Haptic interaction based SPH fluid control

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Abstract

Fluid control has become a research hotspot in recent years. In this paper, a SPH fluid deformation control method based on the haptic interaction was proposed. Firstly, we sample the user-specified object model by the voxelization method to get control model and control fluid's animation. Then, for achieving realistic interaction effect, we calculate the deformation of the control model according to the user control force and the interaction force between the model and the fluid. Finally, a control method of deformation control of the fluid model is proposed. The effectiveness of method was demonstrated in various scenarios.

Keywords: fluid control, deformation constraint, haptic interaction

1. Introduction

Fluid control of haptic interaction is an open and active subject. Traditional methods [1][2] only provide a simple haptic interaction. Terzopoulos et al. [3] pioneered the physical-based haptic interaction calculation method. Mora et al. [4] simulated the interaction between fluid and solid using the grid based method and calculated the feedback force of the fluid haptic interaction by solving the Navier-Stokes equations. Yang et al. [5] simulated the haptic interaction between solid and gas. This method follows the basic law of fluid dynamics and generates 3D textures by measuring the information of surrounding meshes. Cirio et al. [5] used SPH method to simulate the interaction between fluids with solids. This method uses the SPH framework to model the solid and the liquid, and control the input of the feedback force through the force feedback device, and realizes the haptic interaction simulation by this device. Wang et al. [6] used a hybrid method to simulate fluid-solid interaction in which the solids were simulated in a grid and the fluid was calculated using the traditional SPH method. The calculated interaction force by this method is smooth and realistic. However, its computational cost is still high.

In this paper, a new method of SPH fluid deformation control method based on haptic interaction is proposed. In the process of haptic interaction, users input the force to the virtual scene through the haptic interaction device, and control the deformation of the model with the control force, so as to drive the fluid model deformation. For the interactive process, in order to make the fluid model deformation more natural, we take into account the fluid model by the external fluid pressure, buoyancy, and viscous force. The main contributions can be summarized as follows:

1. A haptic interaction based SPH fluid control method is proposed, which can be used to provide a deformation constraint and efficiently control the deformation of fluid model.
2. An interaction based control model deformation method is developed to calculate the deformation of control model when the interaction forces are applied, providing users with a richer interaction experience.
3. A fluid deformation constraint control method is used which can ensure that the fluid particle can be deformed naturally with the deformation of the control model.

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2. Algorithm

2.1 SPH fluid control by haptic interaction

For each particle, we use the following method to calculate the fluid interaction force.

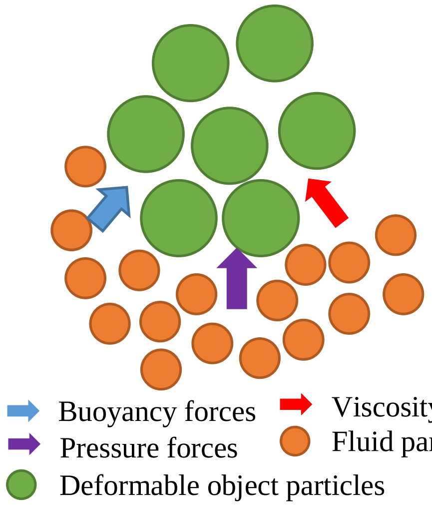


Figure 1. Illustration of the forces for deformable solid particles.

$$f_{interaction} = f_{bouyancy} + f_{pressure} + f_{viscosity} \quad (1)$$

where $f_{interaction}$ is haptic force, $f_{pressure}$ is pressure, $f_{viscosity}$ is viscous. In order to improve the authenticity as much as possible, we introduce the buoyancy force $f_{bouyancy}$ in the interaction force. The pressure at which the particles are subjected to is calculated as follows:

$$f_{pressure}(i) = -\sum_{j \in N(i)} \frac{P_j + P_i}{2} \nabla W(p_i - p_j, \mathrm{H}) \quad (2)$$

where $j \in N(i)$ denotes the particles in the neighbourhood of particle i, P_j and P_i represent particle j and particle *i*, p_i and p_j are particle positions.

$$\rho_i = \sum_{j \in N(i)} m_i W(p_i - p_j, \mathrm{H}) \quad (3)$$

where m_i is the mass of the nearby particle *i*.

In addition, the viscous force is also indispensable, which can be calculated as

$$f_{viscosity}(i) = \mu \cdot m_i \cdot \Delta t(\Delta u_i - u_i) \quad (4)$$

where μ is the viscosity coefficient, *m* is the mass, *u* is the velocity, and Δu_i is calculated as follows:

$$\Delta u_i = \frac{\sum_{j \in N(i)} u_i W(p_i - p_j, \mathrm{H})}{\sum_{j \in N(i)} W(p_i - p_j, \mathrm{H})} \quad (5)$$

Finally, since the buoyancy of the control model is different at different positons in the fluid, and the fluid buoyancy interaction force is calculated in the unified SPH fluid modelling framework. According to the physical properties of the buoyancy, the buoyant force is in the opposite direction to the gravity direction, written as

$$f_{bouyancy}(i) = -\sum_{j \in N(i)} \rho_j d_j W(p_i - p_j, \mathrm{H}) \quad (6)$$

Through the above calculation process, we can get the total interaction force $f_{interaction}$ between the control model and the fluid interaction process. Then the sum of the external forces on the model deformation at time t is expressed as follows:

$$f_{ext}^t(i) = f_{interaction}^t(i) + f_{haptic}^t(i) + G \quad (7)$$

2.2 The constraint control of fluid model deformation

In this paper, the following strategies are proposed to solve the problem of controlling the accumulation of particles in the control model so as to improve the filling ability of the fluid particles. First, the density of the fluid is computed and the density field of the controlled region is obtained. The density field is larger when the fluid particles are filled in a better region and vice versa. A new scaling factor is introduced so that the control force can be scaled by a certain scale based on the density of the surrounding fluid particles under the action of the scaling factor.

$$f_a(j) = w_a \sum_i \beta_i \frac{p_i - p_j}{\left\| p_i - p_j \right\|} W(x_{ij}, H) \quad (8)$$

$$\beta_i = 1 + \frac{\rho_0}{(\rho_i + \eta)} \quad (9)$$

Here, ρ_0 is the initial density of the fluid particles, η is the non-zero scaling factor, m_j is the mass of the fluid particle, and ρ_i is the density at the *i-th* control particle. β_i denotes the scaling factor of the *i-th* control particles. On the other hand, during the movement of the source-controlled particles, there exists a problem that the particle movement is too fast to cause the sudden release control of the fluid particles, thereby causing the problem of unnatural splashing of fluid particles. In order to solve this problem, this paper uses the spring binding force to control the problem of fluid particle splashing in the condition of rapid movement. In this paper, the distance between the fluid particle and the controlled particle is taken as the key parameter, which aims to find the control particle nearest to the current fluid particle. When the fluid particle is moving away from the control particle, the control particle will apply a pulling force to it, so that it returns to its control range. When the fluid particles are too close to the control particles, the control particles will have a thrust. The spring constraint formula is as follows:

$$f(d) = \frac{1}{1+e^{\gamma-\delta D}} \tag{10}$$

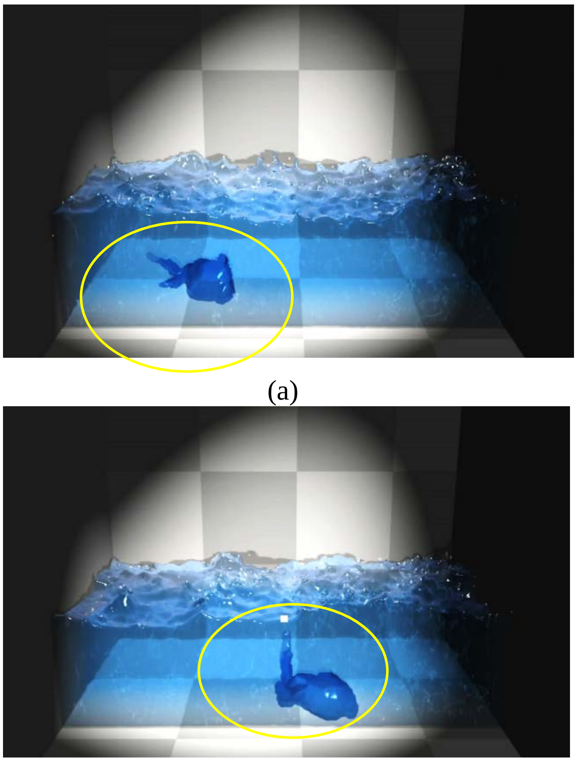
where D is the distance from the fluid particle to the control particle and γ and δ are the variable parameters for adjusting the spring force function. In summary, the spring restraint is applied to the control force to obtain the following formula:

$$f_{spring}(i) = \tau f\left(\left|r_i - p_i\right|\right)\frac{r_i - p_i}{\left|r_i - p_i\right|} \tag{11}$$

where τ is used to adjust the strength of the spring constraint, r_i is the position of the first fluid particle, and p_i is the position of the nearest particle to the control particle.

3. Experiments and Results

All the algorithms in this paper were run on CUDA 7.0. The hardware environments in experiment are: HP desktop computer, CPU i5-4460, GPU GTX745 and memory 8G.



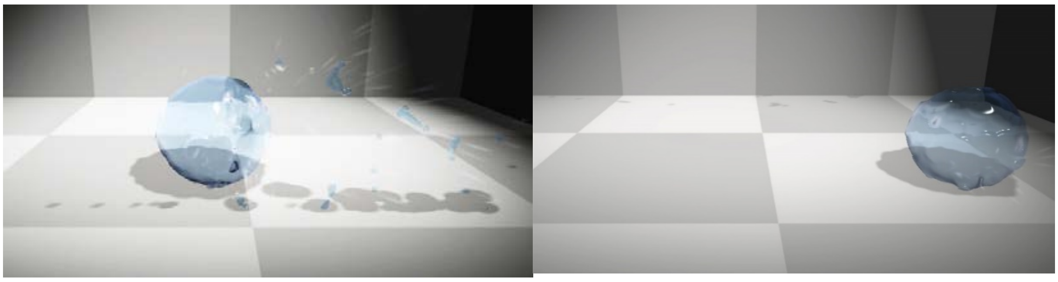
(a)

(b)

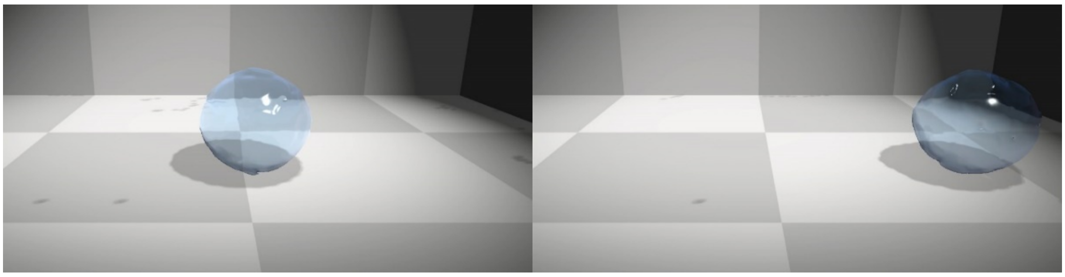
Figure 3. Comparison of the deformation effect between Cirio et al.'s method [2] (a) and our method (b).

Figure 3 shows the comparison between our method and Cirio et al.'s method [2]. It can be observed that due to the buoyancy is involved into our approach, the control model interaction process is more realistic and natural.

As for fluid model control, traditional method [7] only provides a coarse control force, and it is not applicable to a deformable fluid-haptic interaction scenario. Figure 5 shows the comparison of our method with the original coarse control methods. Figure 5(a) is result of the traditional control method [7], which only considers the control of particle attraction to the fluid particles. Figure 5(b) is the result of our paper, which not only considers the coarse control constraint of the control particle on the fluid particles, but also introduces the spring force constraint and velocity constraint. By comparing Fig. 5 (a) with Fig. 5 (b), it can be seen that when the deformation is large, there is a significant particle splash in the control model in (a), while in (b) it can greatly maintain the shape of the fluid model.



(a)



(b)

Figure 5. Comparison of the control effect between Solenthaler et al.'s method [7] and our method. (a) is the original rough control method [7]; (b) is the fluid model deformation constraint control method.

4. Conclusion

In this paper, a SPH fluid deformation control method based on the haptic interaction has been proposed. A deformation control algorithm based on the interaction control model was proposed to calculate the deformation of the control model. In addition, a fluid deformation control method was designed so as to efficiently control the fluid model.

In the future work, we would further improve the accuracy of the current method, so as to provide users with more realistic force feedback during the fluid control.

Acknowledgements

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