Rainfall Simulation in Maritime Scene

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Abstract. Meteorological simulation is an important part of navigation simulator. As a part of meteorological simulation, rainfall simulation has a direct impact on the simulation of final navigation scene. Particle system is an effective way to draw massive particle scene, the property of rain particles are analyzed based on the particle systems, then build the motion model, and control the generation and death properly by calculating the life cycle of the particles. By saving the hardware sources and improving frame rate, the result shows that the rainfall scene can run smoothly.

Introduction

With the rapid development of virtual reality technology and computer simulation technology, the simulation of large-scale scenes is more and more popular, and the pursuit of its simulation effect is also getting higher and higher, so the real-time weather simulation and rendering effects in large scenes increasingly demanding. Weather such as rain has an important influence on the fidelity of the final 3D scene. Therefore, according to the real variety of climate environment, simulate the real-time weather conditions, with a certain degree of practicality.

At present, most of the rain simulation particle system, it can more realistic simulation of the effect of the rain. But in a large-scale scene, a lot of particles must be used in order to simulate these effects in a realistic way. As the number of particles and the system real-time mutual constraints, so without affecting the simulation display, in order to reduce the occupation of computer resources, improve the frame rate of the scene and make the simulation of the scene more fluid. It has become a problem that the number of particles is as few as possible. Based on the requirement of real-time simulation of the scene simulation, the paper divides the rainfall area, analyzes and calculates various initial properties of rain particles, and calculates the rain motion model by the basic principle of Newtonian mechanics. Then analyze the changes of the updated attributes, and use the average life cycle to determine the demise of the particles and reinitialize the extinction particles. Finally, a natural climate scenario system that can simulate real-time rainfall process is established and implemented. It can achieve the frame rate of the normal operation of the navigation scene while meeting the real-time performance of particles.

Rain Particle System and Motion Analysis

Rain Particle System

Rainfall phenomenon does not have a certain structure, do not need to consider the interaction between particles, it is suitable to use random particle system. The rain particle system consists of a large number of raindrop particles. The properties to be considered for the entire rain particle subsystem are the number of particles, the particle generation area, etc.. The properties to be considered for a single raindrop are shape, size, location, color, transparency, speed of motion, direction of motion, life cycle, and so on. Particle system is dynamic. As time goes on, there are new particles added to the system and old particles to be dead. The position and life value of the “surviving” particles in the system also change with time. The key to their normal operation is to determine the initial properties of the particles, the changing rules of the particles, and the factors of drawing.
The following steps are done in each particle's lifetime: 1) Add new particle to stem after generated and given properties by the particle source. 2) Move and transform the particles based on the dynamic properties of the particles, in the meantime, update the particle properties. 3) Judge the value of the life of particles, and delete particles that have passed their life cycle. 4) Change the property values of remaining particle, based on the dynamic properties of particle properties. 5) Draw and display a graph of living particles.

The repeated cycling of steps 1-5 results in the particle dynamic change of the particle system.

**Motion Analysis**

**Rain Particle Initial Properties.**

1) Initial position

The particle settings are distributed in a rectangular area of height H, length L and width W, as shown in Figure 1. Let \((x_0,y_0,H)\) be a vertex of a rectangular region, then for any particle position \((X_i,Y_i,H_i)\) satisfy:

\[
\begin{align*}
X_i &\in [x_0, x_0 + L] \\
Y_i &\in [y_0, y_0 + W] \\
H_i &\equiv H
\end{align*}
\]

(1)

![Figure 1. Particle distribution diagram.](image)

2) Initial movement speed

Suppose that in the absence of wind, the rain particles descend from high altitude and set their vertical velocities at landing height H to be \(V_y\), the velocities in the X and Y directions are \(V_x\) and \(V_y\). Use it as the initial velocity at which particle emitters start to emit particles from a height of H. There is:

\[
\begin{align*}
V_x &= V_x = 0 \\
V_y &= V_y = V_0 \\
V_z &= V_0
\end{align*}
\]

(2)

3) Initial acceleration

The initial acceleration is the acceleration at which particle emitters produce rain particles, i.e., the acceleration at particle height H. The acceleration of rain particles due to the combined force of gravity and friction is \(a = a_x, a_y, a_z = 0.0\,\text{m/s}^2\).

**Rain Particle Attribute Update.**

During the process of landing, the rain does not rotate, and it is only used for free-fall movement at the beginning. When the air resistance of the raindrops is balanced with its gravity, the rain particles make a linear motion at a constant speed.
The position of rain particles at a time:

\[
\begin{align*}
    x &= x_0 + V_{x_0} t \\
    y &= y_0 + V_{y_0} t \\
    z &= z_0 + V_{z_0} t + \frac{1}{2} a_z t^2
\end{align*}
\]

\[(t < T) \quad (3)\]

\[
\begin{align*}
    x &= x_0 + V_{x_0} t \\
    y &= y_0 + V_{y_0} t \\
    z &= z_0 + V_{z_0} (t - T) + \frac{1}{2} a_z T^2
\end{align*}
\]

\[(t > T) \quad (4)\]

where \(x_0\), \(y_0\), \(z_0\) are the initial positions of X, Y and Z directions; \(V_{x_0}\), \(V_{y_0}\), \(V_{z_0}\) are the initial velocities of X, Y and Z directions (in equation (2)); \(a_z\) is the vertical acceleration; \(T\) is the time when the particle starts to make uniform linear motion.

**Life Cycle.**

Particles generated from particle emitters are the beginning of the life cycle. When the height of the particle is less than the height of the sea surface wave at the location of the particle, the life cycle of the particle is considered to be completed.

**Realization of Rainfall Simulation**

**Particle Generation Area**

In order to achieve better simulation results, we must study and consider the characteristics of human visual perception, simplify the model, remove the excess particles as much as possible, and reduce the computational load of the system. In the view we define the observer’s eye as the position of the viewpoint, while the human eye observes the object has the characteristics of a small distance in the near future, namely the perspective effect. Therefore, in order to improve the utilization of rain particles, only need to render objects in the human visual cone in the view, this paper made a certain division of the particles generated area. Figure 2 shows the human cone and particle distribution area schematic.

![Figure 2. Human visual cone and particle distribution area.](image)

where Eye is the location of the human eye, cone-shaped area is visible to the human eye area, the gray rectangular part of the figure that the rain particle rendering area. All the particles are distributed in a certain range within the view cone, so that each particle is displayed in the current screen, to maximize particle efficiency. Particles in the cone area in accordance with their own
attributes of motion properties update and movement, when the particles move outside the area, then the particle extinction.

**Calculation of the Average Life Cycle of Particles**

The particles are generated in a rectangular plane of height H. From equations (3) and (4), it can be seen that when the particle velocity \( v \) reaches a constant velocity, i.e. \( t = T \), assuming in the absence of wind, constant velocity \( \bar{v} \) satisfy:

\[
\bar{v} = v_0 + a_T T = V_0 + a_T T
\]

At time \( T \), the distance of rain particles from the ground \( s \) satisfies:

\[
s = z_0 - \left( z_0 + V_0 T + \frac{1}{2} a_z T^2 \right) = -(V_0 T + 1/2 a_z T^2)
\]

By the equation (5) and (6) we can get the average life cycle of particles:

\[
\bar{t} = -\frac{V_0 T + \frac{1}{2} a_z T^2}{V_0 + a_T T} + T = \frac{1}{2} a_z T^2
\]

**Methods of Particle Generation and Destruction**

The commonly used method to realize the generation and destruction of particles is to apply and release memory. The specific methods are:

**Method1**: Calculate whether each particle completes the collision[5] (Landing to the ground or water, etc.), or other conditions to achieve the experimental methods of deletion (such as beyond the scope of the observer’s cone[4]). It will be deleted from memory.

**Method2**: Calculate the average life cycle of particles[6]. For each particle, determine the survival time, if more than the average life cycle, delete the particle, and add new particles to maintain the total number of particles equal.

However, there are some shortcomings when the above two methods are applied in the context of this article. Method 1 collision detection for each particle, used in this article is running in each frame, respectively detect whether each particle height is less than the real-time sea surface height of the particle projected on the plane, and delete particles below sea level and add new particles. So that each particle should be based on the coordinates of its projection plane to get the height of the sea, greatly taking up memory, when the number of particles is more severe, restricting the visual fluency. Method 2 reduces the collision with the sea surface by judging the average life cycle. However, there are still a lot of particles die and new particles are added, the actual memory consumption and occupancy are still quite a few, and it is not conducive to continuous display of rainfall effects in large scenes.

On the basis of calculating the average life cycle \( \bar{t} \), this paper does not destroy the memory of the particle at the end of its life, but initializes its properties as a newborn particle. That is, when the life time \( t_i \) of a particle is greater than the average life cycle \( \bar{t} \), the particles that should be “dead” are given the same initial properties as the newly generated particle, and a simulation loop is performed so that it is no longer necessary to replenish new particles due to the extinction of a large number of particles.

**Simulation Experiment**

Process the simulation of rainfall on the computer of which CPU is Intel Core i5 3.20GHz, memory is 4GB, the video card is NVIDIA NVS 510 2G, and through the visual studio 2010 OSG 3D rendering engine. The experimental display window size is 1600 pixels*900 pixels. Compare with
methods 1 and 2 in Section 3.3 above and test the average frame rate (fps) achieved when using different numbers of particles for different methods, as shown in Table 1.

| Different number of particles (10^3) | 1   | 5   | 10  | 100 |
|--------------------------------------|-----|-----|-----|-----|
| This paper                           | 182 | 140 | 122 | 76  |
| Method 1                             | 124 | 107 | 91  | 8   |
| Method 2                             | 140 | 127 | 100 | 48  |

“Frame rate-number of particles” results shown in Figure 3.

The experimental environment is a dynamic ocean drawn by OSG, coupled with a simple terrain model and a sky box map background. Also, due to the rapid decline of raindrops, rain particles are relatively small, the human eye's vision to keep the raindrop particles as a line. In the calculation of the actual motion model, the sphere is used to represent the rain particles, but the length of the segment is used in the display to indicate that the raindrop more corresponds to the actual display effect.

Figure 4 is the simulation result of different particle numbers (PN) using proposed method.

![Figure 4. Rainfall scenario with different particle numbers.](image-url)
Conclusion

In this paper, the particle system is used to simulate the rainfall phenomenon in the navigation scene. The rainfall process is continuous and has a certain sense of reality. Considering the physical movement of rain particles, the particle generation area is limited to the cone of the human eye, which greatly reduces the number of particles that have no effect on the visual field before the observer. Also, the calculation of the average life cycle to determine the particle's demise, to a certain extent, reduce the individual calculation for each particle lifetime. Update the properties of new particle, such as the position, velocity and acceleration of the extinction particle, so as to reduce the memory operation due to particle generation and extinction. In the same hardware environment, the same terrain environment is set. Compared with other rainfall simulation methods, the experimental results in this paper can meet the simulation requirements of the marine visual scene and achieve a higher frame rate. The rainfall effect in the navigation visual scene is continuous, and the program can run smoothly.

Due to the requirement of drawing efficiency in this paper, the calculation of air resistance is greatly simplified in Newtonian mechanics-based analysis of the motion of rain particles, ignoring the change of its shape during the falling of raindrops. And the calculation in the collision with the sea is calculated by the average life cycle, lack of randomness, so that the effect of rainfall on the sea is not real enough. What's more, only the gravity and air resistance are considered in the motion analysis of rain particles, and the influence of the wind on the particles is not considered. All these need to be improved and improved in the follow-up work.

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