Rupture Simulation of a Bubble with MPS

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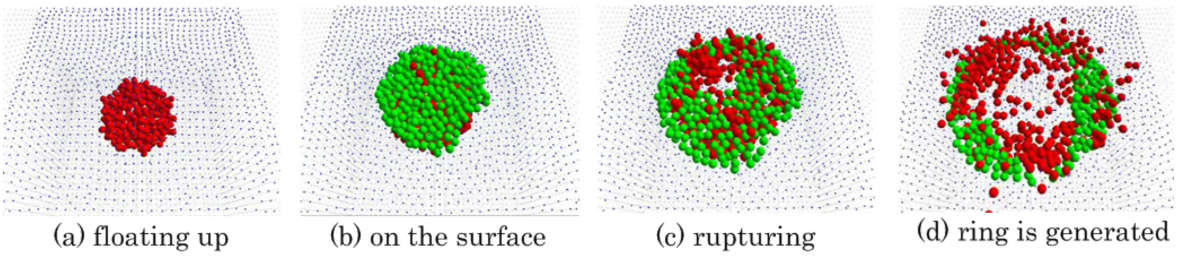

Figure 1: *An image sequence showing that a bubble is rupturing. (a) a bubble is floating up from the bottom of the water to the surface with changing its shape by buoyancy. Red spheres show air particles in the bubble. (b) The bubble is on the surface of the water. Green spheres show film particles constructing the surface of the bubble. (c) The bubble is rupturing. Air particles (red particles), which was inside the bubble, are dispersing out of the bubble. (d) The bubble has ruptured and a ring is generated with some film particles (green particles).*

1 Introduction

One of the most difficult tasks with computer graphics is visualization of liquid, especially bubble that is constructed with air and water. Many scientists have struggled to represent bubble behavior. [Hong et al. 2008] proposed a hybrid method of Eulerian grids and Lagrangian particles in order to visualize small-scale bubbles in large-scale water body. Bubble particles are seeded randomly at the bottom and disappear when they reach the surface. In addition, [Ihmsen et al. 2011] proposed another two-way coupling method for water and air because of the large density ratio of water to air. Each phase is treated separately and combined together. Bubbles are seeded on the fly, treated as foam on the surface and deleted after a user defined time. Both researches use SPH (Smoothed Particle Hydrodynamics) as the particle method and succeeded to visualize the bubble behavior; however, bubbles are generated in calm water and the water is incompressible. They also did not treat the behavior of bubble rupture. On the other hand, [Bird et al. 2010] revealed that numerous small bubbles (daughter bubbles) are generated when a bubble ruptures, and the small bubbles create a ring. Therefore, we propose a method to simulate the rupturing behavior of a bubble with MPS (Moving Particle Semi-implicit), which is another particle method that can treat incompressible fluid.

2 Method

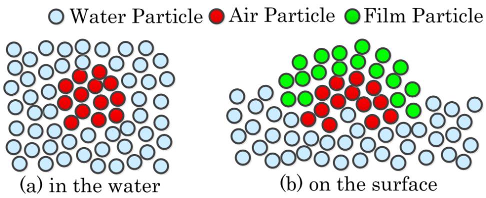

Figure 2: *Bubble Model.*

Fig. 2 shows our model of a bubble, which is constructed with 3 kinds of particles: water, air and film particles. In the water, a bubble is constructed with water and air particles and is floating up to the surface with changing its shape by buoyancy. Buoyancy is calculated with the sum of the force that works on each particle. The particle position is defined by solving equation of continuity and Navier-Stokes equation with surface tension shown as Eq.(1) and Eq.(2), respectively.

$$\frac{d\rho}{dt} = 0 \tag{1}$$

$$\frac{D\boldsymbol{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\boldsymbol{u} + \boldsymbol{G} + \frac{1}{\rho}\kappa\gamma\delta\boldsymbol{n} \tag{2}$$

where, ρ is density, t is time, $\boldsymbol{u}$ is velocity, P is pressure, ν is kinematic coefficient of viscosity, $\boldsymbol{G}$ is gravity, κ is curvature, γ is surface tension coefficient, δ is delta function, and $\boldsymbol{n}$ is normal vector of the surface.

Once the bubble is on the surface, film particle is detected. Film particle is defined as a particle that has free surface and air particle within the radius of influence. Film particle also has surface tension; however, it is not calculated with the last term of Eq.(2) but with the following Eq.(3) according to the idea of [Bird et al. 2010], which is based on MSM (Mass Spring Model).

$$\frac{\partial^2\boldsymbol{r}_i}{\partial t^2} = -\frac{2R\gamma}{m_0}\sum_{i\neq j}\{\delta(|\boldsymbol{r}_j-\boldsymbol{r}_i|-l_{ij})\frac{\boldsymbol{r}_j-\boldsymbol{r}_i}{|\boldsymbol{r}_j-\boldsymbol{r}_i|}\}+\frac{1}{2m_0}\rho_a V_a^2\boldsymbol{n}_i \tag{3}$$

where, $\boldsymbol{r}_i$ and $\boldsymbol{r}_j$ are the positions of particle i and j, R is film radius of bubble, m_0 is the initial particle number of density, l_{ij} is the length between particles of i and j when the film is made, ρ_a and V_a are the density and velocity of air, and $\boldsymbol{n}_i$ is the normal vector of particle i.

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