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A 3-D sound field rendering with digital boundary condition using GPU

ディジタル境界を組み入れた GPU による 3 次元音響レンダリング

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1. Introduction

The graphics rendering technique is widely used in the field of computer graphics (CG). In CG a two-dimensional image can be displayed from the three-dimensional models constructed in the computer. The same approach can be applied to the sound field simulation which is called the sound field rendering. In the sound field rendering, it is required to include wave properties such as diffraction.

Author is starting the project in which the elemental technology of the real-time sound field renderer called "Silicon concert hall" is developed[1]. In the project, the sound field renderer by using the graphics processing unit (GPU) is devolped[2,3]. Using GPU, several ten times the computing performance can be easily achieved compared with CPU. In this paper, the boundary condition with an arbitrary frequency characteristics is realized by an IIR digital filter[4], which is called a digital boundary condition. The digital boundary condition is integrated with the three-dimensional sound field renderer by the digital Huygens' model[5,6] (DHM), then implemented into GPU.

2. Digital boundary condition

In the DHM, the boundary condition can be introduced by the reflection coefficient between the transmission line and the boundary. When the boundary has a surface acoustic impedance Z, the end of the transmission line is terminated by the impedance Z as shown in Fig.1. The local reflection coefficient r between the line and the impedance is given as

$$r = \frac{Z - Z_0}{Z + Z_0} \quad , \qquad (1)$$

where Z_0 is the characteristic impedance of the line. However, the local reflection coefficient r is not equal to the reflection coefficient for the wave reflected at the boundary on the DHM network because the propagation speed on the DHM network is $1/\sqrt{3}$ of the speed along a single transmission line. For a propagating wave on the DHM network, the reflection coefficient R is defined as the following equation

$$R = \frac{(1+r) - \sqrt{3}(1-r)}{(1+r) + \sqrt{3}(1-r)} \quad . \qquad (2)$$

The reflection coefficient R becomes negative value for $r \le 0.268$ with an absorbable boundary, and that makes the filter design difficult. In this paper, $r > 0.268$ is assumed for a reflective boundary.

In order to implement the frequency characteristics in the reflection coefficient r, an IIR filter is connected to the boundary of a DHM network, as shown in Fig.2. The filter coefficients a_m and b_m are calculated by the least P-norm optimal design method provided by the MATLAB filter design toolbox.

In the GPU implementation, the DHM calculation and the calculation for the digital boundary condition are separately executed in different kernels. This is due to two reasons; 1) the calculation performance degrades due to the conditional branch when the digital boundary is processed in the DHM kernel, and 2) the computational efficiency is improved because the thread and the block in CUDA[7] can be defined in two-dimensional for the model surfaces.

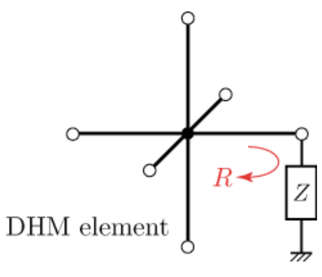

Fig.1 DHM for boundary condition.

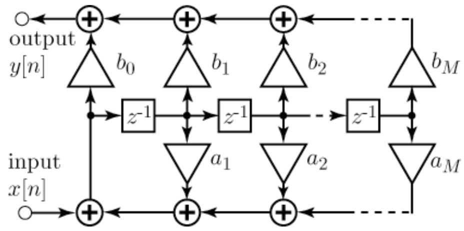

Fig.2 IIR filter.

3. Numerical experiments

To verify the validity of the digital boundary condition, numerical demonstrations are carried out for the three-dimensional sound propagation in air. The numerical model is shown in Fig.3. This is the model proposed by the Architectural Institute of Japan as benchmark platform for computational

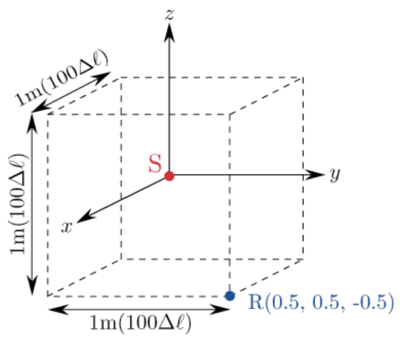

Fig.3 Numerical model (B0-1T).

methods[8] in which a cubic room of $1\mathrm{m}^3$ is assumed. The point source S is located at the center of the cubic room and radiates the sound impulse at t=0. The receiving point R is located at the corner of the room. The impulse response is calculated by the sampling frequency of 8kHz at the point R until 10000 time step. One side of cubic is divided into 100 DHM elements. The GPU used in the calculation are NVIDIA GeForce GTX280 (RAM: 1GB, clock: 1296MHz, processor cores: 240). CUDA version is 2.1 on the Windows XP platform.

3.1 Rigid wall

Figure 4 shows the sound pressure waveforms at the receiving point R when all boundaries are assumed to be rigid. In the figure, the solid line indicates the result by DHM method and the broken one by FDTD method. The calculated results are filtered with the 8th order IIR low-pass filter of the cut-off frequency of 1kHz. Two results well agree and the impulse response is calculated accurately. The calculation time for 10000 time step is 13.9s which corresponds to 8.63GFLOPS.

3.2 Digital boundary condition

Figure 5 shows the frequency characteristic of the reflection coefficient for the digital boundary. The order of the IIR filter is 6. In the figure, the solid line indicates the result calculated by the reflected wave from the digital boundary and the dashed one indicates the desired characteristics. The result by the digital boundary agrees well with the desired result.

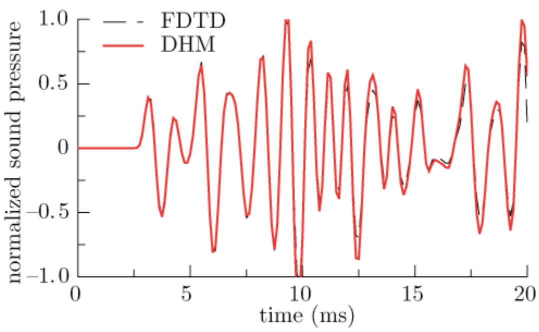

Fig.4 Sound pressure waveforms calculated at R.

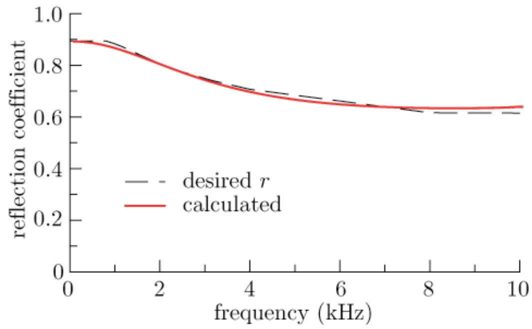

Fig.5 Reflection coefficient.

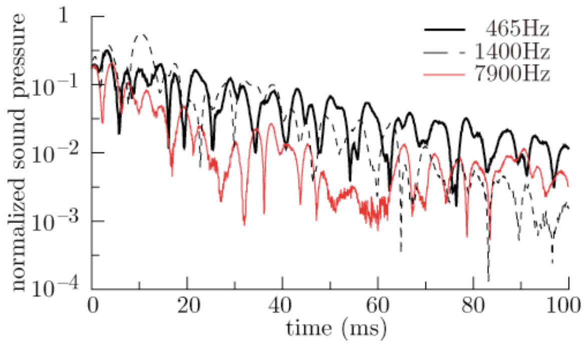

Fig.6 Decaying of the sound pressure at the observation point R for various frequency components.

Figure 6 shows the decaying of the sound pressure at the observation point R for various frequency components, when two boundaries are replaced by the digital boundaries. The sound pressure decays as the frequency becomes high. It is confirmed that the presented model is valid for the boundary condition with arbitrary frequency characteristics.

Acknowledgment

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