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Adaptive Simulation Method of Cloth Grid Based on Observation View Distance

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ABSTRACT

Cloth is everywhere in life, such as clothing, tablecloths, curtains, etc. In order to realize the fast simulation of cloth, an adaptive cloth simulation method based on observation angle is proposed. This method first uses a spring-mass model to simulate the mesh structure of the cloth, and then according to the distance of the observation angle, it adaptively controls the merging and division of the mesh to achieve the effect of accelerating the simulation. The experimental results show that the method can adjust the resolution of the cloth grid at the viewing angle, and by comparing the interaction between the ball and the cloth at different viewing angles, it proves that the proposed method can efficiently and stably simulate the cloth effect.

1. Introduction

Cloth simulation has always been a hot topic in computer animation research, and it is widely used in film and television special effects, large games and virtual reality. After decades of development in cloth simulation, research has made considerable progress in cloth modeling, physical simulation, and cloth rendering. Especially in recent years, researchers have explored many cloth simulation theories (e.g., Tamstorf et al., 2015; Ma et al., 2016; Cirio et al., 2017) and methods (e.g., Kim et al., 2015; Huber et al., 2016; Huber et al., 2017).

The study of cloth simulation started as early as 1986. Weil(e.g., Weil et al., 1986) proposed to simulate the shape of cloth by fitting catenary lines between hanging points and limiting points. Ng(e.g., Ng et al., 1996) used geometric transformation to simulate some special textiles, because the pure geometric method did not consider the physical factors of the cloth. Although it was highly efficient, it could only simulate hanging cloth. Terzopoulos(e.g., Terzopoulos et al., 1988; Terzopoulos et al., 1988) used the elastic deformation model of continuous media to simulate the true physical properties of cloth. Although physical models were introduced, cloth was not a continuous media material in a strict sense, and it could not simulate details such as wrinkles. Due to the huge amount of computational complexity of the continuous medium simulation, which caused the real-time simulation to fail to meet the requirements, Jiang(e.g., Jiang et al., 2017) regarded the cloth as a continuous material, and then used continuous medium mechanics to establish a physical model, but the simulation efficiency was still low. Provot(e.g., Provot et al., 1995) proposed a mass-spring method, which controls the shape of the cloth through the restriction between the mass and the spring, which not only can more realistically simulate the cloth structure, but also has high calculation efficiency.

Collisions occur when cloth interacts with other objects. In collision detection research, Teschner(e.g., Teschner et al., 2004) and Shapri(e.g., Shapri et al., 2009) use hierarchical enveloping to wrap objects, and improve detection efficiency by detecting whether boxes collide. Smith(e.g., Smith et al., 1995) uses octrees to detect deformable bodies with arbitrary motion in space. Volino(e.g., Volino et al., 2000) proposed a collision response model based on geometric correction method, which can effectively detect and handle multiple collisions. Carr(e.g., Carr et al., 2002) and Purcell (e.g., Purcell et al., 2002) gave a ray-triangle fast intersection test algorithm based on GPU ray tracing technology.

In order to improve the efficiency of cloth simulation, this paper proposes a method of adaptively controlling the resolution of the cloth grid based on the distance of the viewing angle, which realizes the effect of adjusting the grid resolution according to the distance of the viewing angle to improve the calculation efficiency under the premise of real simulation.

2. Cloth Modeling

2.1 Mass-Spring Model

The mass-spring model is a method of discrete cloth into many

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mass points. The mass points are connected by springs. The interaction between the springs and the mass points satisfies the classical laws of mechanics. For each particle, physical properties such as position and velocity are carried. For springs, there are three main types: structural springs, shear springs, and bending springs, as shown in Figure 1.

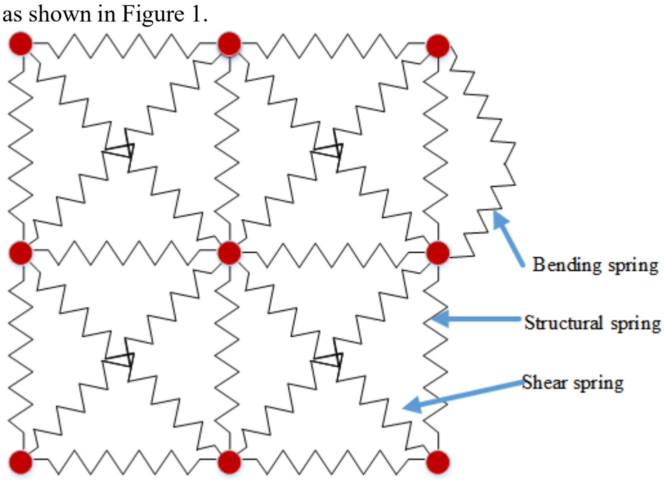


Fig.1. Spring type

2.2 Dynamic analysis of particle-spring model

In the mass-spring model, the state of the cloth is mainly affected by the position of the mass, and the position of each mass is solved by all the combined forces, which are mainly affected by the internal force of the spring and its own gravity. The internal force mainly includes the tensile force, the shear force and the bending force of the spring. These forces are solved by Hooke's law in elasticity. In order to simplify the force solution, the internal force of the spring and the amount of spring expansion and contraction are idealized into a linear relationship in the mass-spring model. For each mass point, the internal force of the spring is the combined force of all the springs connected to the mass point. Therefore, the elastic force experienced by each particle can be expressed as Eqn (1):

$$F_{elastic(i)} = -\sum_{j=0} K_{(i,j)} \left(\left| r_i - r_j \right| - l_{(i,j)} \right) \frac{r_i - r_j}{\left| r_i - r_j \right|} \tag{1}$$

In addition to the elastic force, the main forces acting on the cloth are gravity and damping force. Gravity is the most important force on cloth. The solution of gravity can be expressed as formula (2):

$$F_{gravity} = mg \tag{2}$$

where m is the mass of the particle and g is the acceleration of gravity.

The main function of damping force is to simulate the dissipation of mechanical energy in the particle spring model, to ensure that the cloth presents a relatively stable situation in the simulation process, and to prevent the phenomenon of cloth shaking caused by the too fast movement of particles. The direction of damping force is opposite to that of particle velocity, and the magnitude is linear with velocity. For damping force, it can be expressed as formula (3):

$$F_{resist} = \text{-}kv \tag{3}$$

Among them, k is the damping coefficient and v is the velocity of the particle. When the velocity of the particle is too large, the damping force will increase correspondingly, limiting the movement of the particle.

In addition, wind force is introduced into the simulation, and the solution of wind force in nature is more complex. In order to simplify the calculation, formula (4) is used to solve the wind force:

$$F_{wind} = \lambda N \tag{4}$$

Where λ is the wind coefficient, and N is the unit normal vector of wind force. According to the above analysis, the resultant force of the particle has the formula (5):

$$F_{sum} = F_{elastic} + F_{gravity} + F_{resist} + F_{wind} \tag{5}$$

2.3 Numerical solution of particle-spring model

The effect of cloth is mainly controlled by the movement of particles. The acceleration, velocity and position of the particle in the process of motion can be solved by the constant differential equation, generally by numerical integration. There are two kinds of numerical integration: explicit integration and implicit integration. The explicit integration method can directly calculate the motion state of the next particle according to the current known state. This method is simple in calculation and high in simulation efficiency. However, the implicit integration method needs to use the results of the next moment to solve the problem. In the process of solving the problem, the amount of calculation is large and the efficiency is low.

In order to improve the efficiency of the simulation, the display Euler method is used to solve the motion state of particles. For the acceleration, velocity and position of the particle, there is a formula (6):

$$\begin{gathered} a_i = F_{sum} / m \\ v_i(t+\Delta t) = v_i(t) + a_i \Delta t \\ r_i(t+\Delta t) = r_i(t) + v_i(t+\Delta t)t \end{gathered} \tag{6}$$

Where a_i represents the acceleration of the particle, v_i represents the velocity of the particle, r_i represents the position of the particle, t represents the current time, and $t+\Delta t$ represents the next time.

2.4 Collision detection and collision processing

In order to prevent penetration in the process of cloth simulation, it is necessary to detect and deal with the collision in time. In this paper, AABB hierarchical bounding box method is used for collision detection. When the bounding box collides, firstly, the parts that have not collided are removed, and only the impact area is analyzed. Then, the velocity and position of the cloth particles in the force area are solved. If the position of the particles penetrates, repulsive force is applied to the particles to prevent penetration and make the particles return to the collision surface of the area.

3. Cloth mesh adaptive method

In cloth simulation, the larger the number of meshes used, the more realistic the simulation effect will be, but the calculation efficiency will be reduced, and the smaller the number of meshes will improve the calculation efficiency, the simulation effect will be distorted. In order to ensure the computational efficiency in the simulation process, this section proposes an adaptive mesh division and merges method. During the observation of the cloth simulation effect, when the perspective is close to the cloth, a large number of meshes are used for simulation, showing more realistic details, and when the viewing angle is far away, only the approximate simulation effect can be observed, and a small number of grid simulations can be used.

3.1 Grid Resolution and Viewing Angle

In this paper, the grid resolution is divided into three levels, high resolution, medium resolution, and low resolution. The corresponding grid numbers are, as shown in Figure 2:

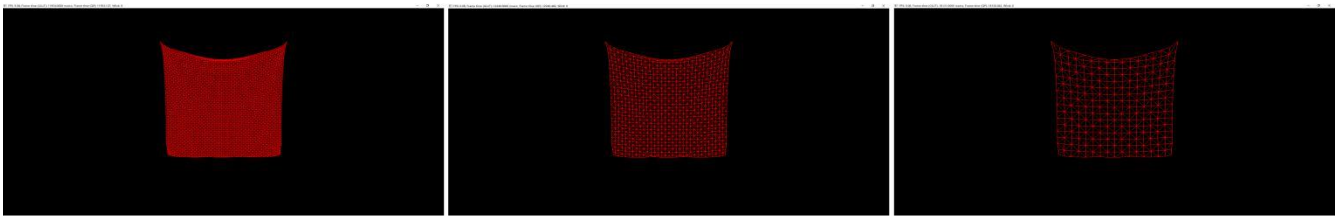


Fig.2. Effect of forming a cloth mesh with different resolutions

The viewing distance for viewing angles is also divided into three distances: within l_{close} meter, l_{close} meter to l_{far} meter, and l_{far} meter apart. Three of them are l_{close} and l_{far}, respectively, the minimum threshold and the maximum threshold when the grid resolution changes. The grid resolution mapping relationship corresponding to each distance is expressed as formula (7):

$$\begin{cases} Grid_{high} & l \le l_{close} \\ Grid_{middle} & l_{close} < l \le l_{far} \\ Grid_{low} & l > l_{far} \end{cases} \tag{7}$$

where l is the distance from the observation position to the center of the cloth, $Grid_{high}$ is high resolution, $Grid_{middle}$ is medium resolution, and $Grid_{low}$ is low resolution.

3.2 Cloth spliting and merging

When the angle of view distance changes to reach the threshold of resolution change, the grid adaptively changes to achieve the purpose of adapting the angle of view resolution. At the same time as the grid changes, the particle-spring model also changes, not only for the simple mesh The cells are divided and merged, and the changes in the properties of the particles and the spring are related to the surrounding particles and the spring.

3.2.1 Grid split

When the viewing distance is increased, the cloth simulation needs more details and the resolution of the grid is increased. That is, for a grid, it needs to be divided into four smaller grids, as shown in Figure 3:

During the grid splitting process, five additional particles and six springs were added. The properties of the springs did not change, mainly due to the changes in the particle properties. For multiple particles , the attribute quantity should be related to the surrounding attributes. The calculation formula of the attribute can be obtained by interpolation. The specific description is shown in formula (8):

$$\begin{cases} A_e = (A_a + A_b)/2 \\ A_f = (A_b + A_d)/2 \\ A_g = (A_d + A_c)/2 \\ A_h = (A_c + A_a)/2 \\ A_i = (A_a + A_b + A_c + A_d)/4 \end{cases} \tag{8}$$

Among them, the attribute represents the attributes such as speed, acceleration, and position, and the mass of a single particle must be recalculated using the relationship between the number of particles and the total mass. The specific calculation method is shown in formula (9):

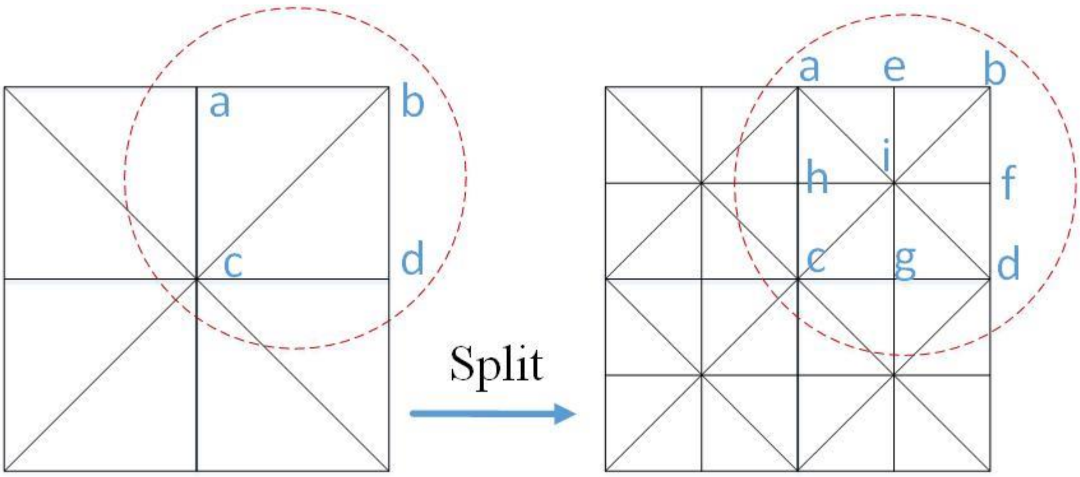


Fig.3. Mesh splitting process

$$m_{new} = m_{total}/n \tag{9}$$

Among them, m_{total} is the total mass of the simulated cloth, and n is the total number of particles in the new mesh.

3.2.2 Grid merge

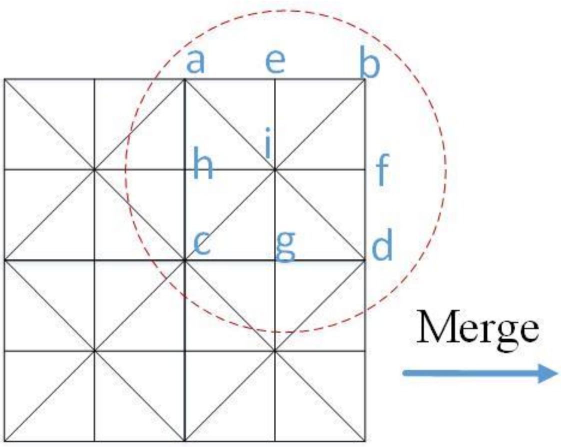


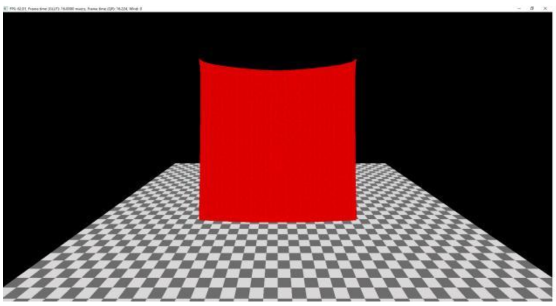
Fig.4. grid merging process

When the viewing angle is far away, it is not necessary to simulate the detailed effect with fine mesh, just simulate the approximate cloth prototype. The merging process of grid can be regarded as the reverse process of splitting process, that is, four small grids are merged into one large grid, and the merging process is shown in Figure 4:

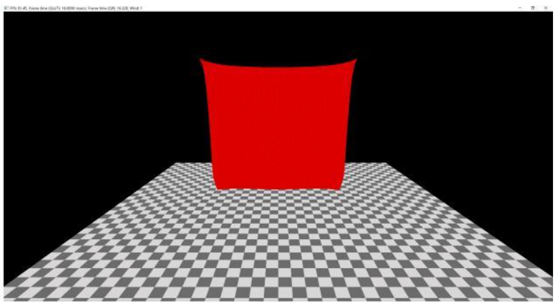
In the process of mesh merging, only the particles in the merged vertex attributes have changed, and other attributes remain in the original state. The calculation of vertex mass after merging can be obtained by formula (9).

4. Simulation results

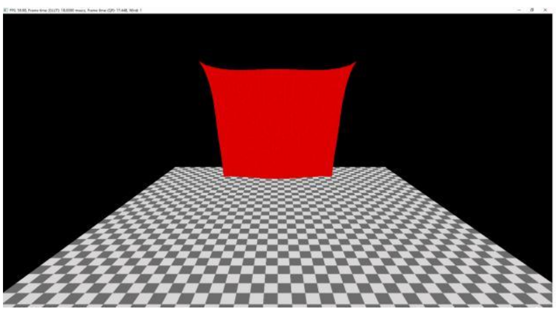
This paper builds a cloth simulation system based on the perspective grid cloth adaptive method. The simulation system experiment environment is set as follows: Inter (R) Core (TM) i5-7400 3.00GHz CPU, 4.00GB memory, GTX 970 graphics card. The programming environment is: Windows 10, Visual Studio 2013.



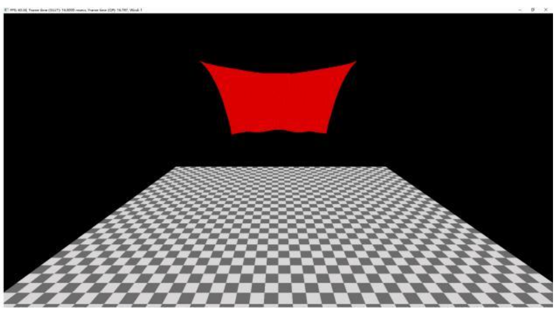
(a)Frame 0



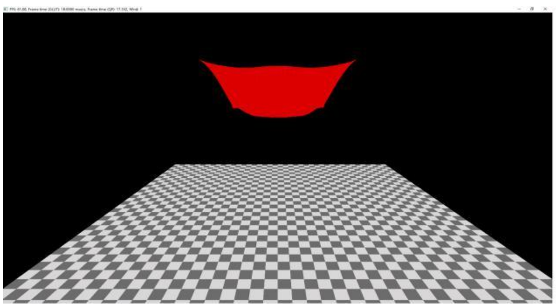
(b)Frame 100



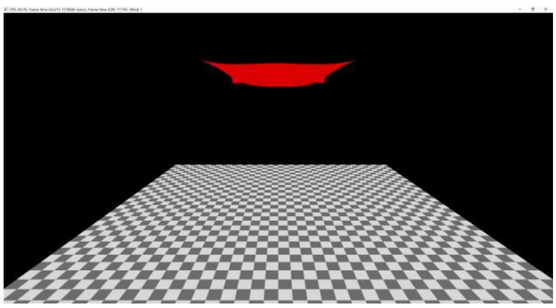
(c)Frame 200



(d)Frame 300



(e)Frame 400



(f)Frame 500

Fig.5. The effect of wind blowing the cloth parallel to the inside of the screen

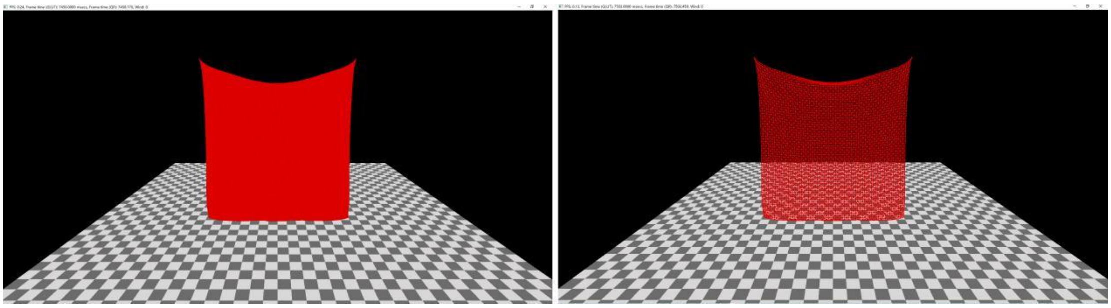
In addition, the important physical parameter settings in the cloth simulation process are shown in Table 1.

Tab. 1. Values of important parameters

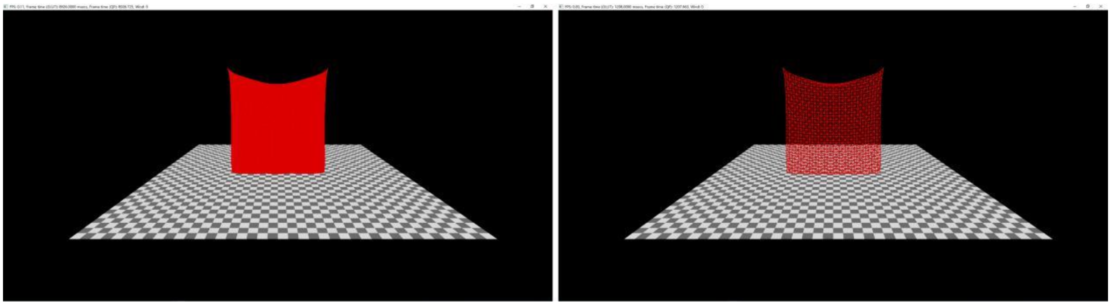
Experimental parameter	Symbol	Value
Damping coefficient	k	20
Wind factor	λ	1
Grid resolution changes the minimum threshold of viewing angle	l_{close}	$1m$
Grid Resolution Changes View Angle High Threshold	l_{far}	$10m$

Figure 5 shows the cloth simulation effect under windy conditions. The grid resolution is 64*64 and the observation distance is 1m. Starting from frame 0, a state diagram is extracted every 100 frames. It can be seen from a series of pictures that the cloth is in a natural drooping state first. Due to the effect of wind, the cloth gradually begins to flutter with the wind, and details such as folds and curls are formed. The effect diagram shows that the simulation method in this paper can simulate the cloth more realistically. Interaction with the wind.

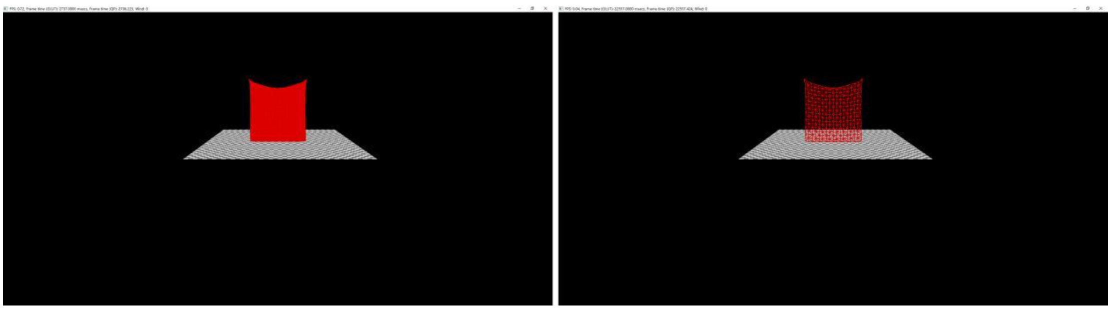
the natural vertical state without wind. Through comparison, it can be found that after applying the texture, the effect of cloth simulation is more realistic. The observation distance of sub-picture (a) is 1 meter. At this time, the grid resolution is 64 * 64. It can be seen that the cloth has formed wrinkles and has obvious distortion at the hanging place. The calculation time of each frame is about 54ms. The observation distance of sub-picture (b) is 5 meters. At this time, the grid resolution is 32 * 32. The simulated cloth has no obvious wrinkles. The bending formed at the cloth suspension is relatively gentle. The calculation time of each frame is about 16ms. (c) The observation distance is 10 meters. At this time, the grid resolution is 16 * 16. When the observation distance is far, only the approximate shape of the cloth can be seen. The bending traces are not obvious at the suspension. The calculation time of each frame is about 5ms. . Comparing the three sub-pictures, it can be found that the closer the observation distance is, the more realistic the cloth simulation effect is, producing more details, and the calculation efficiency is slower. When the observation distance is farther, the cloth only shows the



(a) The mesh resolution is 64 * 64, and the viewing distance is 1m.



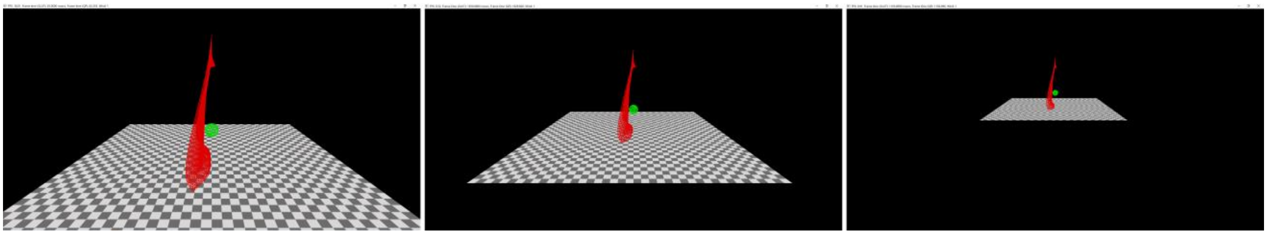
(b) The mesh resolution is 32 * 32, and the viewing angle distance is 5m.



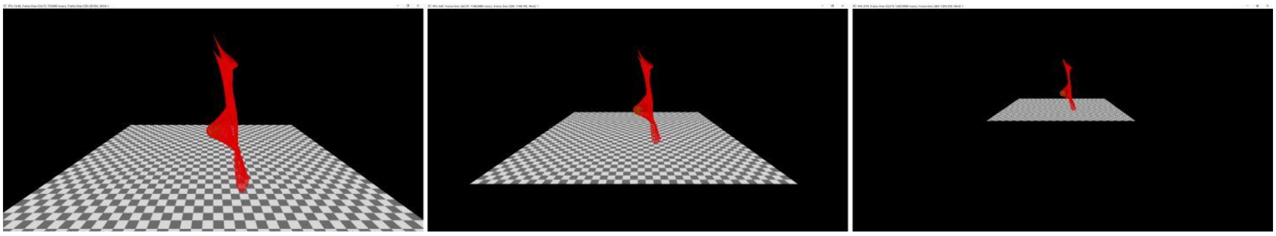
(c) The mesh resolution is 16 * 16, and the viewing angle is 10m.

Fig.6. The effect of wind blowing the cloth parallel to the inside of the screen

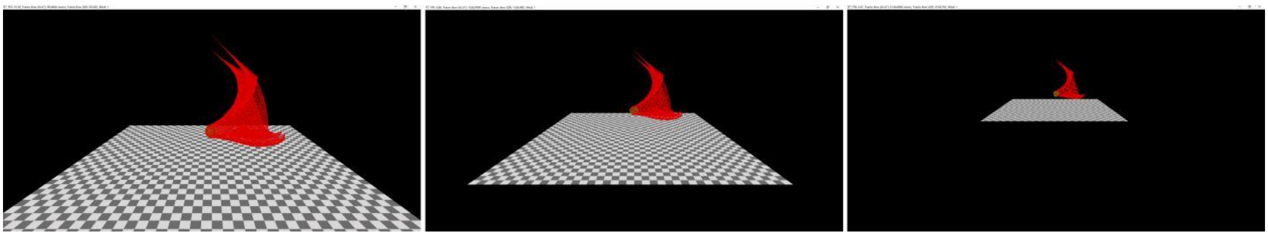
Figure 6 shows the effect of the cloth from different distances in approximate prototype, and the calculation efficiency is higher.



(a)Frame 100 collision effect between cloth and ball at different observation distances



(b)Frame 200 collision effect between cloth and ball at different observation distance



(c)Frame 300 collision effect between cloth and ball at different observation distance

Fig.7. Effect of viewing angle of cloth and ball colliding at different distances under wind

Figure 7 is the effect of collision between cloth and ball under wind. The sub-pictures (a), (b), and (c) are observed at 1m, 5m, and 10m when they are at frame 100, 200, and 300 respectively. Cloth condition. It can be seen from the figure that after the cloth collides with the small ball, it is obviously blocked by the small ball, and many folds are generated at the collision. In addition, the separation rate of the cloth grid at different viewing angles is also different. The simulation visual detail is better than long distance at close range, and the approximate shape of the cloth can be observed at a longer distance. From a series of pictures, not only can the real effect of cloth simulation be shown, but also the scientificity of the method in this paper.

5. Conclusion

In order to improve the efficiency of cloth simulation, this paper proposes a method to control the resolution of the cloth grid according to the distance of the viewing angle. When the viewing angle is close, the method simulates the cloth with a high-resolution grid, which causes poor folds and curls. Angle and other effects, when the viewing angle is far away, some details cannot be observed. Using a lower-resolution mesh to simulate the cloth not only simulates the approximate shape of the cloth, but also improves the computing efficiency of the simulation process. Several sets of simulation experiments verify that the method in this paper can simulate the cloth stably and realistically, and the applicability of cloth simulation is improved through the distance adaptive control mesh of the near and far perspectives.

This article currently provides three resolutions in terms of resolution. Subsequent researches will focus on a wider range of resolutions. At the same time, the accuracy and speed of collision detection is also one of the future research directions.

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