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Shared Memory OpenMP Parallelization of SPH Program and Its Application to Solid Fluid Interaction

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ABSTRACT

This paper presents a parallel framework based on OpenMp with the Smoothed Particle Hydrodynamics (SPH) method, aiming at simulating the interactions between the free surface flow and a falling wedge. For parallel computing, different sub-thread parallel computation is realized with a good speedup performance. The size of model and the number of thread are discussed as well.

Key Words: *SPH, Parallel Computing, Solid Fluid Interaction, OpenMP*

1. Introduction

Smoothed Particle Hydrodynamics (SPH) is a meshless Lagrangian method, originally developed for astrophysics [1, 2].In this method, the continuum is discretized into interpolating points with material property and space information. With the concept of space and kernel function introduced, the system of classical Navier-Stokes equations needs to be solved. Given the advantage of dealing with large deformation problems, the SPH method is suitable to simulate the response of fluid under high-speed transient impact load. However, to describe the detailed phenomena and mechanism of wedge entry problem, the application of the SPH method is hindered by the expensive computational cost. Therefore, the SPH codes are required to be parallelized to obtain better performance.

2. SPH method and realization

Assuming the fluid non-viscous, and thus the Navier-Stokes equations [3] are shown as follows:

$$\frac{d\rho_i}{dt} = \sum_{j=1}^{N} m_j (v_i - v_j) \cdot \nabla_i W_{ij} \tag{1}$$

$$\frac{dv_i}{dt} = -\sum_{j=1}^{N} m_j \left(\frac{p_i}{\rho_i^2} + \frac{p_j}{\rho_j^2} + \Pi_{ij}\right) \cdot \nabla_i W_{ij} \tag{2}$$

Where ρ, m, v, W, p and Π_{ij} are the density, the mass, the velocity, the kernel function, the pressure and the artificial viscosity term respectively.

Taking the compressibility into consideration, Tait's equation [4] is used as the equation of state to link the pressure to the density. The equation is defined as

$$P = B[(\frac{\rho}{\rho_0})^{\gamma} - 1] \tag{3}$$

Where γ is a constant, and γ =7[4] in general. ρ_0 is the initial density and B is a parameter calculated from $B = \rho C_0^2 / \gamma$. C_0 denotes the sound speed.

3. Numerical simulation

3.1. Parallelism of OpenMp

In this paper, the parallel computing is performed based on SMP system. The simulation of the SFI problem is realized by placing OpenMP directives into the source codes. From the analysis of the time consumption of each part in the serial program, we find that the neighbour searching part is the most time consuming one. Besides, the time consumption of the module of updating particle information by solving the Navier-Stokes equations cannot be ignored. The parallel framework of SPH method is presented as Fig 1.

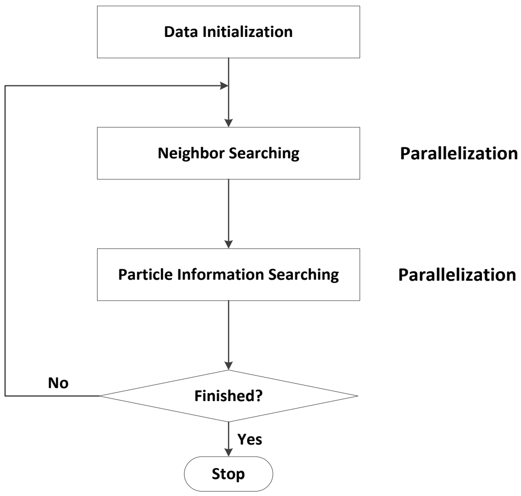

Fig 1 Parallel framework

In the neighbour searching part, the link-list method is used in the serial program. In the parallel process, linear techniques are used to avoid data race. While in the particle information updating part, some information of one particle is stored in the other particle which contributes to the updating process. Thus, the domain is decomposed into many sub-domains. Two sub-domains are presented in Fig 2. To make sure the information cannot be overwritten, the following conditions should be met:

(1) Particles in each domain are calculated by one thread.

(2) Particle information should be updated in each domain to the same order of grid, as shown in Fig 2.

(3) The height of each domain H should meet H>2sh(s is coefficient. In general, s>1 for load balance problem. h is the smooth length)

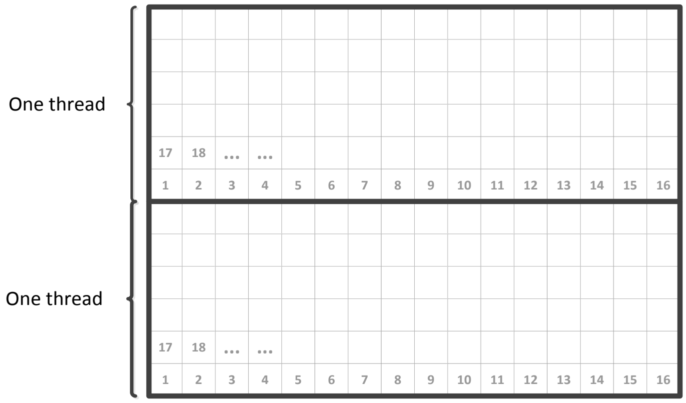

Fig 2 Domain decomposition method

The result of parallel program is same as the serial one. For this parallel method, speedup depends on the size of the system. When the size of the system is larger, the speedup is higher. The speedup also depends on the thread number used in the program. However, when the thread number is greater than the number of threads in one processor, the increasing rate of the speedup decreases significantly due to system time costs, as is shown in Fig 3.

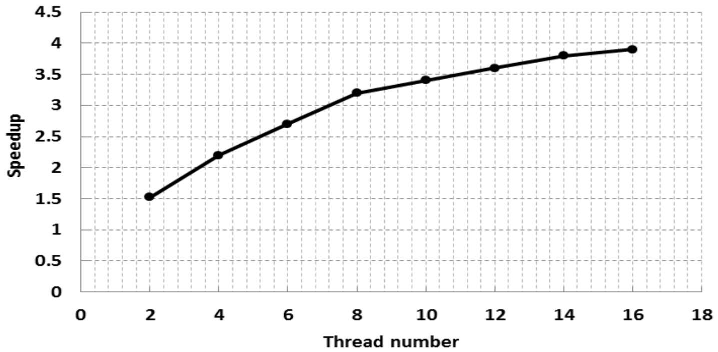

Fig 3 Speedup of penalization for the size of the system 51800

3.2. Wedge entry simulation

To verify the validity of the program, a case of two-dimensional symmetric wedge impacting the free surface is simulated. This simulation has been made with the same wedge and tank as those used in the experiment carried out by Sawan A Shah [5]. The deadrise angle of the wedge is 20°.Fig 4 presents the comparison between the simulation particle distribution and the experimental result when t=0.03s. It is shown that the particles distribution fits well with the experimental pictures. Fig 5 shows the comparison of vertical velocity time histories between SPH and experimental results. In this figure, the simulation data observed seem to be lower during the entry, as the gravity and air cushion effects are not implemented in the simulation. Thus, further work is needed to concern the effect of these factors.

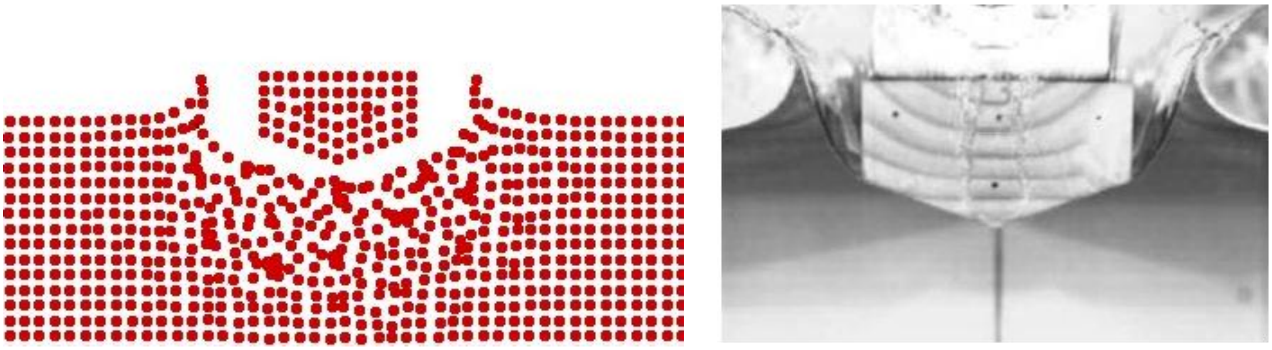

Fig 4 The comparison between simulation particles distribution and experiment

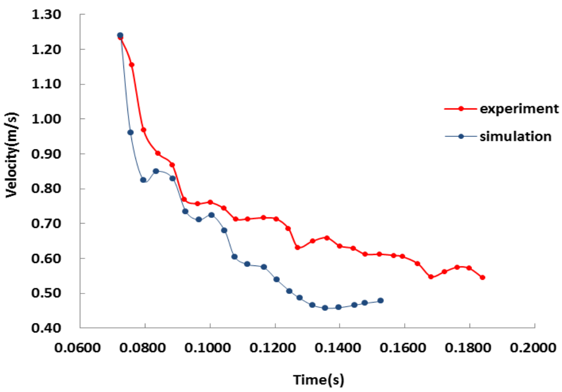

Fig 5 The comparison of simulation wedge velocity with experiment

4. Conclusions and future work

For SFI, the wedge water entry problem has been simulated to validate the parallel computing. Velocity prediction and the evolution are compared with experimental results. To get a more clear understanding of the problem, the effect of air cushion and gravity need further study. For OpenMp parallel computing, a domain decomposition method has been put forward. However, we believe that it is still possible to improve the speedup by a proper data organisation.

REFERENCES

[1] J.J.Monaghan,R.A.Gingold, Shock simulation by the particle method SPH, Comput. Phys., Vol. **52**, pp. 374–389, 1983.

[2] J.J.Monaghan, Smoothed particle hydrodynamics, Annu. Rev. Astrophys., Vol.**30**, pp.543-574,

1992.

[3] Liu.G.R, Liu.M.B, Smoothed particle Hydrodynamics: A Messfree particle method. World Scientific, 2003.

[4] J.J.Monaghan, Smoothed particle hydrodynamics, Rep. Prog. Phys., Vol.**68**, 2005, pp.1703-1759.

[5] Shah.S, Water impact investigations for aircraft ditching analysis [D]. Melbourne, Royal Melbourne Institute of Technology, 2010.