Development of GPGPU-Based Interactive Simulation for Numerical Analysis of Sound Wave Propagation

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ABSTRACT

To date, numerical analysis for sound wave propagation in time domain has been investigated widely as a result of computer development. For time domain acoustic simulation, the reduction of the calculation time and the development of the visualization method are important technical issues. Recently, GPU (Graphics Processing Unit) is used as an acceleration tool for the calculation in various study fields. This new movement has been called GPGPU (General Purpose computing on GPUs). GPGPU gives us the high-performance computing environment at a lower cost; therefore, the approach by GPU-based computing efficiently achieves a significant reduction of the calculation time. Moreover importantly, the use of GPUs has an advantage of visualization of calculated fields; GPU-based computing makes it possible to directly write drawing information to the VRAM on the video card without the transfer through the PCIe bus, because the calculated data is stored in the VRAM itself. In this study, we focus on numerical analysis of sound wave propagation using GPU-based computing with CUDA-OpenGL high speed visualization. We examine a feasibility of an interactive simulation using GPGPU-based parallel computing.

Keywords: Numerical Analysis, FDTD method, GPGPU, Interactive Simulation

1. INTRODUCTION

To date, numerical analysis for sound wave propagation in time domain has been investigated widely as a result of computer development [1,2,3]. Acoustic simulation in time domain is an effective technique for the estimation of time-series sound pressure data (e.g., nonlinear acoustic propagation phenomenon, acoustical measurements and instrumentation, acoustical imaging). For time domain acoustic simulation, the development of the visualization method is an important technical issue.

Recently, GPU (Graphic Processing Unit) is used as an acceleration tool for the calculation in various study fields. This movement is called GPGPU (General Purpose computing on GPUs) [4,5,6]. In the last few years the performance of GPU keeps on improving rapidly. That is, a PC (personal computer) with GPUs might be a personal supercomputer. GPU computing gives us the high-performance computing environment at a lower cost than before. Therefore, the use of GPUs contributes to a significant reduction of the calculation time in large-scale sound wave propagation. Moreover, use of GPU has an advantage of visualization of calculated fields, since GPU is originally architecture for graphics processing.In the GPU calculation, the calculated data is stored in the video memory (VRAM). Therefore, we can directly write drawing information to the VRAM on the video card by combining CUDA and OpenGL.

The purpose of this study is the development of sound field analysis method using the interactive simulation. We examined the high-speed visualization on GPU computing-based platform and demonstrate a feasibility of an interactive simulation using GPU parallel calculation and PMCC (Permeable Multi Cross-section Contours).

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2. ACOUSTICAL NUMERICAL SIMULATION

2.1 FDTD (finite-difference time-domain) method [7]

The governing equations for linear acoustic fields are given in Eq. (1) and Eq. (2).

$$\rho \frac{\partial \vec{v}}{\partial t} = -\nabla p, \tag{1}$$

$$\nabla \cdot \vec{v} = -\frac{1}{K} \frac{\partial p}{\partial t}. \tag{2}$$

In those equations, ρ denotes the density of the medium, K is the bulk modulus, p is sound pressure and v is the particle velocity. Here we assume that the calculation is for a lossless and homogeneous medium.

We can obtain Eqs. (3),(4),(5), and (6) from Eqs. (1) and (2) by employing second-order central difference approximation on a staggered grid.

$$v_x^{n+\frac{1}{2}}(i+\frac{1}{2},j,k) = v_x^{n-\frac{1}{2}}(i+\frac{1}{2},j,k) - \frac{\Delta t}{\rho}\frac{p^n(i+1,j,k)-p^n(i,j,k)}{\Delta x}, \tag{3}$$

$$v_y^{n+\frac{1}{2}}(i,j+\frac{1}{2},k) = v_y^{n-\frac{1}{2}}(i,j+\frac{1}{2},k) - \frac{\Delta t}{\rho}\frac{p^n(i,j+1,k)-p^n(i,j+1,k)}{\Delta y}, \tag{4}$$

$$v_z^{n+\frac{1}{2}}(i,j,k+\frac{1}{2}) = v_z^{n-\frac{1}{2}}(i,j,k+\frac{1}{2}) - \frac{\Delta t}{\rho}\frac{p^n(i,j,k+1)-p^n(i,j,k)}{\Delta z}, \tag{5}$$

$$\begin{aligned} p^{n+1}(i,j,k) = p^n(i,j,k) \quad &- \quad K\Delta t \frac{v_x^{n+\frac{1}{2}}(i+\frac{1}{2},j,k)-v_x^{n+\frac{1}{2}}(i-\frac{1}{2},j,k)}{\Delta x} \\ &- \quad K\Delta t \frac{v_y^{n+\frac{1}{2}}(i,j+\frac{1}{2},k)-v_y^{n+\frac{1}{2}}(i,j-\frac{1}{2},k)}{\Delta y} \\ &- \quad K\Delta t \frac{v_z^{n+\frac{1}{2}}(i,j,k+\frac{1}{2})-v_z^{n+\frac{1}{2}}(i,j,k-\frac{1}{2})}{\Delta z}, \end{aligned} \tag{6}$$

where Δt is the timestep, and Δx, Δy and Δz are the grid size.

3. ACOUSTIC SIMULATION USING GPU

3.1 Analysis Method

The purpose of this study is interactive simulation based on high-speed visualization. We employ FDTD method, because this method directly solves the governing equation using the finite deference with the staggered grid and requires relatively low computational cost. Update of the values on each grid has no dependence. That is, the value of the field can be calculated independently each other: FDTD method is suitable for parallelization on the GPU.

3.2 GPU Programming with CUDA and GPGPU-Visualization with OpenGL

Recently, NVIDIA developed CUDA (Compute Unified Device Architecture). CUDA is a programming language for GPGPU, which is an extension of the C language. Thus, programming for GPU became relatively easier than before.

Next, we describe a schematic procedure of visualization using the CPU/GPU. Figure 1 shows a method of conventional visualization using the CPU. First, the calculation result is converted to the drawing information. Then, it is transferred to video memory (VRAM) for drawing on the video card. In this process by CPU computation, calculation result is once stored and needs to be transferred to the VRAM from main memory (RAM). The PCIe bus transfer is required; therefore, this process might be a bottleneck for visualization of calculated results.

On the other hand, in the implementation on the GPU computing, the data of OpenGL can be associated by CUDA. In addition, the calculated data is always stored in the VRAM. Therefore, it is possible to write drawing information to the VRAM on the video card without PCIe bus data transfer. Figure 2 shows a method of visualization using the single GPU. Next, we describe a schematic procedure of visualization using the dual-GPUs. Figure 3 shows a method of visualization using the dual GPUs and GPUDirect RDMA(remote direct memory access) technology, which provides peer-to-peer direct communication between GPUs. This is a large advantage for high-speed visualization.

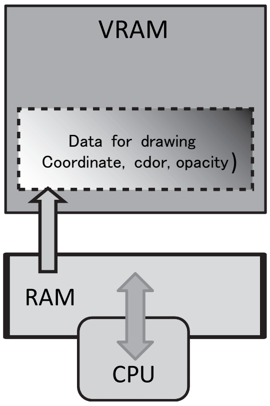

Figure 1 – Schematic procedure of CPU visualization

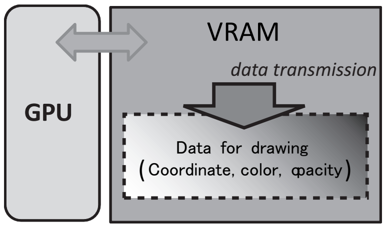

Figure 2 – Schematic procedure of GPU visualization

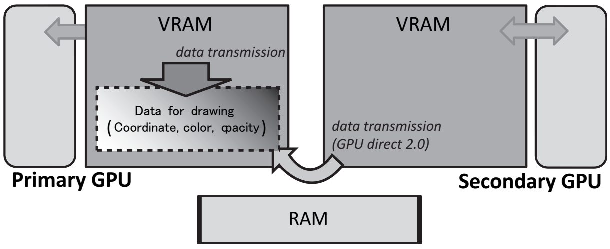

Figure 3 – Schematic procedure of dual-GPUs visualization

4. 3D ACOUSTIC SIMULATION AND VISUALIZATION METHOD

Recently, as a visualization technique so-called volume rendering using opacity has been proposed. The feature of this method is that it uses all information of three-dimensional sound field. Therefore, it can displayed three-dimensional space at one time. However, this method has to handle all information in each voxel of a three-dimensional sound field. This gives a disadvantage for the drawing speed by use of a lot of computational load process. Consequently, drawing speed is reduced compared to other conventional methods.

We have proposed PMCC (Permeable Multi Cross-section Contours) [8] as a visualization method for three-dimensional sound field. PMCC is a method that can set the opacity in the multi cross-section contours. Number and angle of the cross-section can be set arbitrarily; it provides the flexibility in the computational acoustic visualization as a pseudo-three-dimensional expression.

5. HIGH-SPEED VISUALIZATION AND INTERACTIVE SIMULATION

We examine high-speed visualization and interactive simulation combining the OpenGL and CUDA. In this study, we use the GeForce GTX TITAN and Core i7 950. Table 1 shows the specifications of the GeForce GTX TITAN. CPU calculation was parallelized and optimized using OpenMP. The calculations use a single-precision floating-point number.

Table 1 – GeFroce GTX TITAN specs

Architecture	Kepler
Number of CUDA Core	2688
Amount of Memory	6144 [MByte]
Memory Type	GDDR5
Memory Interface	384 bit
Memory Bandwidth	288.4 [GByte/sec]

Next, we compare the speed of visualization. Figure 4 shows the comparison results of rendering speed against the number of grids between the GPU and CPU in 3D acoustic field. From this result, we find that speed of visualization using GPU is much faster than one of the CPU (ca. 10 - 14 times faster).

Figure 5 shows the results of rendering speed against number of grids in 3D acoustic field. By using GTX TITAN (dual GPU), we can actually run at 32.4 fps v.s. 384^3 grids.

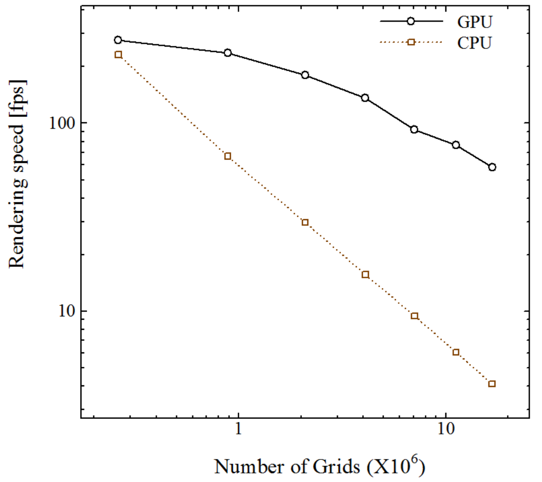

Figure 4 – Rendering speed in CPU and GPU 3D simulation.

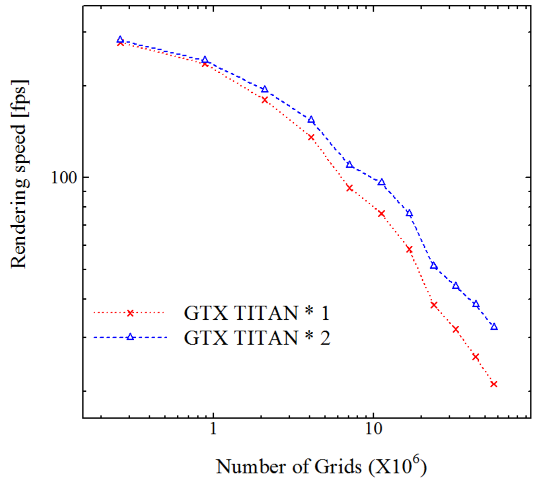

Figure 5 – Rendering speed in single- and dual-GPU 3D simulation.

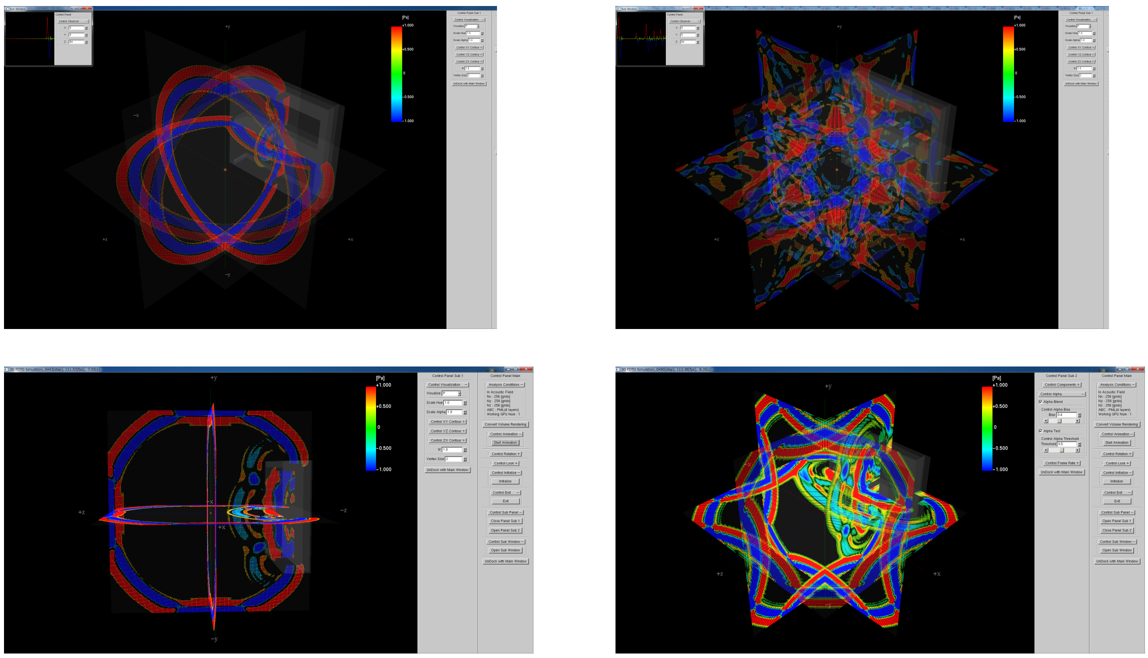

Figure 6 – Examples of visualization for 3D simulation

The high-speed visualization using the GPU makes the following possible:

1. To change the analysis parameters during computation and visualization.
2. To change the viewpoint of visualization during computation and visualization.
3. To switch between PMCC and VR.
4. To dynamically change the analysis point during computation and visualization.
5. To change the input signal.
6. To calculate reversely in the time domain.

Figure 6 shows examples of the 3D interactive simulation. A plot window has a main frame that displays three-dimensional space using the PMCC and sub-frames to display the sound field intensity in a time series for a chosen analysis point. The main window can be assigned the sound pressure or particle velocity of the sound field. In the sub-frame, dynamic analysis is possible because we can move the analysis point during computation and visualization.

6. CONCLUSIONS

In this study, we examine the GPU computing-based high-speed visualization and the feasibility for interactive simulation of three-dimensional sound field numerical analysis. As a visualization method of three dimensional sound field, the PMCC were employed with the GPU calculation. By using dual-GPUs (GTX TITAN $\times$ 2), we can develop a visualization at 32.4 fps for 384^3 grids of field using PMCC. The GPU computing-based interactive simulation can be a new important technique of sound field simulation.

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