Large-scale analyses of electromagnetic fields using numerical human body models

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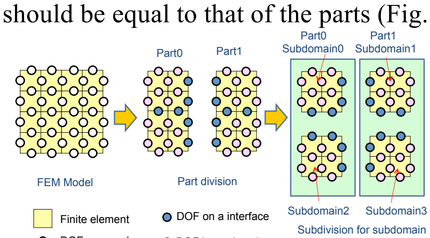
***Abstract*—This paper describes large-scale analyses of electromagnetic fields by the parallel finite element method with an iterative domain decomposition method using numerical human body models. Numerical human body models by National Institute of Information and Communications Technology (NICT) in Japan is composed by the voxel data with all sides of 2mm include skins, blood vessels, bones etc. and internal organs distinguishing with the material flag. The user can evaluate electromagnetic filed distribution inside a human body using NICT numerical human models. Numerical analyses are done using torso models and whole body models.**

I. Introduction

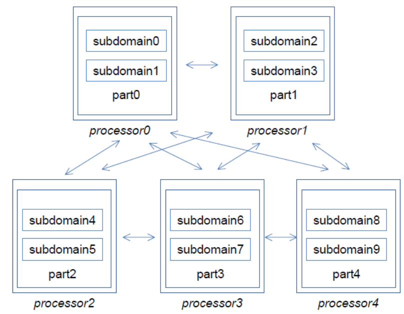
This research purpose is to solve high accurate in inside a human body using a numerical electromagnetic analysis method. Recently, medical equipment using electromagnetic field including a hyperthermia is spreading. In a treatment, it is effective to focus electromagnetic field into lesions in inside the human body. The numerical human body model database is being released for researchers gratis by NICT [1]. This database is constructed using voxels that have a cube of 2 mm edge length. The numerical human model has multi material including skin, blood vessels, bone, internal organs etc. The full-wave electromagnetic field analysis software based on the parallel finite element method for large-scale analysis is investigated in our research group. The full-wave electromagnetic analysis code is employed the hierarchical domain decomposition method (HDDM) as a parallel technique [2]. The adult male model is named "TARO", that has 44 million voxels. The tetrahedral elements of over 200 million are generated from the voxel data. In this paper, we calculate the full-wave electromagnetic fields using the HDDM and show that analyses of the numerical human body model with more than 200 million complex DOF can be solved.

II. Hierarchical Domain Decomposition Method

The original computational domain is first divided into parts, which are further decomposed into smaller domains called subdomains. In the P-mode, all processors perform the FEA, and every CPU can be used without idleness in an environment with 10-120 CPUs. The number of Parent processors should be equal to that of the parts (Fig. 1) [3], [4].



(a) Hierarchical domain decomposition

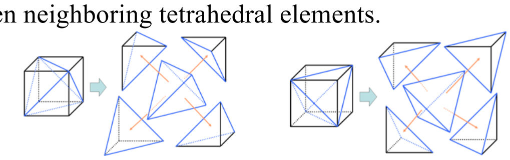


(b) Data distribution and communication in the parallel processor mode
Fig. 1. Schematic of the HDDM

III. Mesh Generation Based on the Hierarchical Domain Decomposition Data Structure

A. Partition of a voxel into 5 tetrahedra

Numerical human body models by NICT used in this research is a binary data where types of organs (including air area) are written on the voxel with all sides of 2 mm. In the case of the adult male model, the binary data is 320 voxels to right and left, 160 voxels to front and back and 866 voxels to height, is represented as “char” type and is 44,339,200 byte. Types of partition are adopted in analyses of this paper as shown in Fig. 2. The partition type 1 and the partition type 2 of Fig. 2 are alternated in order to maintain consistency between neighboring tetrahedral elements.



(a) Partition type 1 (b) Partition type 2
Fig. 2. Two types of partition of a voxel into 5 tetrahedral elements

B. Processing flow for the hierarchical domain decomposed mesh

Fig. 3 shows the procedure for generation of the hierarchical domain decomposed (HDD) mesh. First, the file of the numerical human body model is read and this file is only one input file. Next, the ParMETIS [5] partitions an input voxel data into some “Parts”. After part decomposition, all of the procedures are done without communicating between nodes and independently in each node. In each node, the voxel mesh is transformed a tetrahedral mesh as shown in Fig. 2. The communication table here is a correspondence relationship to send and receive data among nodes. Finally, the METIS partitions a Part mesh into some “Subdomains” and a file of the HDD mesh is output in each node. Figs. 4(a) and (b) show skins and organs voxels, and colors mean the decomposed parts.

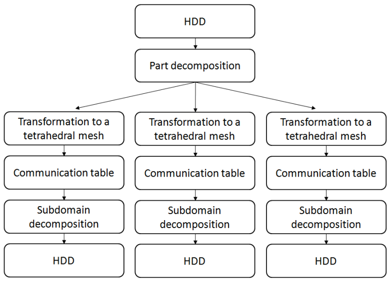
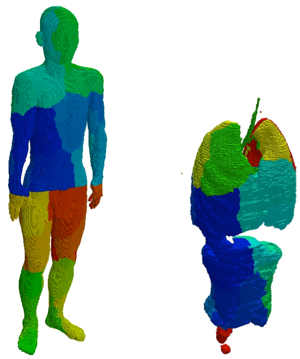


Fig. 3. Procedure for generation of the HDD mesh



(a) Skins (b) Organs

Fig.4. Part decomposed mesh

All computations for generation of the HDD are performed on a 20-node (80-core) PC cluster with Intel Core i7 2600K (3.40 GHz / L2 8MB/Quad Core) and 16 GB RAM. Table I shows the generation conditions of the HDD mesh. Table II shows the generation times of the HDD mesh. In this paper, total four kinds of torso models and full body models of a voxel with 2mm and 4mm are generated. Our decomposer tool in this research is developed to add the voxel partition function to the ADVENTURE Metis [6], [7]. The most calculation time is spent on the subdomain decomposition as shown in Table II. It is difficult to reduce the calculation cost of the subdomain decomposition with largest calculation cost in the ADVENTURE Metis also. However, since communication among nodes in the subdomain decomposition is not required, the calculation time can be linearly reduced by increasing nodes. On the other hand, the calculation times of the transformation to a tetrahedral mesh and the communication table generation for voxel data are only a few percent of the whole calculation time and the large scale initial mesh generation is not required in advance. From these merits, our developed function is very effective method.

TABLE I
GENERAITON CONDITIONS OF THE HDD MESH

	The number of tetrahedral elements	The number of parts	The number of subdomain in each part
Mesh 1: Torso (4mm)	9.6 million	80	500
Mesh 2: Torso (2mm)	76.80 million	80	5,000
Mesh 3: Whole body (4mm)	27.71 million	80	4,000
Mesh 4: Whole body (2mm)	220 million	80	23,000

TABLE II
GENERATION TIMES OF THE HDD MESH

	Total (sec)	Part decomposition (sec)	Transformation to a tetrahedral mesh + Communication table (sec)	Subdomain decomposition (sec)
Mesh 1:	13	7.2	0.59	1.5
Mesh 2:	222	49	5.7	155
Mesh 3:	70	20	1.9	45
Mesh 4:	2,128	120	18	1,896

IV. FULL-WAVE ELECTROMAGNETIC ANALYSES

The electromagnetic fields in human bodies are analyzed by numerical human models shown in Table I. All computations are performed on a 20-node (80-core) PC cluster with Intel Core i7 2600K (3.40 GHz / L2 8MB/Quad Core) and 16 GB RAM. Analysis frequency is set up 1 MHz, 8 MHz, 70 MHz and 300 MHz. These cases are solved by the full-wave electromagnetic analyses based on the parallel finite element method. A dipole antenna as electromagnetic field source is assumed to have current sources of 0.8 A. The antenna is put on above 6 cm from the surface of the breast. The full-wave electromagnetic analyses are done at four kinds of models of Mesh1-4. The calculation time and the average memory requirement in each frequency are shown in Table III.

TABLE III
THE CALCULATION TIME AND THE MEMORY REQUIREMENT

	Complex DOFs	Memory size / core (GByte)	Freq. (MHz)	Iteration counts	Calculation time (h)
Mesh 1: Torso (4mm)	1.36e+07	0.1	1	2,062	0.55
			8	1,087	0.29
			70	1,683	0.41
			300	6,228	1.6
Mesh 2: Torso (2mm)	9.27e+07	1.1	1	5,726	6.7
			8	4,034	4.7
			70	2,136	2.5
			300	17,627	20.4
Mesh 3: Whole body (4mm)	3.19e+07	0.4	1	2,875	1.5
			8	1,641	0.8
			70	2,199	1.1
			300	9,684	4.8
Mesh 4: Whole body (2mm)	2.60e+08	3.0	1	9,028	20.4
			8	4,817	11.0
			70	7,411	16.8
			300	18,306	41.4

V. REFERENCES

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