Particle-Based Simulation of Snow Trampling Taking Sintering Effect into Account

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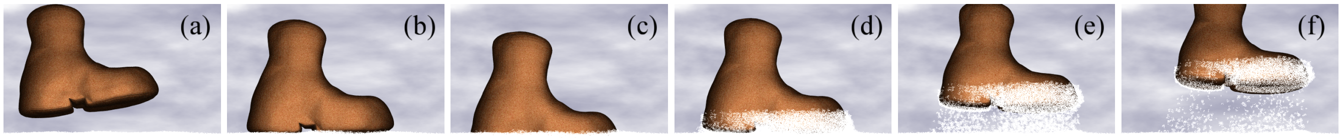

Figure 1: *Simulated snow trampling with sintering effect.*

1 Introduction

In the real world, solid powders are likely to coalesce firmly with each other owing to melting, which is called *sintering* and arises in various daily scenes. We herein focus on sintering with snow. In the conventional computer graphics, adhesion of snow to shoes and/or feet when trampling into snow is not explicitly represented without any consideration of the sintering effect, neglect of which in the involved scenes would reduce the overall quality of the work. Procedural particle animation insufficiently represents the behavior of snow with the sintering effect due to the complexity of the phenomena.

Against this background, we strive to simulate interactions between snow and objects taking the sintering effect into account. We assume that both snow and rigid bodies can be represented as an aggregation of particles. We use the SPH (Smoothed Particle Hydrodynamics) method to approximate the behavior of snow as a fluid. Salient features of our simulation approach are three-fold: (1) behavior of snow by modifying the viscosity term of the Navier-Stokes equations; (2) adhesion of snow to dynamic rigid bodies by appending the sintering term to the Navier-Stokes equations; and (3) thermal conduction of particles including influence from the convection of the external air.

2 Our Approach

2.1 Behavior of snow

Snow is classified as non-Newtonian fluid, whose behavior cannot be governed by the original Navier-Stokes equations for Newtonian fluid. Thus, we represent the behavior of snow by introducing a new viscosity term based on the Herschel-Bulkley model [HB02], which has been commonly used to provide a generalized model of non-Newtonian fluids in the rheology field.

2.2 Sintering effect

Adhesion of snow to objects can be explained as a sintering effect, which cannot be represented by the Navier-Stokes equations modified in Section 2.1. Clavet et al. [CBP05] appended an attraction force formulated by a quadratic function for each particle to have antigravity disposition, and represented flows along the surface of objects. However, this formulation is not able to represent adhesion to dynamic objects because the fluid runs away if forced. Thus, we represent the phenomena by introducing into the Navier-Stokes equations, a new sintering term which is formulated by the interparticle pressure, average of sintering coefficients between particles, and particles' properties such as temperature and moisture. As a side effect of this, snow particles could intrude excessively into a rigid body when collisions are detected between particles as long as we rely on the traditional SPH method. To address this problem, we distribute the force of repulsion to the particles of a rigid body according to the distance from the surface to push snow particles back. This repulsion force depends on the particle properties as well.

2.3 Thermal conduction

Particles exert a force upon each other, and heat propagates among them as well when snow collides with objects. In addition, the sintering force changes according to the temperature of the particles. So we need to keep track of the temperature of the particles. To that end, we discretize the thermal conduction equation with the SPH method. Besides, we incorporate into the computation of thermal conduction, the effect that surface particles of snow are influenced by the convection of the external air.

3 Implementation and Results

We performed regular sampling on the underlying 3D polygons to determine the initial position of the particles of accumulated snow and objects. Scenes were rendered with an open-source ray-tracer POV-Ray ver. 3.62.

Fig. 1 shows a sequence of key snapshots excerpted from the accompanying video, where we used about 131k and 24k particles for snow and a shoe, respectively. From this, we can clearly observe snow compressed with the weight of the shoe ((b)-(c)); and adhesion of snow to the shoe bottom and scatter of some adhered particles into the air ((d)-(f)). Fig. 2 shows a particle representation of the simulation result corresponding to the scene (e) in Figure 1. An average frame rate of the simulation (without rendering) is 0.4 frame per second on a standard PC (CPU: Core i7 860 2.80GHz, RAM: 6.00GB) without using GPU. Additional results are included in the accompanying video.

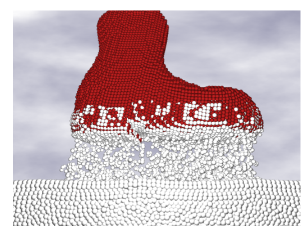

Figure 2: *Particle representation of the scene* (e) *in Fig. 1.*

In future work, we would improve the adhesion among snow particles taking into account other kinds of physics, and attempt to simulate the sintering effect with other sorts of substances such as metal powder, ceramics and glass.

References

[HB02] Herschel, W. H. and Bulkley, R.: *Konsistenzmessungen von Gummi-Benzollösungen,* Springer Berlin / Heidelberg, 2002.

[CBP05] Clavet, S., Beaudoin, P., and Poulin, P.: "Particle-Based Viscoelastic Fluid Simulation," in *Proceedings of the 2005 ACM SIGGRAPH/Eurographics Symposium on Computer Animation,* pp. 219-228, 2005.

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SIGGRAPH 2012, Los Angeles, California, August 5 – 9, 2012.
ISBN 978-1-4503-1435-0/12/0008