High-speed FDTD calculation method specialized for automotive radar analysis

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Abstract: The propagation analysis of an automotive radar using the finite-difference time-domain (FDTD) method uses tens of billions of analysis cells, and the simulation time is several days to several weeks. This study developed a method of accelerating the FDTD simulation for automotive radar analysis using a cluster-type supercomputer with multiple GPUs. An analysis region was divided into blocks, which were allocated to GPUs. The start time of the operation of each GPU was controlled according to radio wave propagation from a radiation antenna. The proposed method reduced the total simulation time by approximately 34\% compared to a conventional method.

Keywords: radar, FDTD, GPU, parallel computation, supercomputer

Classification: Antennas and Propagation

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1 Introduction

The finite-difference time-domain (FDTD) method [1] is a technique for the sequential calculation of electromagnetic fields by discretizing Maxwell's equations. Therefore, electromagnetic field components are arranged on a space grid. The cell size is typically less than 1/10 of the wavelength in the FDTD method with a second-order finite difference approximation in time and space.

Automotive radar analysis performed using a cluster-type supercomputer with GPUs requires tens of billions of cells and terabytes of memory, and the analysis time is several days to several weeks. Therefore, it is necessary to accelerate the FDTD simulation to improve the usability and accessibility of large-scale radar analysis.

The conventional techniques for accelerating the FDTD simulation include (1) devising the calculation principle of the FDTD method, (2) improving computational performance, and (3) improving calculation algorithms.

The approaches for devising the calculation principle of the FDTD method include changing the cell size [2] and dividing an analysis domain [3]. The disadvantage of these approaches is that the placement of an analysis target is limited in the computational model, which can compromise versatility and increase calculation errors.

Computational performance has been improved using CPUs with high clock speeds, multiple CPUs, GPUs [4], and a cluster supercomputer with multiple GPUs. The disadvantage of these methods is that the use of large-scale computer equipment can be considerably expensive depending on the usage time.

The methods for improving calculation algorithms are broadly classified into three types: (i) the parallel FDTD method [4], (ii) distributed FDTD method [5], and (iii) parallel and distributed FDTD method [6].

When large-scale analysis is conducted using the FDTD method, parallel and distributed processing is performed using a cluster-type supercomputer with multiple GPUs. This significantly improves the calculation speed. However, the queuing time for the synchronization process increases with the communication load between nodes on the cluster-type computer. Subsequently, the effect of acceleration due to parallel computing is considerably reduced.

This study developed a method of accelerating parallel and distributed calculation by reducing the internode communication load for synchronous processing based on the features of automotive radar analysis without reducing calculation accuracy. An analysis area was divided into blocks along the longitudinal direction. The blocks were assigned to GPUs to control the start time of the operation of each GPU according to radio wave propagation from a radiating antenna. The proposed method improves the efficiency of the existing FDTD method without changing
the computational principles or hardware.

## 2 Problem statement

General large-scale analysis is conducted using the FDTD method. An analysis region is divided into blocks, which are allocated to GPUs with multiple nodes. At each time step, it is necessary to exchange and synchronize the electric and magnetic field components on the boundary surfaces of adjacent blocks. As the number of boundary surfaces increases considerably with the scale of analysis, the amount of internode communication data for boundary processing increases significantly.

The factors that prevent the acceleration of parallel and distributed FDTD calculation are examined by theoretically determining the calculation time per time step, \( T \) [s/step]. \( T \) is expressed by Eq. (1) and Eq. (2) for the standard FDTD and FDTD methods [2, 4], respectively.

\[
T = \max \left( \frac{39N^3}{pF}, \frac{51 \times 4 \times N^3}{pB} \right) + \frac{\alpha \times 4 \times N \times \left( \frac{N}{m} + \frac{N}{n} \right)}{pM} + T_d \quad (1)
\]

\[
T = \max \left( \frac{75N^3}{pF}, \frac{75 \times 4 \times N^3}{pB} \right) + \frac{\alpha \times 8 \times N \times \left( \frac{N}{m} + \frac{N}{n} \right)}{pM} + T_d \quad (2)
\]

Here, the size of the analysis region is \( N \times N \times N \), and a two-dimensional division is performed using \( p = m \times n \) node computers. \( F \) [Flops] is the floating-point arithmetic performance of the computer, \( B \) [bps] is the memory bandwidth, \( M \) [bps] is the network bandwidth, \( T_d \) [s] is the communication delay time, \( \alpha \) is the number of boundaries per unit, and the data type is a single-precision floating-point number (4 bytes). According to Eq. (1) or Eq. (2), the network bandwidth strongly affects the simulation time. In general, the network bandwidth is significantly smaller than the memory bandwidth (in the case of TSUBAME 3.0, it is approximately 7 times smaller; \( B = 732 \) [Gbps], \( M = 100 \) [Gbps]).

## 3 Proposed method

As shown in Fig. 1(a), the propagation analysis of an automotive radar is performed over an elongated region along a road. On the basis of this feature, this study proposes a method of accelerating the FDTD simulation specialized for automotive radar analysis. In the proposed method, the analysis region is divided into blocks along the longitudinal direction. The blocks are allocated to GPUs to control the start time of the operation of each GPU according to radio wave propagation from an antenna.

The FDTD method initiates the calculation for radar wave propagation from the antenna at the start of the simulation. Fig. 1(c) shows the conventional method, in which the start time of the operation of each GPU is not controlled, i.e., the calculation at each GPU is simultaneously initiated. In contrast, in the proposed method, the calculation at the GPUs is not started and the synchronization process is paused at the start of the simulation. When the radar wave reaches the boundary surface and the electric field value of the radar wave exceeds a predetermined
threshold, the calculation at the GPU for the adjacent block is initiated along with the synchronization process (see Fig. 1(b)).

This makes it possible to reduce the number of contacted GPUs and make the number and area of boundary surfaces smaller than those of the conventional method. Thus, the amount of communication data between nodes can be reduced. In addition, the computational load of the synchronization process can be reduced by pausing the computation at the GPUs where radar waves have not yet arrived. Therefore, the proposed method can accelerate the FDTD simulation for the

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*(a) Example of automotive radar analysis range.*

*(b) Proposed method of controlling the start time of GPU operation.*

*(1) : Conventional method (start time of GPU operation is not controlled)*

*(2) : Proposed method (start time of GPU operation is controlled)*

*(c) Comparison condition.*

**Fig. 1.** Automotive radar analysis and proposed method.
propagation analysis of the automotive radar.

4 Validity verification

4.1 Simulation conditions

Weak scaling measurement is performed to quantitatively verify the effectiveness of the proposed method. Weak scaling measurement is a method of fixing the scale of the problem solved by each GPU, and it can examine the change in the simulation time vs. the number of GPUs.

In the verification, the analysis region is divided into blocks along the longitudinal direction, and they are allocated to each GPU. The conventional method shown in Fig. 1(c) is assumed to be the baseline method for this verification. The threshold for starting the calculation at each GPU is set as $10^{-6}$ V/m (maximum signal-to-noise ratio: -157 dB). This value is considered to be sufficiently smaller than the maximum signal strength, and calculation accuracy can be ensured.

Table I lists the calculation conditions and the specifications of the computer used for the verification. The frequency of the wave radiated from the antenna is 24 GHz, which is the same as that of an actual automotive radar. The analysis region has a maximum range of 112 m, and 100 GPU units are used.

4.2 Result

The verification results are shown in Fig. 2(a). The simulation time of the proposed method is smaller than that of the baseline method, and the difference increases with the number of GPUs (analysis scales). The proposed method reduces the simulation time by approximately 34% at 100 GPU units compared to the baseline method.

Fig. 2(b) shows the acceleration rate, which is defined by Eq. (3).

$$R_a = \frac{T_c}{T_p} \times 100$$

(3)

Here, $R_a$ [%] is the acceleration rate and $T_c$ [s] and $T_p$ [s] are the simulation times of the conventional and proposed methods, respectively.

| Table I. Simulation conditions |
|-------------------------------|
| Frequency | 24 GHz |
| Analysis region | $(896 \times n) \times 448 \times 448$ [cells] |
| | $(112 \ [m] \times 9 \ [m] \times 0.6 \ [m] \times 0.6 \ [m])$ |
| Cell size | 1.25 [mm] (≒1/10λ) |
| Method | FDTD(2,4) |
| CFL | 0.136 |
| Time step | $5.68 \times 10^{-13}$ [s] |
| Radiation source | 1/2 λ dipole antenna, continuous sine wave |
| Number of calculations | $6625 \times n$ [steps] |
| Absorber | PML 32 layers, $R_0 = 1.0 \times 10^{-32}$, $M = 4$ |
| Number of GPUs | $n$ [units] |
| GPU | NVIDIA TESLA P100 for NVlink-Optimzed servers ×4 |
| RAM | 256 [GB] (DDR4-2400 32 [GB] ×4) |
| Network | 100 [Gbps] (Intel Omni-Path Architecture FHI) |
The maximum acceleration rate is 160% at 64 GPU units. Accordingly, the simulation time can reduce from seven days to four days for a large-scale automotive radar analysis. In contrast, there is another simulation load that cannot be reduced by the proposed method. That is the load due to the placement of each GPU in the network on the supercomputer when the number of GPUs is large. In this case, the acceleration rate was lower at 100 GPU units than at 64 GPU units.

5 Conclusion
This study proposed a method of accelerating the FDTD simulation specialized for automotive radar analysis. An analysis region was divided into blocks in the longitudinal direction. These blocks were allocated to GPUs to control the start time of the operation of each GPU according to radio wave propagation from a radiating antenna. The findings of this study are as follows: The proposed method reduced the synchronization process and significantly decreased the simulation time compared to the conventional method. The total simulation time for large-scale automotive radar analysis decreased by approximately 34% at 100 GPU units compared to the conventional method.