A Visual Simulation of Volcanic Eruption in the Use of Particle System

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Abstract: In this paper, a modified particle system is proposed for volcanic eruption with lava, ashes and smoke. In the proposed method each eruptive material consists of particles. The movement of particles is determined by the external force and interaction (attraction, repulsion and viscosity) only in neighbor region. Since the method can be executed in combination with the geographic information, the proposed method may also be useful for disaster prevention.

1. Introduction

It is well-known that representation of natural phenomena is one of the important and attractive topics in the field of computer graphics. Among the phenomena dynamic ones are difficult to visualize exactly because of their complexity. In order to visualize them with suitable quality in suitable computational cost, the so-called particle system[1] is often used. In the system, the phenomena are defined a set of particles whose movement are determined by the external forces (e.g., gravity, wind and temperature) and their interaction. Although the system can simplify the phenomena described by the fluid dynamics, direct visualization of the particles is not enough to represent the phenomena naturally. Also, more particles cause more computational cost because its computation includes their interaction.

In this paper, a modified particle system is proposed for volcanic eruption[2] with lava, ashes and smoke. In the proposed method each eruptive material consists of particles. The movement of particles is determined by the external force and interaction (attraction, repulsion and viscosity)[3] only in neighbor region. Since the method can be executed in combination with the geographic information, the proposed method may also be useful for disaster prevention.

2. Volcanic Eruption

The phenomenon which magma spouts violently on the surface of the earth from underground is called volcanic eruption. The scale of eruption is depend on the quantity of the volatile ingredient contained in magma. Magma has high temperature about $900 \sim 1200K$. When maguma spouts on the ground, it is cooled and becomes the rock called lava. As magma goes up vent, it is ground, and it becomes a small particle(tephra). As maguma including volcanic gas goes up, mixed gas of volcanic gas and particle is generated. This mixed gas goes up to the sky, and forms plume. So, volcanic smoke is considered as a mixed gas of the volcanic gas, atmosphere, and particles of maguma.

3. A Particle Model for the Volcanic Eruption

3.1 Input Parameters

We define input parameters which considered to influence on the volcanic eruption(see Table 1).

Table 1. input parameters

crater	position, scale
particle	density, size, temperature, viscosity, initial velocity, amount of eruption
wind	velocity, direction
temperature	temperature, the ratio of temperature to altitude

3.2 Definition and Property of a Prticle

In this paper, we define lava, volcanic ashes, and smoke as different types of particles respectively and volcano as a obstacle. Each particle has own properties, especially its size. Here we define the detail as the following.

Particle of lava:

- lava consists of particle which blew off on the ground.
- particle moves in response to external forces.
- particle performs an elastic collision to the obstacle and the space where lava density is high.

- particle delivers and receives heat with air.
- The viscosity of a particle changes with its temperature.

Particle of volcanic ashes and smoke

- particle of volcanic ashes is defined by mix of the volcanic gas and pulverization of magma.
- particle of smoke is defined as a set of volcanic gas.
- each particle moves in response to external force.
- each particle gets buoyancy corresponding to difference of temperature from the surrounding atmosphere.
- each particle performs an elastic collision to the obstacle. If there is a region with ash in high density, we assume the region as the obstacle for the particles.
- each particle delivers and receives heat with air.

3.3 Action of Particle

Each particle occurred from crater and vanished when it comes out out of the range of a map or stops moving. At each steptime, particles moves in response to external force. At each steptime, we define eruption of each particle(lava, ash, smoke). The movement of particle is expressed by the following formula with velocity v, position x, mass M for the particle and steptime Δt.

$$\frac{dx}{dt} = v + \frac{f}{M}\Delta t \tag{1}$$

Here, the external force f which works to particle is express with the following formula. If the distance between particles is far more than fixed , attraction, repulsion and viscosity aren't calculated. Note that we don't take buoyancy which works to lava particle into consider.

$$f = f_{ka} + f_{kb} + f_{kc} + f_{kd} + f_{ke} + f_{kf} + M_k g \tag{2}$$

f_{ka}:Attraction received from other particles[N]

f_{kb}:Repulsion received from other particles[N]

f_{kc}:Viscosity received from other particles [N]

f_{kd}:Buoyancy[N]

f_{ke}:Air resistance[N]

f_{kf}:Energy caused by elastic collision[N]

M_k:Mass of a particle[kg]

g:Acceleration of gravity[m/s^2]

3.3.1 Attraction

Attraction f_{ka} is expressed with the following formula (3).

$$f_{ka} = -Mu \cdot \lambda \cdot \exp(-\lambda \cdot r) \tag{3}$$

Mu is the coefficient of an interaction, λ is the dignity of distance. r is the distance between particles.

3.3.2 Repulsion

By repulsion, a particle moves to the space where density is low. Repulsion f_{kb} is expressed with the following formula (4).

$$f_{kb} = s \cdot \sum_{i=0}^{n} f_i(d) \tag{4}$$

Here s is the dignity of the repulsion, $f_i(d)$ is the vector from the particle to neighbor boxel. n is amount of the neighbor boxels.

3.3.3 Viscosity

In movement of fluid, if the portion which speed differs has touched, the external force pulled by the portion with a slow speed works. We define this force as viscosity and express f_{kc} by formula (5).

$$f_{kc} = \beta \cdot \sum_{j=0}^{N} (V_j - V_i) \exp(-\lambda \cdot |d_{ij}|) \tag{5}$$

Here β and λ are coefficient of viscosity, N is amount of the neighbor particles, V_i is the velocity of the particle under calculation, V_j is the velocity of the neighbor particle and d_{ij} is the distance between particles.

3.3.4 Buoyancy

Buoyancy is expressed with the following formula (6).

$$f_{kd} = \frac{\rho_0 - \rho}{\rho_0} \tag{6}$$

ρ_0 is density of atmosphere. Density ρ of the particle is obtained from the equation of gas law PV/T. Since the temperature of particle changes at every steptime, the density of particle (smoke, volcanic ashes) has to be calculated at every steptime.

3.3.5 Air Resistance

We define air resistance f_{ke} as the following formula (7) by giving radius to a particle.

$$f_{ke} = \frac{\rho_0 C \pi r^2 v^2}{2} \tag{7}$$

Here C is the coefficient of resistance, r is the radius of a particle, v is the velocity of a particle. The force which particle receives by the wind is also calculated using this formula. In this case, v denotes velocity of wind.

3.3.6 Elastic Collision

(a) collision against boxel space
We divide the space by the cubes of a certain size (boxel), and define boxel space consisting of a set of boxels [4]. Each boxel has density of particles and temperature at the current time (see Figure 1). If the density of a boxel is high, the particles perform elastic collision each other.

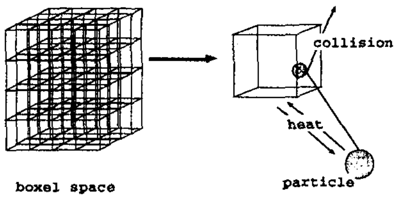

Figure 1. boxel space

(b) collision against obstacle
A collision occurred when a particle moves to the space with an obstacle. The particle after collision has a vector to the right reflective direction. Its new velocity v_h' is expressed by following formula (8) from the elastic coefficient e, velocity of the particle before collision v_h.

$$v_h' = e \cdot v_h \tag{8}$$

If v_h' becomes smaller than a fixed value, particle slides on an obstacle (see formula (9)). A particle continues sliding over an obstacle until there is a certain amount of fall.

$$\vec{v'} = |\vec{v}|(\vec{v} \cdot \vec{unit})\vec{unit} \tag{9}$$

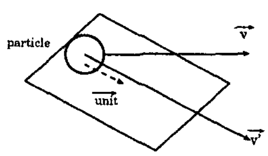

Figure 2. slide model

$\vec{v'}$ is a vector after slide, $\vec{v}$ is a vector before slide, $\vec{unit}$ is a unit vector parallel to a slide side. Also, reduction of the velocity by friction is expressed in formula (10).

Here, v' is the velocity of a particle after the reduction of the velocity, v is the velocity of a particle before reduction, D is reductive ratio of velocity by friction.

$$v' = (D|v|) + (1 - D)\exp(-|v|) \tag{10}$$

3.4 Emission of heat

At each steptime, the particle delivers and receives heat with neighbor boxel according to formula (11).

$$eng[J/s] = \alpha \cdot A \cdot (temp_p - temp_a) \tag{11}$$

Temperature of a particle changes with emission of heat (formula (12)). $temp_m$ is specific heat of the particle, M is weight of the particle. Formula (13) shows temperature change of atmosphere. $temp_a$ is a specific heat of atmosphere, ρ is density of atmosphere, and l is a unit size of boxel. If the temperature of boxel is higher than neighbor one, it lost heat as time goes by.

$$T[K] = \frac{eng}{temp_m \times M} \tag{12}$$

$$T[K] = \frac{eng}{temp_a \times \rho \times l^3} \tag{13}$$

3.5 Proposed Algorithm

step1 Set parameters, and define boxel space and volcano.

step2 A particle is made to blow off from the crater where an eruption occurs. Also, change the environment according to input.

step3 The external force which works to each particle is calculated, and the state of next steptime is determined.

step4 Proceed to next steptime and repeat **step2** $\sim$ **4**.

step5 Calculate the amount of the particles(lava, volcanic ashes) which exist on the ground.

In this paper, we define eruption of each particle at each steptime. Also we take dynamic change of wind and temperature into consider. So this model can respond to the eruption of various scales.

4. Simulation

An example is shown in the case of square of 50km geographical feature data of circumferences of Mt. Aso in Japan. Table 2 shows the set of input parameters.

Figure 3 shows an image of the situation at 1 hours (1800 steps) after the beginning of eruption. The lower of Figure 3 shows the same situation under the small scale of eruption. We can see the smoke diffused in

Table 2. environment for simulation

wind	5m/s, northeast
temperature of atmosphere	300K
number of lava particle	5000
number of ashes particle	10000
number of smoke particle	5000
steptime	2 seconds
boxel size	500m
number of boxel	100 × 100 × 20

the atmosphere under the different scale of eruption. Figure 4 shows spread of lava. Figure 5 shows spread of volcanic ashes. The wind velocity of the lower of Figure 5 is set to 1m/s. From the result, we can easily see damaged area with spread of lava and volcanic ashes. It takes 63 minutes to simulate the situation at 1 hour after the beginning of eruption. The proposed method is one of the simplified version for volcanic eruption. So calculation time is reduced compared with the exact model.

5. Conclusion

In this paper, a modified particle system for volcanic eruption is proposed. In the proposed method, the movement of each particle can be determined according to external forces which works to a particle, and interaction of particles. Since the particle has its size, we can consider the change of volume and buoyancy by temperature of the particle for the movement of volcanic ashes. Also this method can be executed in combination with the geographic information. From the result, The damaged situation accompanying dynamically can be predicted by 2D and 3D images.

Since the various parameters were considered, the simulation corresponding to the scale of an eruption and change of the weather is available.

In the future work, it is necessary to consider the happening phenomena after eruption such as mud flood and pyroclastic flow.

Acknowledgement

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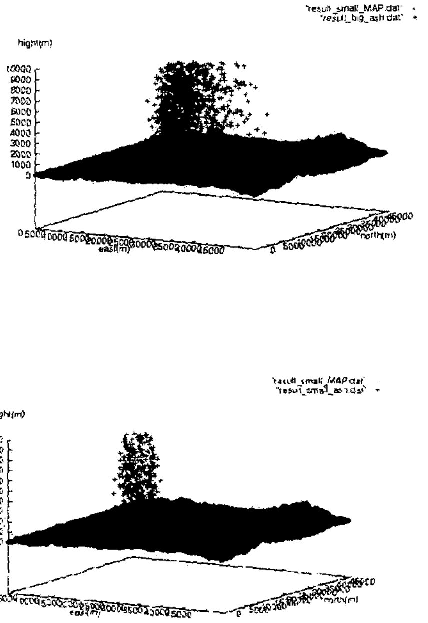

Figure 3. 3D image of eruption

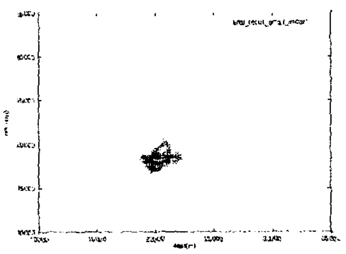

Figure 4. damage situation by lava

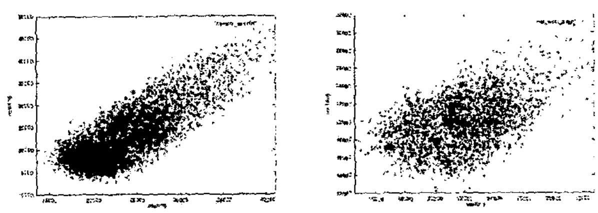

Figure 5. damage situation by volcanic ashes