An icicle generation model based on the SPH method

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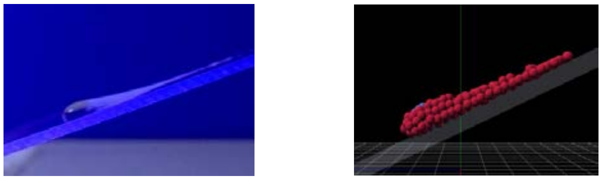

Fig. 1 *Comparison between actual* (Left) *and computer generated water drop* (Right)

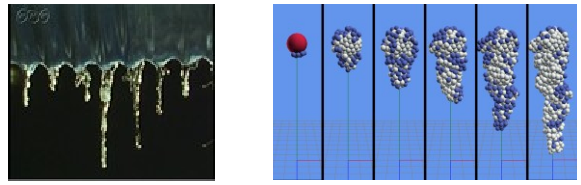

Fig. 2 *Comparison between actual icicles* (Left) *and a sequence of icicle growth simulation* (Right)

1. Introduction

There has been a lot of research done on the water drop model. However, for the icicle growth model, the one by [Kim] has been reported. Although there has been a lot of research on melting ice and icicles, there is no model that can simulate the developing state of an icicle as each water drop drips and freezes. Our model can deal with the phase transition process from start to end, from water into ice, by using an extended model of the SPH method.

2. Previous Work

2.1 Interfacial tension method

In order to represent the shape of a real water drop, an interfacial tension model, which is an extended SPH method, has been devised by [Abe]. This model made it possible to represent the shape of a water drop with different contact angles, as well as the flat shape of a large volume water drop.

2.2 Ice dynamics as a thin-film Stefan problem

Kim et al. [Kim] proposed an icicle generation model that can generate complicated ice shapes, such as in the case of a limited water supply due to a Stefan problem upon freezing, or in the case of an icicle tip model based on an experiment. Their method expresses realistic icicle modeling.

3. Proposed Method

3.1 Behavior of a water drop

An icicle grows due to freezing water drops that drip on its surface. The shapes of icicles vary greatly according to how the water drops adhere to them. However, as the interfacial tension model devised by Abe et al. doesn't consider any kinetic contact angles for water drops, it is difficult to precisely represent the state of a water drop dripping onto an icicle.

We have extended the model of Abe et al. [Abe] and propose a water drop model that puts an emphasis on dynamic behavior. The biggest difference between the resting state and the motion state of a water drop shape is the contact angle. The contact angle of a water drop in the motion state is called the kinetic contact angle (See Supplement Figure 1). By using this model, and with consideration of the kinetic contact angle, we can represent a water particle dripping on a solid surface with more realistic movement (See Figure 1, Supplement Figure 2 and Video 1).

3.2 Heat Transfer and Freezing between Particles

In order to represent the state of freezing water, we install a heat transfer system between particles into the model mentioned in the previous section. The temperature of a water particle i is regarded as t_i. This model doesn't distinguish air, water particles, ice particles or the water-ice interface, and regards anything that touches particle i as particle j.

Q_i as the amount of heat transferred to particle i can be calculated by the following Equation (1):

$$Q_i = \sum_{j=0}^{N_i} k_{ij} A_{ij} (t_j - t_i). \quad (1)$$

Here, N_i is the total number of particles contacting particle i, k_{ij} is the specific heat transfer rate for the contacting particles i and j, A_{ij} is the contact area. After its temperature drops to 0˚C, the water particle goes through a phase transition into ice and its latent heat of condensation is lost.

4. Results

Figure 1, Supplement Figure 2 and Video 1 show the water drop generated by our model. Due to the effect of the kinetic contact angle, a water drop shape with tails extending both to the traveling direction and the reverse direction was generated.

Figure 2 and Supplement Videos 2 and 3 show the result of icicles generated by our model. The icicles' shape becomes thinner as it goes from its root to the tip. Furthermore, ripples are generated on the surface of the icicles.

Figure 3 shows the difference between Kim et al.'s results and ours. Although our model is simple, we obtained a similar result.

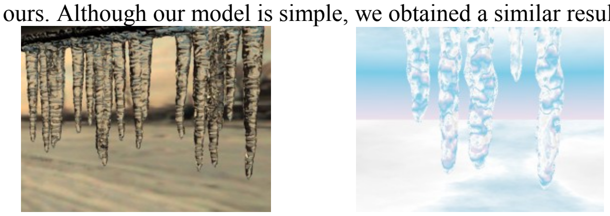

Fig. 3 *Comparison between Kim et al.'s result* (Left) *and our results* (Right) *of icicle generation.*

5. Conclusions

We have proposed a model to simulate the developing state of an icicle as each water drop drips and freezes. By using this model, we were able to generate a model that could generate an icicle with ripples on its surface, the same as a real icicle, and that grows with each drip of water. We will consider high speed processing for a larger simulation in the future.

References

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