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Accuracy Evaluation of Acoustic Analysis Using CIP Methods with Sub-grid Technique

サブグリッド･テクニックを用いた CIP 法による音場解析の精度評価

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1. Introduction

To date, numerical analysis for sound wave propagation in time domain has been investigated widely as a result of computer development[1]. Now, the development of accurate numerical schemes is an important technical issue.

The Constrained Interpolation Profile (CIP) methods is a novel low-dispersive and highly accurate numerical scheme[2-9]. CIP methods have multi-type of scheme (e.g., type-C, type-M, and so on) Those are a kind of method of characteristics (MOC)[9]. In our past study, we have applied the CIP methods to numerical analyses of sound wave propagation.

However, these methods uses additional memory due to use of derivative. Therefore, new reasonable grid systems are required for CIP simulations of complicated heterogeneous media or large-scale simulations of wave propagation. To overcome this problem, we employ the sub-grid techniques[10]. This technique has an advantage of using a small amount of memory. Sub-grids are defined as those smaller than the surrounding grids.

Additionally describing, sub-grids in CIP methods can be set as an arbitrary integer ratio. That is, we can use suitable multi size grids in an analysis domain according to a calculation model. In this study, we propose a sub-grid technique for acoustic simulation by CIP methods.

2. Sub-grid techniques in CIP method

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

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

In these equations, ρ denotes the density of the medium, K is the bulk modulus, p is the sound pressure, and $\vec{v}$ is the particle velocity. Here, we assume that the calculation is for a lossless medium.

In CIP analysis, these equations are transformed into advection forms. Figure 1 shows the aspect of sub-grid technique in the two-dimensional (2-D) simulation. Here, Δx and Δx_s represent the course grid size and sub grid size, respectively[11].

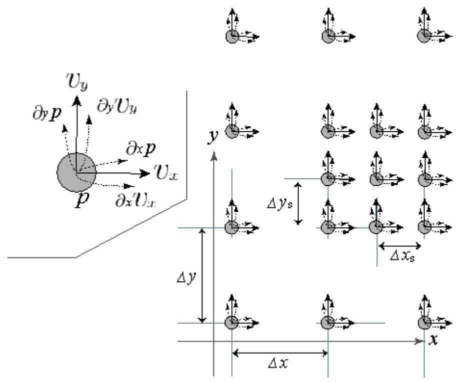


Fig. 1 Sub-grid technique in the CIP method

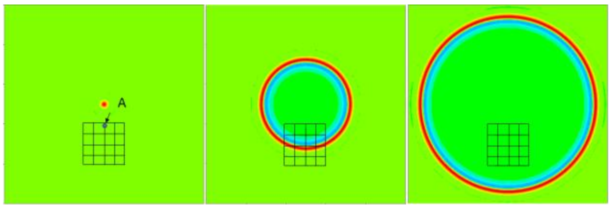
3.Results

We show the numerical results obtained using the sub-grid technique in the CIP analysis and compare the sub-grid and the uniform grid results. Figure 2 shows the sound pressure distributions obtained by CIP-MOC analysis with sub-grids at t = 10, 500, 1000 Δt. Here, the meshed area is the sub-grid region. Calculation parameters are: grid size, $\Delta x, \Delta y$ = 0.06 m; sub grid size, $\Delta x_s, \Delta y_s$ = 0.02 m. Figure 3 confirmed that the boundary in the sub-grids has good permeability characteristics.

Figure 4 shows the results under anothoer condition; Δx, Δy = 0.06 m; sub grid size, $\Delta x_s, \Delta y_s$ = 0.03 m. i.e., the grid ratio is 2:1 in Fig. 4, while the ratio is 3:1 in Fig. 2. Figure 5 also confirmed that the boundary in the sub-grids has an extremely low reflection.

Next, we investigated the calculation time required for some sub grid models. Here, we employ the PC with Intel Core i7-980X Extreme Edition 3.33GHz. This processor has 6 cores and 12 hyperthreaded cores, or effectively scales 12 threads. The parallel computation using OpenMP was applied for all analyses.

Figure 6 shows the comparison of calculation time, where the calculation is divided into 500 time



(a) $t = 10\,\Delta t$ (b) $t = 500\,\Delta t$ (c) $t = 1000\,\Delta t$

Fig. 2 Distribution of the sound pressure

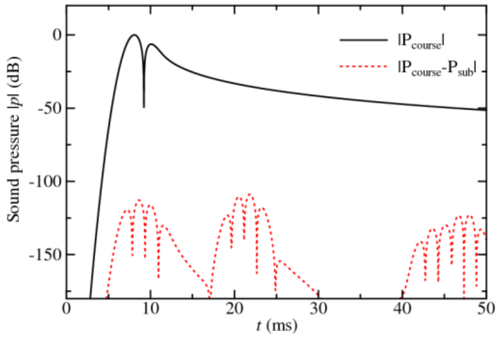
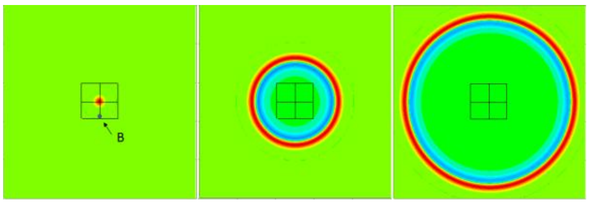


Fig. 3 Absolute pressure value: $|P_A^{coursee}|$ and $|P_A^{coursee} - P_A^{sub}|$



(a) $t = 10\,\Delta t$ (b) $t = 500\,\Delta t$ (c) $t = 1000\,\Delta t$

Fig. 4 Distribution of the sound pressure

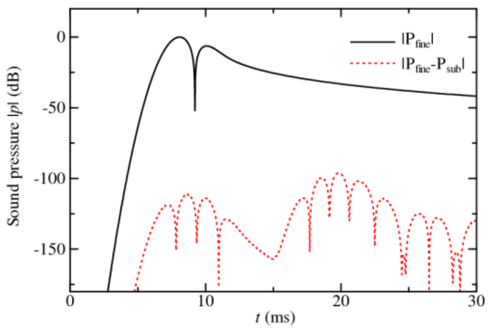


Fig. 5 Absolute pressure value: $|P_B^{fine}|$ and $|P_B^{fine} - P_B^{sub}|$

steps. The sub-grid model has a much shorter calculation time than the fine grid model. Here, Table 1 shows the calculation parameter of grid size.

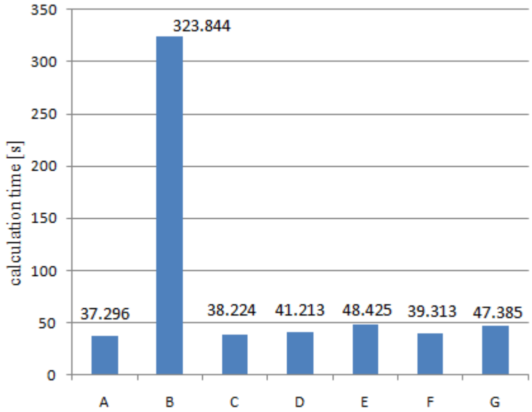


Fig. 6 Calculation time

Table . 1 Calculation parameter

	course grid;(0.06m)	fine grid;(0.02m)	fine grid;(0.03m)	fine grid(0.015m)
A	800 * 800			
B		2400 * 2400		
C	800 * 800	50 * 50		
D	800 * 800	100 * 100		
E	800 * 800	150 * 150		
F	800 * 800		100 * 100	
G	800 * 800			100 * 100

4. Discussion and Conclusion

The adobe examination results demonstrated that, in acoustic simulation using CIP methods, the correct treatment of boundary between the course grids and the sub-grids produces extremely low reflection for the calculation with as an arbitrary integer ratio; and clarified the feasibility of reduction of the calculation time by the use of a suitable multi-size grid.

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