made by the eight center points is divided in eighth small cubes. If two material IDs are found in a small cube, it is cut in two triangle prisms. Then, tetrahedra are generated in the triangle prism and the small cube.



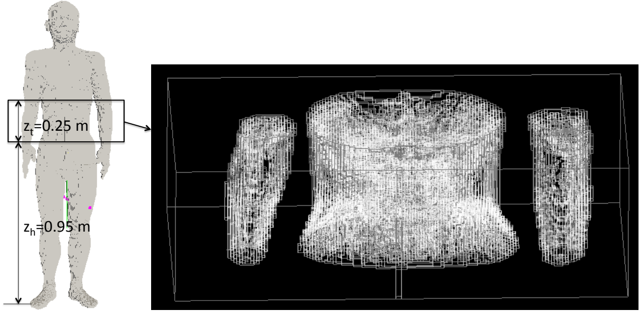
(a) Generating of triangle prisms (b) Cutting of voxel by triangle prism.

Fig. 5. Concept of the mesh smoothing

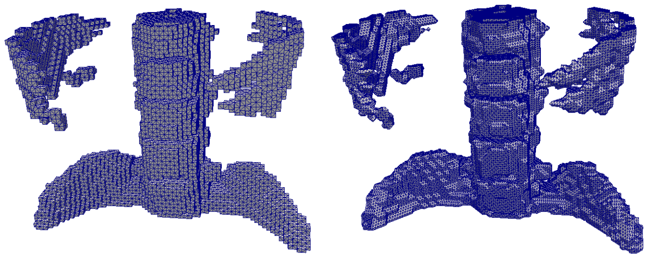
Fig. 6 shows a mesh-smoothing example. The torso numerical human body model (Fig. 6(a)) is constructed by voxels with 4mm pitch. The torso model is made from the whole body model by cutting out width Z_t=0.25 m from the position of height Z_h=0.95 m. Fig. 6(b) shows the ribs, the backbone and the pelvis before smoothing while Fig. 6(c) shows them after smoothing. We can obtain step shapes on the boundaries to be smoothed.

The smoothing algorithm is relatively simple and robust. However, in this algorithm, the insertion of triangle prisms has the side effect of increasing model size. In the case of using the numerical human model, when the smoothing is executed, the model size becomes ten times larger. In order to solve such large models we consider using HPCI systems. In our research, analysis code should be improved on HPCI.

Fig. 7 shows visualization examples of the electric field. These contour maps are visualized as a cut plane in the human body. Electric fields around the backbone and pelvis are observed. In the result without smoothing (Fig. 7(a)), reflection and scattering of the electric fields occur around the bones. On the other hand, in the result with smoothing (Fig. 7(b)), the electric field shows a natural distribution in bones and at the boundary of other organs. It is understood that smoothing reduces the noise in the electric field along the voxel shape in the vicinity of the spine surface by comparing enlarged views in Fig. 7. From this result, thanks to mesh smoothing, reflection and scattering of the electric fields are not occurring.

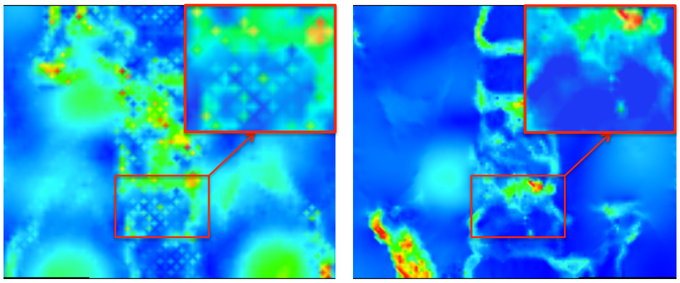


(a) Torso mesh model



(b) Original voxel model (c) Smoothed model

Fig. 6. Example of smoothing (Ribs, the backbone and pelvis)



(a) Without smoothing. (b) With smoothing

Fig. 7. Visualization of numerical results at Torso model (300(MHz))

REFERENCES

[1] NICT EMC group home page: http://emc.nict.go.jp/bio/index.html

[2] A. Takei, K. Murotani, S. Sugimoto, M. Ogino, T. Yamada, S. Yoshimura,“Performance Evaluation of Parallel Finite Element Electromagnetic Field Analysis using Numerical Human Models,” Journal of Advanced Simulation in Science and Engineering, Vol.1, No.1, pp.127-140, 2014.

[3] G. Karypis, V. Kumar, ”A fast and highly quality multilevel scheme for partitioning irregular graphs”, SIAM Journal on Scientific Computing, Vol.20, No.1, pp. 359-392, 1999.