An Active Model of Water Movement by Activity-Based Method for Simulation of the Virtual Environment

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Abstract

It provides a method which uses water movement to simulate diverse situations generated in virtual environments. The existing simulation models are limited to a fixed set of situations or focused on visual effects. Our model is based on diverse set of water activities that sense and react to geographical information acquired externally. Our model has three major elements such as water, environment and rules. This method makes water can act properly on diverse situations generated in virtual environments.
Keywords: virtual environment, water movement, various situations, activity-based, rule

I. Introduction

Water movement is an important part of the virtual environment. We suggest a water movement model which is based on its activities against diverse situations in the virtual environment.
There have been many simulation models for water movement in the fields of computer graphics, computer games, virtual reality, geology etc. Kass and Miller, Foster Mextax and O'Brien's models based on Navier-Stokes equations focused on realistic visual effects of water movement in the computer graphics field. Although these methods are excellent in visual effects, but they are applicable to only restricted situations [1],[2],[3].
Recently works in the Computational Fluid Dynamics(CFD) field use fluid dynamics for simulation to improve realism, but only with very high computation cost [4],[5].
The merge-split method has been proposed to overcome those defects. It models water in terms of particles and divides water state into static and dynamic state. And it applies appropriate water activities to each state. Because it adopted the particle system, it can represent water movement in detail but incurs expensive computational cost when representing large bodies like river or sea [6].
We proposed the lump system to overcome shortcomings of the particle system. It enhances the activities of merge-split model and makes the effects of activities to be reflected on their environment. In other words, water exchanges information with its environment in order to be applicable to diverse situations. Also, we propose internal action of water can affect physical

property of facing object. For example, if object met water, the object could be wet or absorb it and increases its mass.

This model can apply to other fluid such as oil, alcohol and acetone. In this case, it is necessary to adjust cohesion, adhesion and attribute values with the fluid. Besides, it also can be applied to a method using Navier-Stokes equation because our model has particle surface.

II. Related Works

A. *Particle System*

Many models have been proposed to simulate diverse natural phenomena such as a liquid, a gas, a wind, a cloud, a fire, an explosion carried out. Reeves used the particle system to model fuzzy objects such as an explosion, a fire, a cloud etc. It assumes that this system expresses liquid in terms of particle by connecting particles via relations with elasticity [1]. Such a relation impacts on one particle to propagate its adjacent particles and they in turn affect their own neighboring particles and soon [2].

An advantage of this system is to be able to represent changes due to external impacts in limited region, e.g., simulation of a flying flag in wind or moving water surface. However, this model is not adequate for continuous streams with inflow and outflow. Also, it cannot handle unrelated particles [3].

B. *Computational Fluid Dynamics(CFD)*

Computational Fluid Dynamics(CFD) simulates a natural movement of water by using physical equations to compute water movement. By using CFD, Foster and Fedkiw handles viscous liquid moving in 3D environment and improves interaction between liquid and solid objects. It also controls water movement through a control curve. Still, this method is limited with computation complexity [4],[5].

C. *Merge-Split Method*

Although merge-split method is based on the particle system, it doesn't focus on realistic description but concentrate on diversity of situations. Thus, it can lighten the computation cost incurred in CFD and achieve reasonable levels of logical reality (in contrast to visual reality). The system divides the state of water into static and dynamic. It represents water flow (stream, river etc) and water fall by using activities [6].

III. Activity-based Method

A. *Overall Structure*

The overall structure of the proposed system is shown in Fig. 1. The three components of this model are water, rule and environment parts. Each component has its own elements and those components reference each other for interaction. The rule part has the relevant physical laws for water movement to be used by environment and the water parts for their own activities [9]. The environment refers to the geography except water and the other objects in the virtual environment. That is different situations have different components. Water has three components such as the attribute, state and activities. It recognizes the situation of the environment, and carries out activities according to the state based on the rules. The results of carrying out the activities will affect water's own attributes and state. Also it could influence the environments as well.

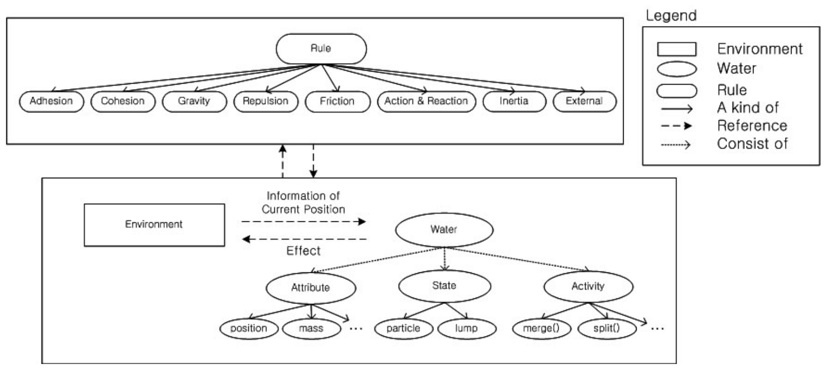

Fig. 1. Overall structure of simulation model [6]

B. ***State of Water***

There are particle and lump state as shown in Fig. 2. The particle state is suitable for representing a droplet or a rain drop. The shape of the particle is defined as a sphere. The mass and volume have constant values [7].

The lump state is suitable for representing large body of water like stream, river and sea, and allows its form to be changed according to the situation of the environment. The lump state is composed of the interior and the boundary as shown in Fig. 2. The interior has no fixed shape because it changes according to the boundary. The lump controller handles the positions and activities of the interior and boundary. The boundary allows us to identify the place where the activity occurs. The interior is used to perform activities related only to water movement and state change in order to model large bodies like river and stream. In other words, it is approximation of a water body made of merged particles. The lump controller controls the lump when the lump is changed in volume or mass, when the lump moves with performing activities, or when the boundary is to split from the lump [8]. The lump state is divided into the static-lump and dynamic-lump to distinguish stagnant water from flowing water.

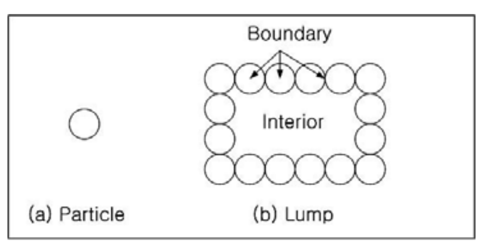

Fig. 2. State of water

The static-lump state represents water in stagnant with similar quantities of inflow and outflow such as water source, pond or reservoir. The container is an object walled in all directions except one in the opposite of gravity. In this case, the shape of water is decided by that of its container.

The dynamic-lump state represents a water flow like one in a river. Water body flowing from a static-lump has dynamic-lump state. The start-point and end-point specify the start and end points of water flow where the end-point changes according to the force. If a water body in the dynamic-lump flows into the container and remains still, it changes into the static-lump state [6].

C. *Attribute of Water*

The attributes to specify the position and properties are position, start-position, end-position, radius, length, height, width, mass, volume, velocity(vector), acceleration(vector), force(vector), condition(in-air, in-collision, on-object, in-object)

Water has different sets of attributes according to its state.

1) particle state

- condition, position, mass, radius, velocity, acceleration, force

2) static-lump state

- condition, mass, height, volume

3) dynamic-lump state

- condition, start-position, end-position, mass, height, length, width, velocity, acceleration, force

There is dependency among some attributes as shown in Fig. 3. Condition attribute reflects the spatial relation between water and the environment. With the attribute, we identify the associated values and evaluate them to obtain the forces. Position, velocity, acceleration values of water body will be updated according to the obtained force value instantly.

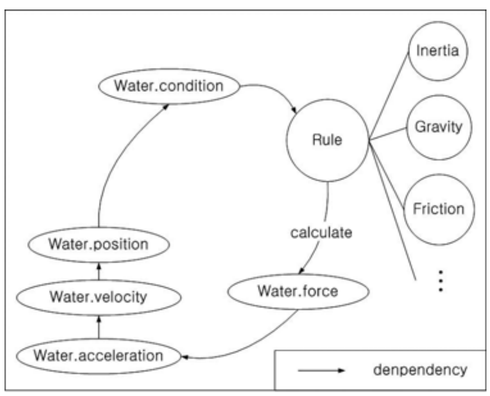

Fig. 3. Dependency between attributes with rule

D. *Activities of Water*

The activity is performed based on the associated rules and against the environment. We consider the gravity, inertia, repulsion, friction, action & reaction of rule at the position in the virtual environment to compute the force to work on the water [9]. The force value is calculated by the formula which applied differently according to current state or position of water. The position of water body is changed according to the force and it brings changes in water condition. And then water performs an appropriate activity to the situation such as merge, split, fall, collide, adhere, soak, flow.

1. **Merge**

When water body meets other water body, a merge activity occurs and the result is different from the state. After performing activity, attributes of a water body will be updated.

```
Algorithm merge
// W1, W2 : two waters in union //
// Pu : union position //
pre W1 meets W2
if  W1.state = particle and W2.state = particle then
    increase W1.cohesion and W2.cohesion toward each
    direction
else if W1.state = particle and W2.state = static-lump then
    increase W2.mass
    increase W2.height
    delete W1
else if W1.state = particle and W2.state = dynamic-lump then
    increase W2.mass
    delete W1
else if W1.staet = static-lump and W2.state = dynamic-lump then
    W2.end-point ← Pu
    increase W1.height
    increase W1.mass
else W1.staet = dynamic-lump and W2.state = dynamic-lump then
    W1,W2.end-point ← Pu
    fix W1,W2.end-point
    create new water Wn
    Wn.state ← dynamic
    Wn.attribute ← W1.property + W2.property
end.
```

2. **Split**

The split activity occurs only in the lump state. It occurs in case a water body is divided into two streams, or in case the particle dropped out of boundary by a soak activity, and a particle is peeled off from the interior to fill the resulting. If the water body becomes water drops in a waterfall since the base object ceases to exist for any reason, we need to create a new lump in order not to interfere with the flowing lump.

```
algorithm split
// B : boundary, I : interior, L : lump //
// O : obstacle //
// R : branch road //
// BO : base object //
if B satisfies precondition of adhere or soak or collide activity then
    create new boundary Bn
    Bn.property ← B.property
    decrease L.mass as B.mass
else if L.height ≤ O.height or R.height then
    create new two lump W1, W2
    W1,W2.state ← dynamic-lump
    W1,W2.condition ← contact-object
    W1,W2.start-point ← meeting-position
//The force of previous lump is divided into two directions with a ratio
M to N //
    W1.force ← L.force * M and W2.force ← L.force * N
    W1,W2.property ← environment.property
    fix L.end-point
else if L.end-point = BO.end-point then
    create new dynamic-lump DLn
    DLn.start-point ← BO.end-point
```

```
        DLn.force ← L.force + Rule.gravity
        fix L.end-point
    end.
```

3. **Fall**

A water body in the air will fall basically due to the gravity and inertia until it hits another object. We also consider other coincidental forces.

The wind force, a coincidental force, could be formulated as:

$$f_x(t) = f_x(t-1) - \mu mg + W_x \quad (1a)$$

$$f_y(t) = f_y(t-1) + mg - \mu mg + W_y \quad (1b)$$

where f is a force, x is the horizontal axis, y is the vertical axis, g is gravity, μ is a friction, m is mass and W is wind force.

4. **Collide**

The collide activity is performed in case an object collides with other objects after or during a movement like a fall activity. The position and velocity of a fluid after collision are determined by the velocity, direction, coefficient of repulsion and incident angle of the object. In case the repulsive force exceeds limit, it would be involved in another fall activity [7].

Forces are formulated as:

$$f_x(t) = e \times f_x(t-1) \times \cos(\sigma - \theta) \quad (2a)$$

$$f_y(t) = e \times f_y(t-1) \times \sin(\sigma - \theta) \quad (2b)$$

where e is coefficient of repulsion, σ is incident angle of the water and θ is incident angle of the base object [7].

5. **Adhere**

The adhere activity could occur in case water body contacts with other object as follows:

precondition : Water.state == particle & Rule.adhesion > Rule.gravity + Rule.cohesion
procedure : water body adheres to the face of the contacted object
effect : increase in wetness of contacted object

6. **Soak**

The soak activity is typically performed after adhere activity. When water contacts with base object, water particles filter into gap or porosity in the base object as follows (porosity refers to the percentage of porous space to the total volume of the base object):

precondition : Water.state == particle & baseObject.permeability > Water.volume
procedure : Set condition for in-object.
water soaks into the porous space or gap of the base object.
effect : increase in baseObject.wetness
decrease in baseObject.porosity

7. **Flow**

The flow activity is a method that water body runs on or through the base. The speed of water body depends on the current speed and the friction from the base as follows:

$$f_x(t) = f_x(t-1) + mg\sin\theta - \mu mg\sin\theta \quad (3a)$$

$$f_y(t) = f_y(t-1) + mg\cos\theta - \mu mg\cos\theta \qquad (3b)$$

E. *Qualitative Changes*

When the base object becomes drenched by a soak activity without dry portions left, the property of the base object can be changed in its materialistic natures. Basically, its mass increases as much as the water is absorbed in. The gaps among molecules could widen or shrink though their molecular properties differ from their object types. For example, if paper gets wet, it can be easily torn because water molecules occupy gaps among paper molecules leading to weaker attractive forces among those molecules. Further if the base objects was combustible, the soaked water will keep the base object from burning until the water dries up by heat.

F. *Internal Flow*

There is internal flow only in lump state. We represent it using moving average method. It means values calculated averages from the current position and the environmental position as window size. It makes the internal flow to flow upon landform properly and flow of liquid will be more flat the farther it gets from the ground. It is formulate as [7]:

$$Water.position(x,y) = \frac{\int_{-WINDOWSIZE.height}^{WINDOWSIZE.height} Environment.positon(x,y)dx}{2 \times WINDOWSIZE \times height} \qquad (4)$$

where Water.position is current position of the water, height is length between water and land, WINDOWSIZE is window size of moving average, Environment.position is current position of land.

We can compute net force of object in the water as shown in Fig. 4. Computation needs gravity, hydraulic power, buoyancy, friction and inertia. The inertia value comes from moving average.

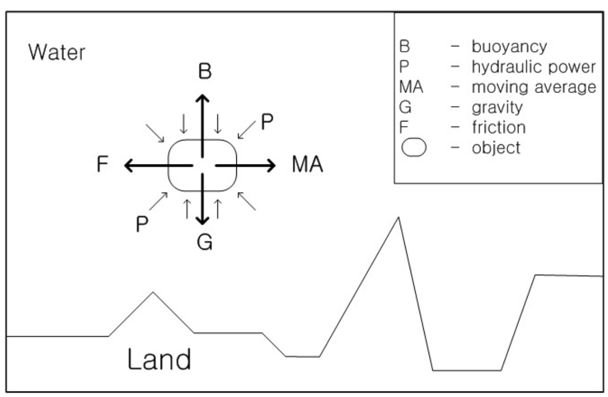

Fig.4. Object in water

Ⅳ. Conclusion and Future Work

We have proposed a simulation model for water movement which properly reacts to various situations. The existing simulation models are limited to a fixed set of situations or focused on visual effects. The proposed model is designed to be a comprehensive model in that it is focused on diversity of situations rather than realistic simulation of limited scopes. To dynamically adapt to diverse environment our model interacts with the environment, and performs activities based on strict physical laws. This model can be applied to various fields to use basic actions of water. As the future works, we are going to develop water surface movement and flow of inner boundary. Moreover, we will investigate the interactions with objects that float on or sink into water.

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