Visual Simulation of Glazed Frost

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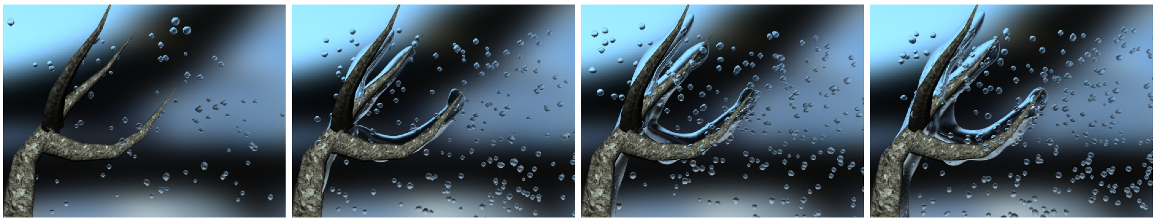

(a) 1,000 timesteps (b) 4,000 timesteps (c) 7,000 timesteps (d) 10,000 timesteps

Figure 1: *Simulation and rendering results of generation of glazed frost.*

1 Introduction

Glazed frost is a crystal clear ice and formed from supercooled raindrops that freeze when they hit object surfaces such as the ground and branches of trees. Simulation methods for formation of ice crystal, such as frost, on the surface of objects have been proposed by Kim et al. [Kim et al. 2004]. However, a supercooling state has to be considered for simulating freezing rain, and fluid simulation is required for reproducing the effect of raindrops running down on the ice surfaces. To our best knowledge, there has been no research presenting glazed frost by using a fluid simulation. We use the fluid simulation based on FLIP method [Zhu and Bridson 2005]. Hence, raindrops and obstacles are represented by particles which are used to calculate the advection term, and the update of velocity field are calculated by using grids except for advection term. We propose a method to create an animation of glazed frost formation by taking into account the heat transfer between particles and the outside grids.

2 Our Simulation Method

The heat transfer from a particle to the grid is calculated by using the FLIP method similar to the velocity field. The heat transfer between particles and grids is calculated according to the Fourier's law. Heat transfer is not calculated between particles, but calculated between grids. Heat transfer between grids is calculated by solving heat transfer equations. After calculating heat transfer, the heat is distributed to the particles. To update the velocity field, a time step is set according to the CFL conditions. We employ the Crank-Nicolson method to solve the heat conduction equation (1).

$$\frac{\partial T}{\partial t} = a\frac{\partial^2 T}{\partial \mathbf{x^2}}, \tag{1}$$

where T is a temperature, t is time, a is a thermal diffusivity and $\mathbf{x}$ is position vector. We decide the time to freeze by considering the heat flux on the surface of the raindrop. Amount of heat flux is calculated until freezing from the adhesion on the obstacles. The speed for freezing is decided by the following sum of heat flux.

$$Q = Q_s + Q_l + Q_f \tag{2}$$

It is known that the smaller the sum of flux Q in negative value is, the faster the freezing speed is [Jones 1996]. So we use as the condition for freezing or not whether the time integral of Q_s and Q_l which have negative value exceeds the required amount of heat Q_f. The integration calculation is limited to the time during the water drop adheres on the obstacles, and we assume that, in case the water drop does not adhere on the glazed frost or obstacles because of the influence of gravity or other raindrops, it does not freeze.

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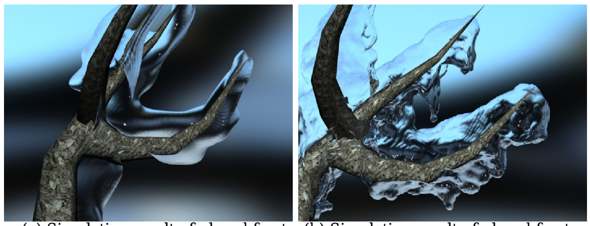

(a) Simulation result of glazed frost taking into account the wind (b) Simulation result of glazed frost of icicle shape

Figure 2: *Simulation results of generating glazed frost.*

3 Results and Conclusion

Figure 2 shows two simulation results of generating glazed frost. We can represent that supercooled water in some cases freezes instantly after collision, and in some cases gradually condensates in the process of running down on objects. This is the result by considering heat flux and can be reproduced like this because of calculation of the time to freezing. By this effect, ice covering tree branches, as typically seen in glazed frost, can be reproduced.

We have proposed a technique which is highly compatible for FLIP method to solve the heat conduction equation and we have reproduced formation of glazed frost.

References

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