Representation Method of Snow Splitting and Sliding on a Roof

Nobuhiko Mukai, Yusuke Eto, and Youngha Chang

***Abstract*—**One of the challenging issues in computer graphics field is to represent natural phenomena such as falling water, floating cloud, accumulating snow and so on. There are some previous works related to snow representation such as fallen and accumulated snow, blizzard, avalanche, and sintering. However, there is little research for representation of splitting snow on a roof although there are some for shattering on the ground. Therefore, we propose a representation method of snow splitting and sliding on a roof. The method uses EDEM (Extended Distinct Element Method), which is one of particle methods and can consider connection and scission between particles. In addition to friction and adhesion between snow and a roof, density and moisture rate of snow are considered for connection and scission between particles. As the result of the simulation, we have been able to represent snow splitting and sliding on a roof.

***Index Terms*—**Computer graphics, EDEM, particle method, snow.

I. Introduction

By using computer graphics, many natural phenomena can be represented such as falling water, floating cloud, accumulating snow and so forth. Snowy scene is important for production of movies, TV commercials, and games. Fearing *et al*. [1] proposed a method of representing fallen snow, and represented some scenes covered with computer generated snow by using accumulation patterns and stability test. Feldman *et al*. [2] extended the method of [1] for snow drift by wind blow, and represented accumulation patterns of windward and leeward drifts. Moriya *et al*. [3] also proposed another modeling technique for fallen snow formed by drift. They used pre-computed radiance transfer to represent snowflakes without fluid dynamics simulation so that the scene was rendered in real time. On the other hand, Wang *et al*. [4] rendered falling rain and snow by mapping textures onto a double cone, which is tilted for camera movement, elongated for motion blur, and scrolled for falling rain and snow.

Production of snowy scene is very important especially for movies so that Walt Disney Animation Studios also reported some works. Coony *et al*. [5] created a system called "python scripted pipeline", which could build a variety of snow shots from text-based meta-data files. Somakhin *et al*. [6] represented packing snow effect, which is representation for snowball to be compressed while moving down on a slope. They generated a method of user-controllable elasto-plastic constitutive model by using Eulerian/Lagrangian Point Method, and the method generated a scene that a snowball was grown on a hill, collided against a wall and shattered on the ground. In addition, Takahashi *et al*. [7] represented snow trampling scene by considering a phenomenon called sintering, which coalesces snow powder firmly by treading on it.

On the other hand, there is a scene, where part of snow fallen down on a roof melts and splits while sliding down on the roof. Snow sliding down on a roof sometimes hits cars or even humans so that it is a very dangerous phenomenon. However, there is little research for representing snow splitting and sliding on a roof. Therefore, we have been proposing a method for representing this scene [8], [9]. In this paper, we propose the extended model that can consider not only connection and scission between particles, but also density and moisture rate of snow in order to represent splitting of snow. Friction and adhesion are also considered for sliding of snow on a roof.

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Nobuhiko Mukai is with Tokyo City University, Tokyo 1588557 Japan
Yusuke Eto is with Tokyo City University, Tokyo 1588557 Japan
Youngha Chang is with Tokyo City University, Tokyo 1588557 Japan

II. Method

A. Particle Model

The snow model proposed in this paper is composed of particles, and the model uses EDEM (Extended Distinct Element Method) as the particle method. EDEM is an extended method of DEM (Distinct Element Method), which supposes that a particle has a radius although other particle methods such as SPH (Smoothed Particle Hydrodynamics) or MPS (Moving Particle Semi-implicit) consider a particle as just a point that does not have a radius. Two particles of i and j are considered to be connected if the following equation is satisfied.

$$d_{ij} \leq r_i + r_j \tag{1}$$

where, d_{ij} is the distance between particles of i and j, and r_i and r_j are the radiuses of particles of i and j, respectively. If two particles are connected, bonding power occurs, which is constructed with two types of forces: normal and shear ones. The power is defined as follows.

$$F_n = k_n u_n + \eta_n v_n \tag{2}$$
$$F_s = k_s u_s + \eta_s v_s \tag{3}$$

where, suffixes of n and s mean normal and shear, respectively. F is force. k and η are spring and viscosity constants, respectively. u and v are displacement and velocity of a particle, respectively.

In this paper, EDEM is used instead of DEM. EDEM has an extended radius that is larger than the radius defined in DEM.

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Then, particles are considered to be connected if the following equation is true.

$$d_{ij} \leq c(r_i + r_j) \tag{4}$$

where, c is a coefficient that extends the radius virtually.

When both normal and shear forces disappear, particles are disconnected and any forces do not work thereafter. The disconnection condition for normal direction is that the distance between particles becomes larger than the limit of elasticity. On the other hand, the disconnection condition for shear direction is as follows.

$$F_s > F_a + \lambda F_n \tag{5}$$

where, F_a and λ are adhesion force and coefficient of dynamic friction between particles.

B. *Density and Moisture Rate*

Snow is classified according to its density. Table I shows the relation between snow quality and density [10].

TABLE I: SNOW QUALITY AND DENSITY

Quality	Density (g/cm^3)
Fresh snow	0.05-0.15
Slight fastened snow	0.15-0.25
Fastened snow	0.25-0.50
Coarse grained granular snow	Around 0.30
Granular snow	0.30-0.50

In addition, distribution of snow quality on a roof was researched by Sakurai *et al*. [11], and it can be described as follows.

1) For the horizontal direction of a roof, the central part of a roof has higher density snow than the edge part.
2) For the tilt direction of a roof, the eaves of the roof have higher density snow than the ridge.
3) There is some randomness for density distribution.

According to 1) and 2), the snow quality distribution should be the figure shown in Fig. 1.

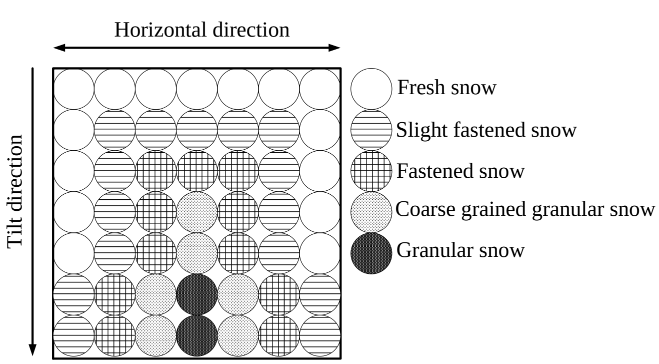

Fig. 1. Distribution of snow quality in horizontal direction.

Spring constants used in (2) and (3) should be decided according to the density of a snow particle, and changed a little bit randomly in order to reflect the randomness described in 3).

In addition, we can infer the next statement.

4) For the vertical direction, the lower part of the accumulated snow has higher density than the upper part.

Then, the snow quality distribution on a vertical cross section of a roof should be the figure shown in Fig. 2.

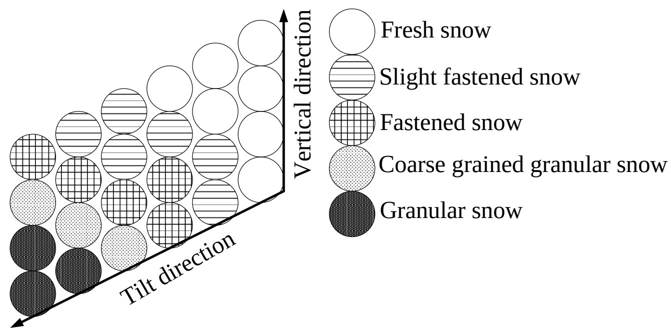

Fig. 2. Distribution of snow quality in vertical direction.

When snow melts, it becomes water and flows. On the other hand, when snow is frozen, it becomes ice, and particles are connected firmly. Then, we should consider the moisture rate of snow in order to decide connection or scission between particles. Yoshida researched the moisture rate of snow on a roof [12], and we can see that the inner part has higher moisture rate than the outer part. The abstract figure on a vertical cross section of a roof is shown in Fig. 3.

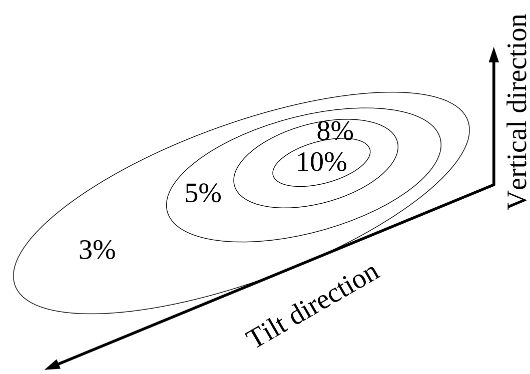

Fig. 3. Distribution of moisture rate on a vertical cross section.

Then, the spring constants used in (2) and (3) are decided according to the density and moisture rate of a particle as follows.

$$k_{ij} = \{k/(|\rho_i - \rho_j| + 1)\}\{1 - (w_i + w_j)/2\} \tag{6}$$

where, k_{ij} is the spring constant between particles of i and j, k is a standard spring constant, ρ_i and ρ_j are density of particles i and j, respectively. w_i and w_j are the moisture rate of particles i and j, respectively. (6) decides spring constant according to the following rule.

A) If the density difference between particles is larger, the spring constant is smaller because the snow quality is

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different between particles. Then, the spring is weaker and the particles tend to be disconnected.

B) If the average moisture rate of particles is higher, the spring constant is also smaller because it tends to be water and the connection should be weaker.

C. Friction and Adhesion

Snow slides on a roof with the help of the gravity; however, there are friction and adhesion between snow and a roof as the resistance forces. Then, the sliding force F_s can be calculated with the following equations [13].

$$F_s = F_g - (F_f + F_a) \tag{7}$$

$$F_g = mg\sin\theta \tag{8}$$

$$F_f = \mu mg\cos\theta \tag{9}$$

$$F_a = 90 - \{79 - (1 + 0.3(1 - w))\} \tag{10}$$

where, F_g is driving force by gravity, F_f is friction, F_a is adhesion, m is mass of a particle, g is gravity, θ is tilt angle of a roof, μ is static friction coefficient, w is moisture rate of a particle.

III. SIMULATION

The algorithm of the simulation is as follows.

<Algorithm for splitting and sliding snow>

S1) Initialization: set snow particles as if fallen snow is accumulated on a roof according to Fig. 1 and Fig. 2. Moisture rate of snow is also set according to Fig. 3.

S2) Split calculation: calculate the force that works between particles if they are connected. Otherwise, split particles.

S3) Slide calculation: calculate sliding force and move particles on the roof. After a particle leaves the roof, it falls according to the gravity.

S4) Repetition: repeat S2) and S3).

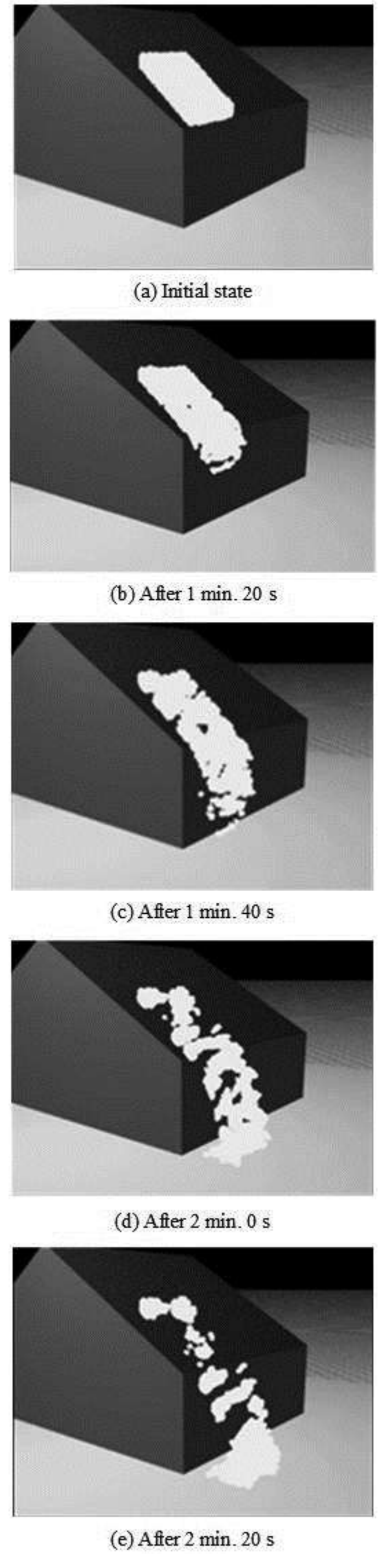
Table II shows the simulation condition used in the paper.

TABLE II: SIMULATION CONDITION

CPU	Intel Core i5 3.20GHz
Memory	6GB
OS	Windows7
Particle number	1,500
Particle radius	3 cm
Tilt angle of the roof	40 degrees

Fig. 4 shows a simulation result with the proposed method. The time shown in Fig. 4 is the calculation time of the simulation excluding transforming from particles to polygons and rendering. After the simulation, the polygon model is transformed from particles to polygons with marching cubes, and the generated polygons are rendered with a software called POV-Ray.

On the other hand, Fig. 5 shows the comparison of the simulation result with a real photo. In the initial state, no split snow can be seen on the roof. When snow starts to fall at the eaves, the protruding part of snow begin to be split. As time passes, many split blocks can be seen, and the split direction is also various.



(a) Initial state

(b) After 1 min. 20 s

(c) After 1 min. 40 s

(d) After 2 min. 0 s

(e) After 2 min. 20 s

Fig. 4. Simulation result.

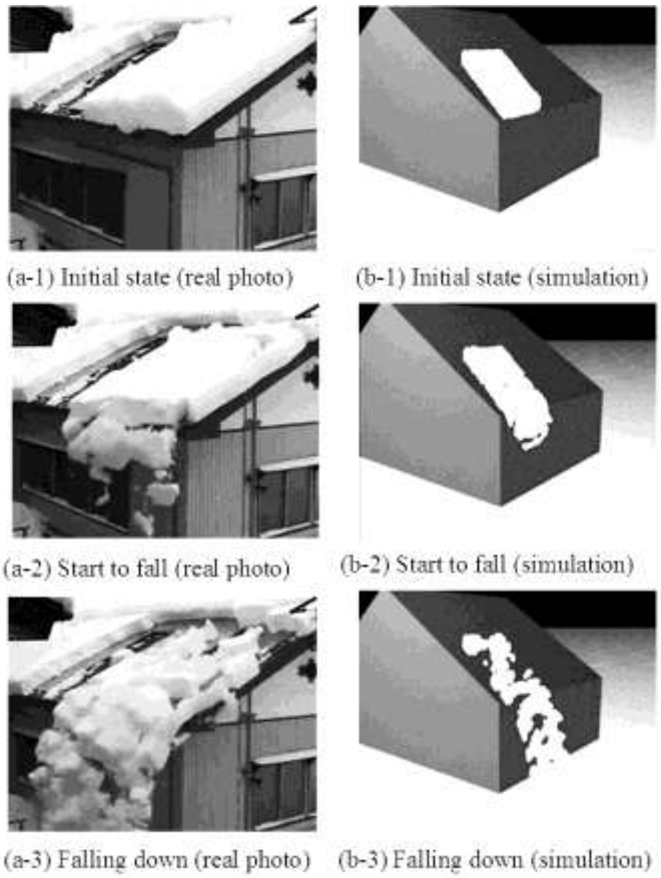


Fig. 5. Comparison a simulation image with a real photo.

IV. Conclusion

We have proposed a new particle-based method to represent snow splitting and sliding on a roof. The method can consider the connection and scission of particles by using density difference and average moisture rate of particles. It also can calculate the sliding force on a roof by considering gravity, friction and adhesion. As the result of the simulation, we have confirmed the splitting and sliding snow on a roof, which is very similar to a real photo.

However, the paper did not represent the scene that snow is shattered after it collides with the ground. In addition, density and moisture rate change according to the surrounding temperature, and the friction and adhesion are also change according to the characteristics of the roof. Then, we plan to solve these issues by expanding the proposed model.

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Nobuhiko Mukai is a professor of Tokyo City University. He received his B.E., M.E. and Ph.D degrees from Osaka University in 1983, 1985, and 2001, respectively. He started to work at Mitsubishi Electric Corporation and changed to work as an associate professor for Musashi Institute of Technology in 2002. He is currently a professor of Tokyo City University from 2007. His research interests are computer graphics and image processing. He is a member of ACM, SAS, VRSJ, IEICE , ITE, IPSJ, IIEEJ, and JSUM.

Yusuke Eto is a undergraduate student at Tokyo City University. His research interests are computer graphics and physical simulation.

Youngha Chang is a Lecturer of Tokyo City University. She received her B.E. from Ewha Woman’s University in 1998. She also earned Ph.D from Tokyo Institute of Technology in 2004. She became a researcher, a research associate, and an assistant professor at Tokyo Institute of Technology in 2004, 2006, and 2007, respectively. She is currently a lecturer at Tokyo City University from 2012. Her research interests are image processing and color science. She is a member of SAS and IPSJ.