Bubble Rupture Simulation by Considering High Density Ratio

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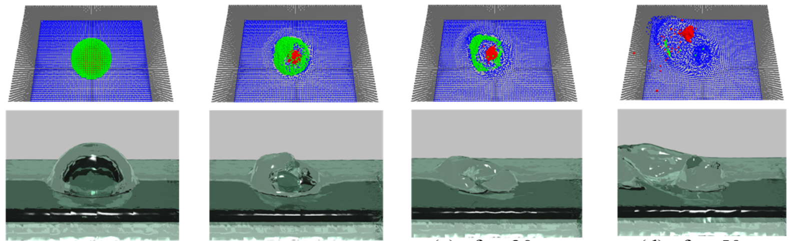

(a) initial state (b) after 22ms (c) after 30ms (d) after 50ms

Figure 1: Sequence of bubble rupturing (Particle rendering and Ray-tracing). (a) Initial state where a bubble is generated on the water surface. (b) Bubble starts to rupture when a hole is generated on the top of the bubble film. (c) Bubble ruptures by the difference force between the inside pressure and the surface tension of the film. (d) Air particles that were inside the bubble blow off rapidly into the air and a wave is generated on the water surface.

1 Introduction

[Hong et al. 2008] proposed a hybrid method of Eulerian grids and Lagrangian particles to represent small-scale bubbles in large-scale water. In the simulation, bubbles rise freely in the water; however, bubble seeds are set at random at the bottom and they disappear as soon as they arrive at the water surface. [Patkar et al. 2013] also proposed a hybrid Lagrangian-Eulerian framework to visualize both small and large scale bubbles. A bubble that exits the spout of a water dispenser flows up in the water with changing its shape; however, they did not simulate the rupture process of bubble. Then, [Mukai et al. 2012] tried a rupture simulation by using MPS method; however, it did not consider the high density ratio of the water to the air so that the bubble ruptured gradually. Therefore, this paper proposes a method of bubble rupture simulation, where a wave is generated after a bubble has ruptured rapidly, by considering the high density ratio of the water to the air.

2 Method

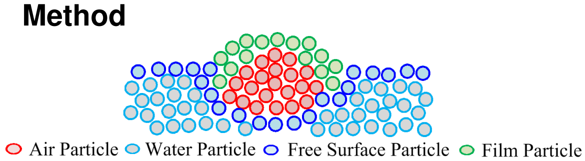

Figure 2: Bubble model.

Fig. 2 shows our bubble model. A bubble is composed of four kinds of particles: air, water, free surface and film particles. Particles except for air particle are included in water particle category. Free surface particle is defined as water particle that has particle density lower than 0.97 times of the initial density. Film particles change to free surface particles when they become to have no air particles within the radius of influence or they are placed below the water surface after the rupture. Film particles are also mutually connected with springs, and the behavior of film particles can be calculated with Eq. (1).

$$\frac{\partial^2 \vec{r}_i}{\partial t^2} = -\frac{2R\gamma}{n^0}\sum_{i\neq j}(\delta l_{ij}\frac{\vec{r}_j-\vec{r}_i}{|\vec{r}_j-\vec{r}_i|}) + \frac{1}{2n^0}\rho_a V_a^2 \vec{N}_i \tag{1}$$

where, $\vec{r}_i$ and $\vec{r}_j$ are the positions of particle i and j, t is time, R is the film radius of bubble, γ is surface tension coefficient, n^0 is initial particle density, δ is delta function, l_{ij} is stretched length between particles of i and j from the initial one, ρ_a and V_a are the density and velocity of air particle, and $\vec{N}_i$ is the normal vector of particle i. Bubble rupture can be simulated with equation of continuity and Navier-Stokes equation with surface tension (Eq. (2)).

$$\frac{D\vec{v}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{v} + \vec{G} + \frac{1}{\rho}\kappa\gamma\delta\vec{N} \tag{2}$$

where, $\vec{v}$ is velocity, ρ is density, P is pressure, ν is kinematic coefficient of viscosity, $\vec{G}$ is gravity, κ is curvature, and $\vec{N}$ is normal vector of the surface. The last term is surface tension that works for free surface particles. The density ratio of the water to the air is 1,000 so that we cannot solve Eq. (2) at the same time. Then, at first, Eq. (2) is solved for only water particles including free surface and film particles by giving free surface particles the average pressure of air particles. After that, Eq. (2) is solved for air particles by setting free surface particles as a rigid pressure wall. Fig. 1 is a result of the simulation, which shows both particle rendering (top view) and ray-tracing (side view). The bubble ruptures when a hole is generated on the top of the film, and a wave is generated after the bubble has ruptured rapidly.

References

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