IOP Conf. Series: Earth and Environmental Science **57** (2017) 012010 doi:10.1088/1755-1315/57/1/012010

Simulation of actual terrain ocean tide in the bays with SPH

Wang Tao

Guangzhou institute of Geographic, Guangzhou, China

E-mail: wangtao8869@163.com

Abstract. The real-time simulation of large-scale fluid scenes is of great value in both research and application. Water when relatively still has a well-defined surface; however, water changes its shape as it moves. In the case of ocean waves, features on the water's surface move, but the water itself does not travel. The simple surface topology can become arbitrarily complex when the water becomes turbulent. Splashing, foaming, and breaking waves are complex processes best modeled by particle systems and volumetric techniques, but these techniques are inefficient in nonturbulent situations. Ocean tide in different bays can experience rotary tidal currents or other situation. We choose the physical-based SPH(smoothed particle hydrodynamics) fluid simulation method. SPH method belongs to particle method which is has no grid. The advantages of SPH are as follows: simulating liquid convection by particles directly to eliminate numerical fluctuation at free interface; grids unnecessary avoid grid distortion and reconstruction; simulating the fluid problem of significant transformation, especially in dealing the problems such as maximum distortion, the interface of motion material, the deformation boundary and free surface flow. Application of rapid neighboring particle search method, set the number of Department of Physics, as well as the presentation and rendering of fluid material, and finally use the Lagrangian method SPH system initialization and calculate the fluid density, pressure, internal forces and external forces, define the time integration and collision handling. With the analysis of physical-based ocean tide simulation, we can create the animation of the environment, and predict damage of ocean tide.

1. Introduction

In the geographical information system, there are no real 3d display system that can simulate ocean tide in the real terrain scene.

There are two kind of methods for ocean simulation. One is water surface based on the statics by using height simulation, another is physics based fluid simulation[1, 2, 3, 4].

In grid-based numerical methods, mesh generation for the problem domain is a prerequisite for the numerical simulations. For the Eulerian grid methods like FDM, constructing a regular grid for irregular or complex geometry has never been an easy task, and usually requires additional complex mathematical transformation that can be even more expensive than solving the problem itself[5-9].

Grid-based methods have been favored the most to solve the mathematical equations for fluid flow, but often they lack the ability to create interactive fluid simulations together with detailed fluid surfaces[1].

The key idea of the meshfree methods is to provide accurate and stable numerical solutions for integral equations or PDEs with all kinds of possible boundary conditions with a set of arbitrarily distributed nodes without using any mesh that provides the connectivity of these nodes or particles[10-15].

SPH is a meshfree particle method, the problem is discretized with particles without a fixed connectivity. Treatment of large deformation is relatively much easier, Discretization of complex geometry for the MPMs is relatively simpler as only an initial discretization is required, refinement of the particles is expected much easier to perform than the mesh refinement.

Smoothed particle hydrodynamics (SPH) is a meshfree, Lagrangian particle method of modeling fluid flows. SPH was first invented to solve astrophysical problems in three-dimensional open space, in particle polytrope. 1983, Reeves first introduce the particle to the field of computer graphics. Muller use it to simulate the movement of fluid in 2002.Today, the SPH method is being used in many areas, such as the simulations of binary stars and stellar collisions, collapse[2].

In this article, we try to simulate the actual terrain ocean tide in the bays with SPH.

2. Algorithm

In summary, the governing equations for dynamic fluid flows can be written as a set of partial differential equations in Lagrangian description. The set of partial differential equations is the well-known Navier-Stokes equations, which state the conservation of mass, momentum and energy. (expressed in equation (2.1)and (2.2))

$$\rho(\frac{\partial}{\partial t}+\mathrm{u}\bullet\nabla)u=-\nabla p+\mu\nabla\bullet(\nabla u)+f \tag{2.1}$$

$$\nabla\bullet u=0 \tag{2.2}$$

where ρ stands for the density of the fluid, u is velocity, μ is viscosity, f is external force.

Lagrangian also use Navier-Stokes equation to simulate the movement of fluid, it is expressed in equation (2.3):

$$\rho\frac{du}{dt}=-\nabla p+\mu\nabla^2 u+f \tag{2.3}$$

Left side of the equation is internal and external forces, forces are expressed in euqation (2.4) as:

$$F=f^{\text{internal}}+f^{\text{external}} \tag{2.4}$$

In the SPH method, the state of a system is represented by a set of particles, which possess individual material properties and move according to the governing conservation equations. SPH particles have some properties, such as: location accelaration carry material properties, and are allowed to move in light of the internal interactions and external forces.

Values are interpolated from a discrete set of points.

（1）Density

Density is expressed as equation (2.5)：

$$\rho_i=\rho(r_i)=\sum_j\rho_j\frac{m_j}{\rho_j}W(r_i-r_j,h)=\sum_j m_jW(r_i-r_j,h) \tag{2.5}$$

where W is kernel function， m is the mass， h is radius, j is the number of particles i in the radius of kernel. r_i， r_j are the position of particle i and j.

(2)Internal force

Internal force arise from the particle interaction .such as: pressure and viscosity.
pressure is expressed as equation (2.6)：

$$f_i^{\text{pressure}} = -\sum_{j \neq i} \frac{p_i + p_j}{2} \frac{m_j}{\rho_j} \nabla W(r_i - r_j, h) \tag{2.6}$$

viscosity is expressed as equation (2.7)：

$$f_i^{\text{viscosity}} = -\mu \sum_{j \neq i} u_j \frac{m_j}{\rho_j} \nabla^2 W(r_i - r_j, h) \tag{2.7}$$

(3)External force

External force include gravity and buoyancy. It is expressed in equation (2.8).

$$f^{\text{external}} = \sum_{\text{n}} f^{\text{n}} \tag{2.8}$$

where gravity is expressed as equation (2.9)：

$$f_i^{\text{gravity}} = \rho_i g \tag{2.9}$$

buoyancy is expressed as equation （2.10）：

$$f_i^{\text{buoyancy}} = b(\rho_i - \rho_0) g \tag{2.10}$$

where g is acceleration due to gravity, b is coefficient of buoyancy.

(4)Time integration

In order to simulate the fluid, it is necessary to set the time step. Leap-Frog is used for time integration. The advantage of the Leap-Frog algorithm is its low memory storage required in the computation and the efficiency for one force evaluation per step[1].

In the SPH method, since the smoothing function has a compact support domain, only a finite number of particles are within the support domain of dimension kh of the concerned particle, and used in the particle approximations. These particles are generally referred to as nearest neighboring particles for the concerned particle. The process of finding the near nearest particles is commonly referred to as nearest neighboring particle searching. Unlike a grid-based numerical method, where the position of neighbor grid-cells are well defined once the grids are given, the nearest neighboring particle in the SPH for a given particle can vary with time[1, 2].

Tree search algorithm works well for problems with variable smoothing lengths. It involves creating ordered trees according the particle positions. Once the tree structure is created, it can be used efficiently to find the nearest neighboring particles.

3. Algorithm

Here we use the open source code SPH Fluid Simulator for CPU and GPU to simulate the ocean tide. The workflow of the SPH is shown as follow figure 1:

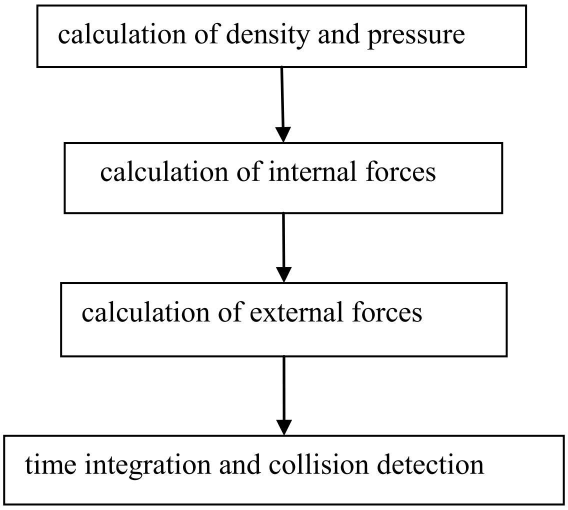

Figure1. Workflow of SPH

Simulation results are shown in the figure 2 .

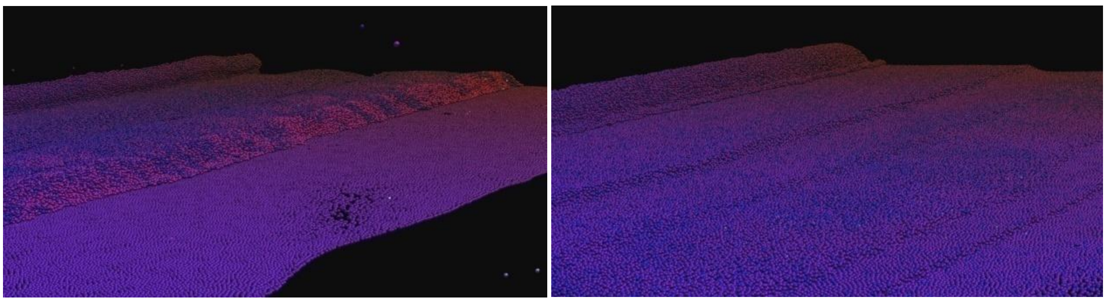

Figure 2. Simulation of ocean tide with SPH

4. Conclusion

In this article, we use SPH algorithm to simulate ocean tide in the bays. It shows a good result. But there are a lot of work to do in the future, how to use the real terrain scene to simulate the ocean tide in the bay. How to rewrite the source code to accelerate. How to render the environment.

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