Real Time Cloth Simulation using Particle System and Bounding Volume Hierarchy

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ABSTRACT

Real-time clothing simulation is constantly being researched in and built to represent a virtual cloth that is similar as it would in life. Current issue in clothing simulation would be in the way to represent the cloth properties in the virtual environment in real time situation. The problem issue also increases when the cloth is required to perform inter-collision with other object that is static or even moving. This paper proposed particle system model and using self-created Axis-Aligned Bounding Box (AABB) group under Bounding Volume Hierarchy (BVH) to help in collision computation and also reducing the time needed to compute collision resolution. The result of experiment shows real time behavior of cloth able to produce a realistic motion with acceptable frame per second. The result shows that the technique is capable of running in real-time having an average frame per second that is higher than the border line of 25 fps. The current technique still can be improved especially to find the best collision detection time on cloth node checking time properly.

Keywords : *Cloth Simulation, inter-collision, physical system model, Bounding Volume Hierarchy*.

I. INTRODUCTION

Cloth simulation had always been in the field of interest for many researchers and also application developer which are mainly in the area of computer graphics. The process of producing the cloth are also a challenge for researchers as lots of obstacles are faced in the process of computing the best result for the cloth simulation. Over the previous years, many new techniques and algorithms had been introduced and together with the advancement of the hardware technology of the computing system, the modeling and simulation of cloth can be achieved in non-real time with very good and realistic results that shows the cloth behaving exactly the same as how it would in the real life.

The way cloth is generated and represented in the virtual world during the early years where computing system is not that fast is in the form of non-real time situation or under circumstances that the cloth is programmed accordingly towards a predefined reaction. As the general processing system had advanced from years to years, the ability for representing the cloth in the virtual world had increased a lot and also towards showing a more realistic cloth simulation process.

Major component that are part of the cloth simulation process are the component that handles or affect the cloth behavior in the virtual environment which most system uses a mass physical system. The cloth would be represented with its own properties such as mass, spring and force that are intended to be as close to real world properties of a cloth. Therefore, this component serves as the purpose which are much alike as in defining the cloth material and would be an important component as it would affect the rest of the simulation result. Other components that are involved in the simulation process would be the collision response system that functions in detecting collision between cloth (self-collision) and also with other object (inter-collision) to ensure the cloth would have its own volumetric space in the virtual environment and also behaving like a real world cloth.

The previous years of hard work and effort from researches around the world in references [4], [30] and [29] had benefit in the realism of representing cloth such that natural wrinkles which can be produced by using the particle model with the immediate buckling assumption and the robustness of handling collision that have been considered improved.

Those efficient algorithms that have been developed in many parts of the simulation and modeling field such as simulation cloth on virtual character animation and also in featured films as it provides a more convenient way for the animators to visualize the result with a reduced burden in producing the animation if compared to using hand. Fashion industry also gain interest in the use of cloth simulation to predict the motion and drape of specific fabrics which indirectly would reduce the need to manufacture the specific garment for the sake of viewing its effect, thus, making it easier for garment designers and textile engineers to work with fabric in a cost efficient way.

Therefore, cloth simulation in real time would be a major benefit in lots of computer graphics field and compromising also for non-computer graphics areas. Although the speed of simulation is currently at a reasonable speed that can be accepted in animation and simulation field, the clothing simulation still cannot produce the motion of cloth to a satisfactory state even when the process of simulation takes into account only the basic fashioning features such as cutting and sewing in the garments construction part. Fast, accurate and general techniques are the ideal for a realistic and attractive result. With significant advances have been achieved, the cloth simulation still remains an active area of research while providing lots of new ways to explore into and experiment with from different simulation view.

II. RELATED WORK

Cloth simulation began in the year 1930 in the textile engineering community. Extensive research has been put into this field to produce a realistic cloth in the virtual environment. Among those researches were such as simulation of garment quality, real-time simulation, and efficient collision resolution technique. Most of the simulation aims was to develop a physical based method that can represent cloth properties that is stable when dynamically represented. Moreover, the realistic of virtual cloth is added with the implementation of complex collision resolution technique to represent cloth that behaves as a real cloth.

A. Cloth Model

Reference [7] argued that cloth is not a homogeneous material but a mechanism of threads woven into an interlocking network and the fabric is not held together by molecular bonds but by friction. Euler integration method has been the standard way to use with particle system model as it calculates the time history of the particle trajectory efficiently.

As cloth simulation takes into consideration of internal and external force which may account to large force magnitudes, the integration method will not be suitable as it will be unstable and undesired result might occur as stated in reference [3] where they used Implicit Euler Integration. The downside of using Euler integration increases when collision handling is involved as the particle trajectory result will be unstable. Reference [18] suggested that each particles velocity within the objects should be corrected after each time step using the equation shown below:

$$v_j^m = \frac{x_j^m - x_j^{m-1}}{dt} \quad (1)$$

where v_j^m represent the velocity of the particles, x_j^m and x_j^{m-1} represent the positions at the current and the previous time step and *dt* represents the infinitesimal time step. As to achieve a more numerically stable model when considering particle position at difference time steps, verlet integration method is being introduced where the position of the particle is computed without using any velocity term. The method of verlet integration is shown as below:

$$x_j^{m+1} = x_j^m + x_j^m - x_j^{m-1} + dt^2 \frac{f_j^m}{n_j} \quad (2)$$

where f_j represent the accumulated external forces and n_j represent the particle mass. With this equation in 2, the cloth particle system can be introduced with damping force that could affect the appearance of the cloth as small amount of dragging effect can be achieved. The equation in 3 with the used of damping force is shown as below:

$$x_j^{m+1} = x_j^m + (1 - \kappa_d)\left(x_j^m - x_j^{m-1}\right) + dt^2 \frac{f_j^m}{n_j} \quad (3)$$

B. External Force

External force such as aerodynamics and friction will help in producing realistic cloth simulations. The model that have used for air resistance is a simple one, similar to in reference [9], where the force on each particle is:

$$F_{air} = \frac{1}{2} p c_w A(\hat{n} \times v_{rel})\, v_{rel} \quad (4)$$

where, *p* represent specified weight of air, c_w represent resistance coefficient, *A* represent surface area represented by the particle, $\hat{n}$ represent unit surface normal at that point and v_{rel} represent the velocity of the particle with respect to an ambient wind vector. Reference [12] can be referred to for a more realistic treatment of aerodynamic effects in cloth simulation.

III. CLOTH COLLISION DETECTION

A widely used method for detecting cloth collisions is to put small repellent proximity forces between the cloth surface and the deformable rigid or cloth surface as describe by [4], [1], [19], [3], [7] and [24] while the actual collisions are tested with pairs of particle-face or face-face of the current positions.

Bounding Volume Hierarchy (BVH) can be easily employed to accelerate collisions among the BVs that are used widely to build coarse representations of the objects are spheres in references [13], [25], [20], [16], [5], [10] and [6], Axis Aligned Bounding Boxes (AABB) in references [23], [22], [27],[26]and [30], Oriented Bounding Boxes (OBB) in references [25], [8] and [11], Oriented Convex Polyhedra in references [21] and [2] and Hybrid Combination Bounding Volume in references [22] and [15]. Most researcher in 3D simulations used bounding box because it has a simple box, require small space of storage, fast response of collision and easy to implement. Refer in reference [17].

IV. BOUNDING VOLUME HIERARCHY

After the cloth and ball model have been created, the BVH for each model will be created. The cloth model will have a different BVH primitive grouping but the approach for creating and traversing both BVH will be the same. The BVH will be created using a top-down approach that subdivides the current space that holds the whole primitive object.

The first part of the computation process would be to create the bounding box for the vertex points of the cloth for collision resolution purpose. All of the cloth vertex point will be bounded with bounding box first which is also known as leaf node.

The second step would be to create a main bounding box that bound the whole cloth vertex point and recursively subdivide into 8 child node where each child node will contain the bounding box of the primitive intersecting in it. When the child node is less than 8, no more subdivide of the space is done. Therefore, there exist only 1 bounding box first and all child bounding box are linked together in a hierarchical tree since it will provide the smallest number of overlap test for collision and for the purpose of preventing all collision checking with each bounding box at each frame.

V. CLOTH MOVEMENT

The cloth model will use verlet integration which uses time step and constraint satisfy to govern the cloth movement and effect. The type of physical mass computation will be taken into consider is the spring force and each cloth vertex point will be treated as a node.

The spring calculations will consist of four steps as stated below:

1. For each node, calculate the resultant force from all the springs it's connected to.
2. For each node, calculate an acceleration (based on the force) and a velocity.
3. For each node, loop through all polygons and check if they collide.
4. Place nodes which should have a fixed position to that position.

After making movement towards the cloth vertex particle, constraint operation will be carried out for each linked particle under the strut and diagonal method used. The two particle that are linked will check their distance between them with the initial rest length that is stored and if the distance is too large, both movable particle point will be move closer to each other and vice-versa if the distance between them is too near.

The constraint operation will be carried out for a number of times to achieve better result of the cloth movement but will have a considerable default number that ensure the application will not use too much time in this constraint operation computation. The particle movement for the constraint operation will follow the pseudo-code in Figure 1 where each particle will move half the distance back to reach its original rest length:

```
ParticleNode = p2 - p1;
ParticleNodeLength = sqrt(ParticleNode * ParticleNode);
NodeDist = ParticleNodeLength * (1- RestLength/
ParticleNodeLength);
Node_Half = NodeDist /2;
p1 += Node_Half;
p2 -= Node_Half;
```

Figure 1 Pseudo-code of the constraint operation.

VI. INTER-COLLISION CHECKING

The process of testing AABBs intersection or overlapping will be carried out on each pair of node and only the intersected node will have further test carried out on their children nodes by traversing the hierarchy tree. Van Den Bergen G. (1997) concept of traversing hierarchies will be used and the procedures are outlined as follow:

- If the current nodes for both objects are leaf nodes, then the primitives bounded inside will be tested for the occurrence of intersection to determine whether collision occurs. If collision happens, then further collision resolution will be performed.
- If the current nodes are leaf nodes and the other is an internal node, then the leaf node is tested repeatedly for the occurrence of intersection with the children of the internal node and the process stop when a leaf node is reached.
- If the current nodes for both objects are internal nodes, the node with smaller volume size is tested for the occurrence of intersection with the children of the node with the larger volume size.

Triangle-point intersection test will be carried out if both BVH object are leaf node. The point for the cloth vertex particle will be check first to see if it is penetrating the triangle of the model. For example, (x,y,z) of current point location and (x',y',z') of previous point location from cloth will be check with $\vec{X_1}\ \vec{X_2}\ \vec{X_3}$ of the triangle by shooting a ray in the direction of old cloth point position to current cloth point position ($\vec{X_4}$). If the ray intersect the triangle by passing through it, the barycentric coordinate (w_1, w_2, w_3) for the triangle will be computed. The barycentric coordinate can be computed using the following equation:

$$\begin{bmatrix} \vec{X}_{13} * \vec{X}_{13} & \vec{X}_{13} * \vec{X}_{23} \\ \vec{X}_{13} * \vec{X}_{23} & \vec{X}_{23} * \vec{X}_{23} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} = \begin{bmatrix} \vec{X}_{13} * \vec{X}_{43} \\ \vec{X}_{23} * \vec{X}_{43} \end{bmatrix}$$

$$w_1 + w_2 + w_3 = 1 \tag{4}$$

Equation 4 will be used to find the third coordinate of the barycentric and with this 3 coordinates, the new point $\vec{X}_5$, with coordinate $(x^t,\ y^t,\ z^t)$ that lies on the triangle plane which the ray intersect is computed using the Equation 5 below:

$$\begin{aligned} x^t &= w_1\overrightarrow{X_1} \\ y^t &= w_2\overrightarrow{X_2} \\ z^t &= w_3\overrightarrow{X_3} \end{aligned} \tag{5}$$

The next step would be to check which point ($\vec{X}_5$ or $\vec{X}_4$), is nearer to the old cloth vertex point. If the new point is nearer, the collision will resolve with moving the current cloth vertex point location to the location of $\vec{X}_5$ + *length* of the cloth thickness * the direction from the old cloth vertex point to the new point.

If the new point is further, then current cloth point will be used to check if its distance to the new point is less than the cloth thickness. If the distance is smaller, the current cloth point will be corrected to a new position based on how near it is from the new point.

VII. RESULT

Figure 2 shows the cloth model BVH of different level. Cloth BVH leaf node box in red color that represents collision being detected and collision resolution approach being carried out.

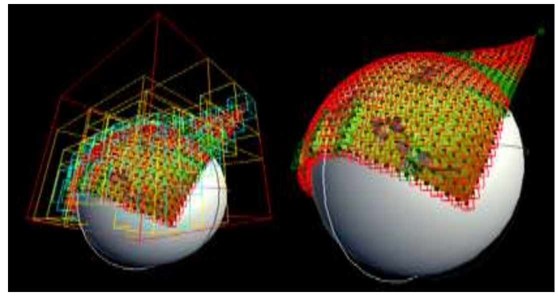

Figure 2 Cloth BVH for level 1 to 5.

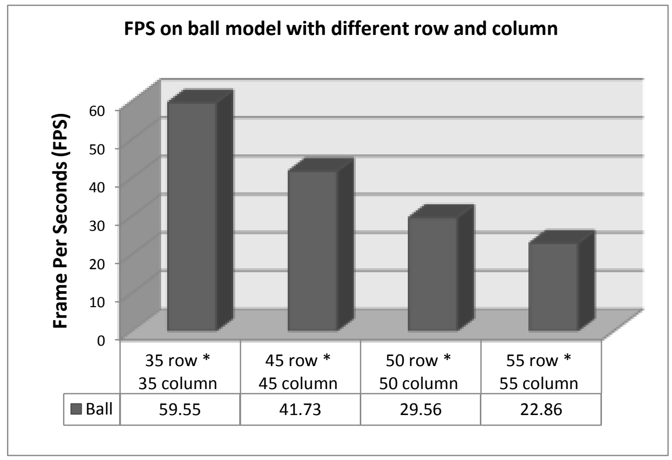

Figure 3 Cloth simulation's FPS on ball model with different row and column used

Figure 3 shows that a 50 row and 50 columns of cloth particle is recommended to provide a smooth viewing of the simulation. However, the result varies if a more powerful hardware is used for the simulation and normally, allowing a higher value of row and column to be achieve before the FPS drops below the border line for real-time

VIII. CONCLUSION

This project will start with creating the cloth object, constraint between the particles, the cloth BVH object and followed by extracting the model's data and creating the BVH for the model object. It can be carried out in large time step as the constraint between the particles has been used. Updating the cloth particle position will be carried out based on external force like gravity and wind. This project also provides inter-collision detection and collision resolution to ensure the cloth stays on the surface of the ball model

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