Research on Motion Simulation of Smoke Effect

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Abstract: This paper puts forward the factors related to smoke behavior, which include the speed of smoke movement, smoke temperature and the effect of wind on smoke, and describes the physical equation of each element by classification, simulates the information movement of each element particle reasonably, and generates the effect motion image of smoke by studying and using the most basic rendering algorithm. The simulation results show that the method is simple and effective for the simulation of smoke effect.

1. Introduction

In virtual combat games, the effect of smoke is a very common phenomenon in the game, such as the smoke produced by the burning of the target after being hit. So whether the smoke can be rendered realistically and in real time in the game will directly affect the reality of the virtual game [1].

2. Description of Smoke Behavior

Simulation of smoke behavior is based on the study of factors related to smoke behavior. Its factors include the speed of smoke movement, smoke temperature and the role of wind.

The first factor that affects smoke movement is smoke velocity. If the smoke enters into the air at a certain speed, because of the friction between the smoke and the air, the smoke will be affected by the shear force of the air and produce rotation and deformation, which will make the smoke and air mix and produce the effect of turbulence. The second factor that affects smoke movement is smoke temperature. In the smoke, because the buoyancy of the part with higher temperature is large, the rising speed will be faster [2]. On the contrary, the buoyancy of the part with lower temperature is small, and the rising speed will be slow correspondingly. Therefore, because of the difference in temperature, the smoke will also produce shear effect and diffusion. The third factor affecting smoke movement is the role of wind. If the smoke is driven by the wind, it will drift at a speed close to the wind speed in the horizontal direction, and the smoke will move upward under the action of air buoyancy.

3. Physical Equation Description of Smoke Movement

The gas compression of the smoke generated by the combustion of the object is basically nonexistent, so the smoke is considered as an incompressible gas. Then the Navier-Stokes equation can be described as:

$$\frac{\partial u}{\partial t} = v\nabla \cdot (\nabla u) - (u \cdot \nabla)u \tag{1}$$

In the formula, ∇ is the operator of shaving degree and u is the velocity of smoke movement. Therefore, the temperature of the smoke will increase, its density will become smaller, and the smoke will also generate buoyancy by the surrounding cold air. Its buoyancy is as follows:

$$F_k = -\beta g_v (T_v - T_k) \tag{2}$$

Where β is the expansion coefficient of the thermal gas, g_v is the weight of the smoke particles, T_k is the average temperature of the gas around the smoke particles, and T_v is the temperature of the smoke.

The temperature change of smoke particles can be described by the following differential equation:

$$\frac{\partial T}{\partial t} = \lambda \nabla \cdot (\nabla T) - \nabla \cdot T_u \tag{3}$$

The smoke rising force f_k can be expressed as:

$$f_k(t) = H \cdot (T(t) - T_e) \tag{4}$$

Here $T(t)$ is the temperature of the particle, H is the control parameter of the rising force of the particle, and T_e is the ambient temperature. In the gas field, the upward lift of smoke particles is caused by the rising process of particles themselves [3].

The above equations (1) to (4) can be solved accurately in theory, but the solution is very complex, which requires constant iterative operation of the difference equation, and the computational complexity is very high.

The smoke model described by Navier-Stokes equation is usually used for accurate simulation and visualization of smoke. The smoke in the battlefield environment only needs to satisfy the human's visual reality, and does not need to conform to the physical equation very precisely. In equations (1) to (4), equation (1) describes the diffusion process of smoke particles, equation (2) describes the initial buoyancy of smoke particles, equation (3) describes the temperature change process of smoke particles, and equation (4) describes the upward lift of smoke particles. In the movement of smoke particles, the rising force f_k, which plays the main role, is the driving force of the rising smoke particles. After analyzing the main factors that affect the movement of smoke, the following simplified method is used to describe the movement of smoke: only the rising force f_k of smoke is considered. In order to represent the diffusion of smoke particles, when painting the smoke particles, the dynamic smoke particle texture is used to represent the morphological changes in the diffusion process of smoke particles.

4. Motion Simulation of Smoke Particles

The temperature change of smoke particles is described by the following equation:

$$T(t) = (T_v - T_e) \cdot e^{-ct} + T_e \tag{5}$$

Here, $T(t)$ is the temperature of smoke particles, T_e is the ambient temperature, and c is the temperature decay control coefficient. The motion equation of smoke particles is as follows:

$$Ma(t) = f(t) \tag{6}$$

$$a(t) = dv(t)/dt \tag{7}$$

$$v(t) = dx(t)/dt \tag{8}$$

In the formula, M is the mass of smoke particles, $a(t)$ is the acceleration of particles, $x(t)$ is the position of particles at time t, $f(t)$ is the force on particles at time t ($f_k(t) = H \cdot (T(t) - T_e)$).

The difference of differential equation is expressed as:

$$v(t + \Delta t) = v(t) + \Delta t \cdot f(t)/M \tag{9}$$

$$x(t+\Delta t)=x(t)+\Delta t\cdot v(t) \tag{10}$$

Through equations (equation and equation 10), the position and velocity of particles at each time are obtained [4].

5. Drawing of Smoke

If the attribute of particle position is determined, the frame image can be generated by the rendering algorithm. In the process of rendering, the ball is used as the basic particle in the particle system to simulate the smoke movement. If the triangle mesh is used to approximate the spherical surface, there will be some problems in this process: firstly, more triangular patches will increase the cost of particle rendering; Second, in order to enhance the reality of smoke, it is difficult to avoid the seams of common edges in the process of texture mapping of ball particles, especially the large particle ratio will affect the visual effect of smoke. Moreover, the smoke particles also have the following characteristics: first, the density and density distribution of the smoke particles should be centrosymmetric, and the smoke particles have no fixed shape, so from any point of view, the shape of the smoke particles should be roughly the same; second, the motion of the smoke particles is similar, that is, the smoke particles generally experience the process of generation, deformation, diffusion and disappearance[5].

According to the above problems, a cross and two sides method is proposed to simulate the shape of smoke particles, which can not only meet the reality of visual effect, but also greatly reduce the cost of rendering. As shown in Figure 1:

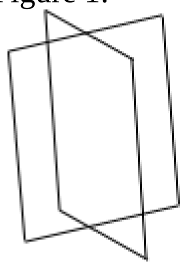

Figure 1 Shape of particle intersection

According to the similarity of smoke particle motion, we can express the change of smoke particle motion with dynamic texture [5].

In order to enhance the authenticity of smoke, the method of random disturbance is used to enhance the visual effect of smoke diffusion. The transparency is calculated by:

$$Alpha = Alpha1 * Alpha2$$

$$Alpha1 = 1.0-(r+g+b)/3.0+0.1*Rand()$$

$$Alpha2 = (T-T_e+0.1*\sin(T-T_e))/(T_{\max}-T_e)$$

$Alpha1$ is the texture transparency and r, g, b is the component of the texture color. T, $T_{\max}$, T_e represents the particle temperature of the smoke, the maximum starting temperature and the ambient temperature.

6. Simulation Effect

According to the above description of the smoke motion law, refer to the developed particle system toolkit, and simulate the smoke effect. Figure 2 shows the final smoke simulation.

Because the special effects will be embedded in the large-scale virtual scene finally, according to the model optimization theory of particle system, according to the observer's viewpoint distance to optimize the smoke particles, we get the multi-level LOD model of the smoke effect based on the viewpoint distance, and its effect is shown in Figure 3 – Figure 6:

Figure 2 Smoke simulation effect

Figure 3 Smoke effect at 1000 meters from the observer

Figure 4 Smoke effect 500 meters from the observer

Figure 5 Smoke effect 100 meters from the observer

Figure 6 Smoke effect 10 meters from the observer

7. Conclusion

According to the behavior mining of smoke, the expression of physical equation of motion of smoke, the simulation of particle motion of smoke, and the process of smoke drawing, this paper studies the simulation of smoke effect based on the developed particle system toolkit. According to the simulation results of 10 meters, 100 meters, 500 meters and 1000 meters, it can meet the requirements of real-world simulation.

References

[1] Y.C. Zhou, L.H. Fang, X.Y. Zheng, X.L. Chen. (2015) Virtual battlefield smoke special effect simulation based on particle system, Computer Simulation, pp. 417-420.

[2] H. Peitgen, H. Jurgens and D. Saupe. Chaos and Fractals, New Frontiers of Science, 1992.

[3] Y.X. Zhou, J.Y. Shi, J.R. Yu. (2006) Physics-based smoke animation. Journal of Computer Aided Design and Graphics, 18 (9): 1367-1371.

[4] Y.H. Pan, L.Z. Ma. (2009) Vodeo based simulation on realtime snow falling and accumulation. Journal of Computer-Aided Dsign & Computer Graphics, 2121(8): 1164-1169.

[5] A.Z. Li, J.N. Ren, W. Cui. (2010) Universal iterative solution for tridiagonal equations. Teaching and Technology, 12 (4): 33-37.