Proceedings of ISAP2016, Okinawa, Japan

Large-Scale Electromagnetic Analysis of Realistic Human-Body Exposure Using GPU Supercomputer

Jerdvisanop Chakarothai, Kanako Wake, Soichi Watanabe
National Institute of Information and Communications Technology, 4-2-1 Nukuikita-machi, Koganei, Tokyo, Japan

Abstract - **Numerical analyses of a human-body exposure have been performed on a GPU supercomputer of TSUBAME system. We have developed a numerical FDTD code for multi-node/multi-GPU parallel computations. Its validity has been demonstrated by scattering analysis of dielectric spheres in comparison with Mie's results. Whole-body average SAR of a Japanese adult male model illuminated to an EM planewave at 1-10 GHz was then calculated using GPU supercomputer. It has been indicated that the WBA-SAR of human model with 2 mm tends to show a higher value than those of 0.5 mm. Speed of more than 12 billion cells per second was achieved.**

Index Terms - **Exposure assessment, large-scale simulation, GPU, FDTD method.**

1. Introduction

Numerical electromagnetic (EM) simulations using an anatomical human model has been increasing in many applications. For numerical dosimetry, the finite-difference time-domain (FDTD) method has been considered as one of the most effective technique for its capability to handle inhomogeneous biological bodies such as a human [1]. Recently, finely-detailed realistic human models have been developed by many research groups. EM analyses of the absorption power of such a detailed model inevitably requires use of high-performance computation. Specifically, as frequency increases, penetration depth of EM waves in the human body decreases. For example, the penetration depth for skin tissue is approximately 3.8 mm at 10 GHz. In consequence, analysis of human-body exposure due to EM fields at 10 GHz requires use of finely-detailed human model with a resolution less than 0.5 mm. Calculation of such a fine model, however, can take prohibitively long time and may be not feasible with the use of an actual workstation.

With a rapid development of computer technology, use of Graphics Processing Unit (GPU) and Many Integrated Core (MIC) Architecture has been increasing due to needs for high-performance computation [2]. Calculation algorithm of the FDTD method is suitable for parallel computation since it requires only field information at the adjacent grid point.

In this paper, a parallel FDTD algorithm for numerical EM exposure assessment of finely-detailed human model is implemented on the TSUBAME GPU cluster at Tokyo Institute of Technology, Japan. Electric and magnetic field data are mapped into each GPU's memory by applying a 3D/1D hybrid domain decomposition, in which the total analysis domain is divided into small regions along three axes (x, y, and z), and those regions for each node are further divided along one-dimensional axis in order to improve communication efficiency between nodes. We first demonstrate validity of the method and then apply it to computation of power absorbed into a human body illuminated by a plane wave.

2. Parallel FDTD Computation on GPU Clusters

Since the FDTD method is based on a finite difference scheme, electric and magnetic fields at a grid point are updated by referring information at the adjacent grid point. In this paper, we implement the parallel FDTD method as proposed in [3] in order to trace convergence of the solution in time series. At the boundary, since the adjacent grid data resides in another GPU memory, we need to copy the data from one GPU memory to another GPU memory. The process of communications in the GPU cluster consists of three steps; (a) memory copy from GPU to host (b) MPI send and receive communications (c) memory copy from host to GPU. Since the data in a node is mapped to multiple GPUs and the data in GPU memory does not locate in a consecutive order, so we need to rearrange the data to a consecutive temporary memory in each GPU in order to be copied once to the host memory and then we collect the data from each GPU and copy to the host memory. It should be noted that the communications between the GPUs inside a node can be done effectively and directly by using the NIVIDIA GPUdirect function (cudaMemcpyPeer).

In order to perform calculation on a GPU cluster, we need to transfer material data of a human model to GPU memory. The loop of the FDTD calculation is then started with update of the electric field data. It should be noted that some special treatment and calculation; e.g. separate memory allocation, for the field data at the PML boundaries is required. After updating the electric field, the field data at the boundary between GPUs inside a node is directly transferred with the (GPUdirect) function, whereas the boundary data must be packed into one bundle to reduce number and time of communications. The data bundle in the GPU memory is then transferred to the host memory and communicated. Before updating magnetic field, the boundary data is then copied back to the GPU memory and unpacked to the original grid points. Then we update magnetic fields and those at the PML boundaries, the inter-GPU and internode communications are performed in the same way with those done for electric field data. The loop is repeated until the whole-body SAR or total absorbed energy reaches the convergence.

3. Numerical Simulation

(1) Dielectric Sphere

Most of our simulations are compiled and executed on a large-scale GPU cluster of TSUBAME2.5 system at Tokyo Institute of Technology, Japan. Whole-body SAR of a dielectric sphere having a radius of 20 cm, and dielectric properties of $\varepsilon_r = 2$ and $\sigma = 0.1$ S/m, illuminated by a plane wave at 200 MHz. Strength of incident electric field is 1 V/m. Total size of analysis region was 1052×1052×1052 cells with a resolution of 0.5 mm in each axis. Number of calculation time steps was approximately 12000 steps. It was observed that the whole-body SAR converged within 1.2 periods. The whole-body SARs (WBSARs) obtained by CPU (24 parallel threads) and GPU calculations were determined as 8.54 μW/kg and 8.52 μW/kg, respectively, showing good agreement of that obtained by analytic Mie's solution of 8.43 μW/kg. Errors between the Mie's result and the FDTD method were about 1.4% and 1.1% for the CPU and GPU computations, respectively, demonstrating the validity of the method. Calculation time for 12000 time steps using 648 GPUs (216 nodes) in parallel was about 114 minutes. Highest performance using 648 GPUs in parallel was achieved at more than 12 billion cells per second.

(2) Human Exposure

Here we employ our parallel FDTD method to EM exposure assessment of a human body irradiated to an EM plane wave at 1-10 GHz. We use a Japanese male model developed by National Institute of Information and Communications Technology, Japan [4]. The model is composed of 51 different tissues and organs with an original resolution of 2 mm and 0.5 mm. Height and weight of the model were 173 cm and 64 kg, respectively. The permittivity and conductivity of biological tissues are extracted from the Gabriel's data [5]. The propagation direction of the z-polarized incident plane wave was along $+y$ direction. Total sizes of analysis domain was 1064×598×3494 cells with a model resolution of 0.5 mm respectively.

Numerical results at 1-10 GHz are shown in Fig. 2. WBSAR of the human model was calculated as 9.28 μW/kg and 8.28 μW/kg for a model resolution of 2 mm and 0.5 mm, respectively, for an incident electric field strength of 1 V/m at 3 GHz. The difference between those of 2 mm and 0.5 mm was 12%. It has been shown that the WBSAR tends to show smaller value for 0.5 mm than those calculated by the model with 2 mm resolution. The difference was as high as 400% at 10 GHz. Calculation time in finding the whole-body SAR for 0.5 mm resolution was approximately 32 minutes using a 96 GPUs (32 nodes), while it would take 1090 minutes with no parallel thread (single CPU). Speedup was about 34 times.

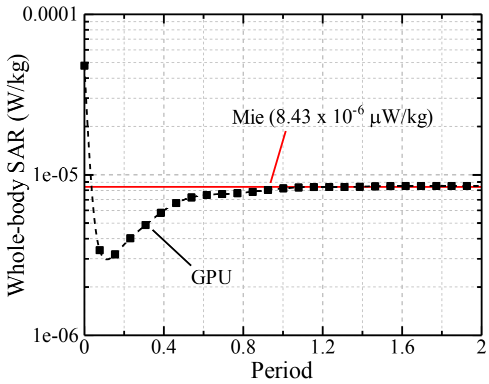

Fig. 1 Whole-body SAR of dielectric sphere.

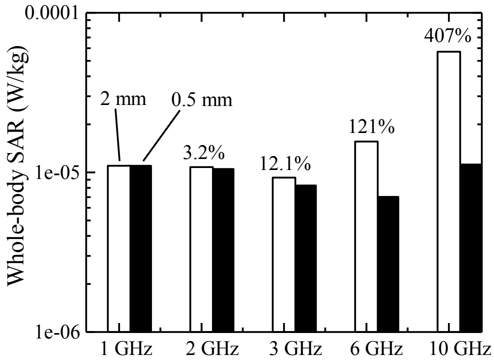

Fig. 2 Whole-body SAR of human body with 2 mm and 0.5 mm resolution at 1-10 GHz.

4. Conclusion

Validity of the parallel FDTD method for a GPU cluster was demonstrated by comparing with the analytical Mie's results of the dielectric sphere. Numerical exposure of a Japanese adult male model having a resolution of 0.5 mm irradiated by EM plane wave at 1-10 GHz, has been performed and compared to those having a resolution of 2 mm.

Acknowledgement

This study was financially supported by the Ministry of Internal Affairs and Communications, Japan. Numerical results were carried out using a high-performance GPU cluster of TSUBAME system at Tokyo Institute of Technology, Japan.

References

[1] K. S. Yee, " Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," *IEEE Trans. Antennas Propag.*, vol. 14, no. 4, pp. 302-307, 1966.

[2] T. Nagaoka and S. Watanabe, " Accelerating three-dimensional FDTD calculations on GPU clusters for electromagnetic field simulation," in *Proceeding of EMBC'12*, pp. 5691-5694, 2012.

[3] J. Chakarothai et al., " Convergence of a single-frequency FDTD solution in numerical dosimetry," *IEEE Trans. Microwave Theory and Techniques*, vol. 64, no. 3, pp. 707-714, 2016.

[4] T. Nagaoka et al., " Development of realistic high-resolution whole-body voxel models of Japanese adult and females of average height and weight, and application of models to radio-frequency electromagnetic field dosimetry," *Phys. Med. Biol.*, vol. 49, pp. 1-15, 2004.

[5] C. Gabriel, " Compilation of the dielectric properties of body tissues at RF and microwave frequencies," *Brooks AFB, San Antonio, TX, Brooks Air Force Tech. Rep.*, AL/OE-TR-1996-0037, 1996