DYNAMIC CLOTH INTERACTION INCLUDING FAST SELF-COLLISION DETECTION

Nur Saadah Mohd Shapri 1, Abdullah Bade 2, Daut Daman 3
1,2,3 Department of Computer Graphics and Multimedia, Faculty of Computer Sciences and Information System, Universiti Teknologi Malaysia, 81310 Skudai, Johor.
nursaadah5@gmail.com 1, abade08@yahoo.com 2, daut@utm.my 3

ABSTRACT

This paper describes interactive simulation of cloth which can be used in certain applications such as games, animation, virtual reality, medical and Computer-Aided Design (CAD). In order to create high quality of cloth simulation, we use a mass-spring system, which is the universal model in cloth simulation. For the animation of the particles, we considered internal and external forces to create cloth to look more realistic. As cloth simulators, to handle the cloth self collision is more complicated. So, several methods have been suggested by numerous researchers. Furthermore, we discuss numerous methods for an efficient avoidance of self collision detection. So that the efficiency animation of cloth can be improved much.

Keywords: cloth simulation, physically based modeling, collision handling, interactive application.

1 INTRODUCTION

Cloth has a few unique features. The features consist of flexible, elastic and easy to pleat and shape. Therefore, it is no wonder if there are many researchers interest to study the structure and their characteristics. The characteristics are very complex to simulate and difficult to elaborate and making their prediction. According to Volino et al. [1], computation algorithms have been developed over many years and do not only simulate static clothes but also complex moving garments. There are two types collision in cloth: cloth with environment and cloth with cloth. Collision for complex cloth sometimes the researchers encountered a period of difficulty to construct stable cloth model, strong and realistic.

Collision handling becomes the most important issue to avoid penetration between object animation. It is usually one of the bottlenecks in real-time animation. In addition, collision in virtual environment is one live natural nature in object. It is usually classified into three phases. First phase is identifying either existing collision between object. Second phase is determining point true position collision and third phase is generating reaction collision based on object qualities. Most of previous works, various of techniques were produced by researcher in their finding and solution which is related to collision. However, these techniques mainly suitable for certain environment only depend on the object and the physical property in certain applications such as robotics, animation, virtual reality, medical and Computer-Aided Design (CAD). Robotics technology usually involves study in solid object. Generally, collision between solid object can be changed the position, object direction and speed. This happened when the higher pressure imposed on object collides.

Using the physical based cloth modeling, Weil [2] defined a cloth animation using an approximated model based on relaxation of the surface and approaches a two-step process to model the rectangular cloth structure hanging from constraint points. This approaches creation more realistic cloth model and their algorithm can be improvements in the time and space. Kunii and Gotada [3] used a hybrid model to model garment wrinkles. Haumann et al. [4] simulate animation focused on flags moving in the wind. Aono [5] simulate handkerchief using an elastic model. [6, 7, 8] Interaction of clothes with synthetic actors in motion marked the beginning of a new era in cloth simulation in more complex situations. However, there were still a number of restrictions on the simulation conditions on the geometrical structure, imposed by the simulation model.

Another way to approach cloth simulation is work on deformable objects by using more specific mechanical simulations such as triangular grids, polynomial surfaces [9, 10] and particle systems [11]. Baraff et al. [12] used the Implicit Euler Integration method to compute cloth simulation in real-time. The bottleneck of real-time cloth simulation is the fact that the time-step must to be
small in order to avoid instability. They described a method that can stably take large time steps.

As mentioned in the previous section, self-collision detection usually relates to flexible objects. For example for cloth modeling, Baraff and Witkin [9] proposed a technique that is able to handle large time steps (see Figure 1). They proved that using hybrid technique, a combination of implicit integration method with special enforcement to cloth particle was stable even though the system underwent large time steps.

Recently an algorithm for fast processing for collision which also models cloth rubbery was mentioned [13]. The simulations shown in the paper are really fast and proposed the efficient method of cloth animation. The proposed approach was able to deal with constrained particle-based model. By allowing the algorithm to process several number of constraints, limitation of the tensile length of the stretch and shear connection, the realistic look of cloth modeling can be produced. Furthermore, to ensure that the process can be done efficiently, most of the unwanted particles were removed using the bounding sphere hierarchy.

2 OVERVIEW

This paper tries to describe an algorithm that is able to simulate a piece of real time cloth. To achieve the high degree of natural motion of cloth simulation for wrinkle and twist cases, collisions with self collision are handled.

Self collision detections usually have various issues that must be resolved in order to come out with good collision detection algorithm. Our first challenge of course the complexity of mathematic computation. Self-collision detection considers both intersection of surfaces comprising the objects and other objects. Durupinar [14] strongly stated that self-collision detection is a special case of collision detection where both of the intersecting geometrical primitives are located side by side. In other words, these primitives are the collection of geometrical primitives that create the deformable object. Series of tasks are going to be faced such as detecting multiple collisions, collision consistency and adjacency in primitives and bounding boxes. In this situation, the propose algorithm and technique should robust and efficient enough to handle various type of collisions setting simultaneously.

In particle system, cloth is represented by a set of particles and each of particles is connected by internal and external forces. In our algorithm, we handle internal forces which inspired from Provot [15]. Provot [16] mentioned that using classical model, unrealistic deformations will occur at the constraint points. So, the stiffness could be increased. To solve this problem, Provot [16] proposed a mass-spring model in those springs around the constraint points to determine if any exceeded the predetermined threshold.

The external forces like gravity are applied straightforward, which able to push in the direction of the negative y axis equally on all particle in the cloth.

![Figure 1. Top row- Cloth draping on cylinder. Second row- Sheet with two fixed particles. Third row- Shirt on twisting. Bottom row- Walking man [12]](image)

3 CLOTH SIMULATION

In cloth simulation, there are many factors to generate wrinkles cloth simulation more realistic and stable such as by considering the suitable physical model, handling interaction between particles, checking the collision detection for each particle and consider the internal or external forces [17]. Terzopoulos et al. [18, 19]; Volino [1] and Baraff [12] also considered cloth as rectangular mesh to support the need of wrinkle cloth to be modeled realistically. On the other hand, Breen et al. [11]; Provot [16]; Choi and Ko [17] and Bridson et al. [20] used cloth as mass-spring model to simulate cloth. Currently, mass-spring model is the most popular model to simulate cloth compared to other techniques. In cloth physical model area, Terzopoulos et al. [18] proposed the first physical model for cloth simulation. Carignan et al. [6] modified this model by adding damping and collision-handling features. Breen et al. [11] developed a non-continuum particle model for predicting cloth drape. Eberhardt et al. [21] modified the model of Breen et al. [11] to create a dynamic simulation method based on a Lagrangian formulation. Volino et al. [1] developed
a cloth model based on elastically theory and used a Newtonian formulation as an alternative of Langrangian formulation. Eischen et al. [22] modeled cloth using non-linear shell theory as a standard nonlinear finite element procedure was used to find the system equation. Since Baraff and Witkin [12] ongoing using the semi-implicit method, the technique has become of a popular technique for integrating the equations of motion in cloth simulation by [23, 24]. Desbrun et al. [25] technique precomputed the opposite of the basic Hessian Matrix to make likely real-time cloth simulation. Kang et al. [26] designed the semi-implicit method that avoids the precomputing the basic Kessian matrix and large linear system.

Based on the issues that have been discussed before, physical based models have been used widely to improve the quality of the cloth model. Choi and Ko [17] showing that those models from a post-buckling instability that can be challenging when wrinkles are created and is therefore independent of the numerical method employed. His research assumed that application of a compression force on cloth directly buckling rather than compression. These simulations produced realistic wrinkles without the post-buckling instability.

Our goal is to simulate the arbitrary cloth. Therefore we decide to use triangular mesh for representing the cloth. The edges of triangular mesh represent the structural springs and the vertices are the particles. Figure 2 shows the particle connections with three spring types. Structural springs give cloth look like the basic shape. However, the shear springs prevent the particles to look unnatural shape and always stable on their plane and the flex springs allocate the cloth to bend more easily. The connected of particles are treated as springs that give the cloth elastic behavior.

The equations that manage out model are very simple. Newton Second Law of motion $\dot{F}_{\text{total}} = m\ddot{x} = \frac{d^2x}{dt^2}$ can be used to simulate the mass spring thus only requires computing force for each mass point. For each mass, the total force damping and external forces is generated using the Hooke’s Law $F = k\Delta l$, where $k$ is the spring constant and $\Delta l$ is the displacement spring from original length.

To set up our equation for position and velocity, the standard equation can be used.

$$\begin{align*}
\frac{d\ddot{x}}{dt} &= \ddot{v}(t) \\
\frac{d^2x}{dt^2} &= \dddot{x}(x) \\
F_{\text{total}} &= \sum (k, \Delta l) - \ddot{v}(t). d + F_{\text{external}}
\end{align*}$$

$F_{\text{total}}$ is the total force on mass m at position $x$ and velocity $\dot{x}$.

$k$ is the springs stiffness constant

$\Delta l$ is the displacement stiffness constant

d is the damping force acting

To handle equation 1, we have to split the two types of forces (external and internal) which are giving affected to the particle.

$$F_{\text{total}} = F_{\text{internal}} + F_{\text{external}}$$

After that, we will discuss how to deal between the internal/external forces and springs. Finally, we will show how to calculate the much shift of particle position within some small amount of time.

### 3.1 Internal Forces

Internal force is the main forces that move and perform the cloth behavior. [11, 21, 1, 12, 27, 17] has been done to develop models to look realistic cloth. Most of their models consider the shear, bending and stretch properties. To give explanation for our model, let we begin with simple model mass-spring system, which is the universal model in cloth simulation. This model simulates cloth more realistically than the others.

The interaction for each particles is handled by linear springs. So, in order to stretch the spring and acts in the opposite direction of stretch, the equation force $F_{ij}$ on a mass point $p_i$ connected to another mass point $p_j$ as a linear elastic spring shows follow:

$$F_{ij} = -k_s (|p_{ij}| - r_{ij}) p_{ij}$$

$k_s$ is the springs stiffness constant

$p_{ij}$ is the vector from mass point


\( r_{ij} \) is the rest length of the spring

Using the linear spring, cloth still becomes stiffness and look not realistic. In order to solve the problem, [12, 24, 28] proposed to use a very large spring constants and implicit method equations. The other idea is come after [16] suggest to used spring with small \( k_s \) and apply the post step correction for constrains which are overly elongated.

Provot [16] used mass-spring model to model the cloth. Figure 3 shows the structure of the spring in the mesh. The \( m \times n \) particles is a mesh of cloth that linked to its neighbors by spring. There are three types of spring that used to linked neighbors which are structural, shear and flexion spring. The motion equation of the particles can be derived when the properties of the spring are specified and suitable. This structure is same to the model inspired from Kunii et al. [3] model and similar structure proposed by Fan et al. [29]. Provot [16] mentioned that using classical model, unrealistic deformations will occur at the constraint points. So, the stiffness could be increased. To solve this problem, Provot [16] proposed a mass-spring model in those springs around the constraint points to determine if any exceeded the predetermined threshold.

![Figure 3. A spring-mass system proposed by [16]](image)

Furthermore, to understand the movement between two particles together clearly, we like to think about the problem geometrical. Let say we push the particle by applying the acceleration vector and of course the particle move in the direction of acceleration vector (see Figure 4). The problem is when two particles move together along their path, only one of them move along their axis or both of them are move together by the same distance (in case of external constants). With that scenario, the integration formula can be apply to offset the current position by the acceleration vector (see Figure 5).

![Figure 4. Case 1: Particle movement in the acceleration vector.](image)

To simulate cloth behavior, all particles should returning back to the same position when the external forces affect the cloth such as wind and gravity. The particles connections on constraints are focus on between pairs of particles. According the Figure 3, constraint between two particles has their own distance that would it like to return back to the rest_length distance. So that, when the all particles move around, their distances maybe too far or too near each other. To solve this problem, we introduce constraint satisfaction to modify their position and return it back to the rest_length distance. The following Figure 6 show two particles too far away from each other.

![Figure 6. Case 4: Particle movement too far each other.](image)

### 3.2 External Forces

External forces is the most important in cloth simulation. Gravity is a kind of external forces that is affecting to apply on each particle. In our model, we set the gravity forces by

\[
\mathbf{f}_g^i = 9.81 g \mathbf{m}_i
\]

\( g \) is the normalized direction vector which points to the ground

### 4 INTEGRATION METHOD

Hauth et al. [27] stated that numerical integration is an important factor to perform the dynamic cloth simulation systems. In cloth simulation, there are used semi-implicit integration scheme to solve the motion differential equation. This scheme is consider both for performance and accuracy Volino et al. [24] than explicit integration scheme because it is does not require the large sparse linear system for each of iterations.
Therefore, there are numerous methods have been suggested for cloth simulation such as Euler method, higher-order RK method, Midpoint method and so on. However, these methods is hard to handle and have a badly limitation time steps especially to provide cloth more accuracy, efficiency and stability.

4.1 Explicit Euler

Explicit scheme is currently widely used in cloth simulation application. Runge-Kutta methods are based on quadrature schemes, which is given by

\[
\begin{align*}
v_i^{n+1} &= v_i^n + \frac{F_i^n}{m_i} \, dt \\
x_i^{n+1} &= x_i^n + v_i^{n+1} dt
\end{align*}
\]

\(v_i^n\) and \(v_i^0\) are the position and velocity of particle \(i\) in the time step \(n\)

\(F_i^n\) is the force

\(dt\) the simulation time step

Although this method implemented the motion of the particles more easily and efficiently, it is still unstable for large time steps when strong forces involved. In our method, the external force for gravity is not high. So, this is not giving more effect for our simulation.

In our simulation, we are able to set the damping value to 0.99 to give the movement of the cloth look more natural. If we set the damping to 1.00, it mean that it is no occurs.

5 COLLISION HANDLING

5.1 Self-Collisions

Self-collision detection is the most time-consuming part in cloth simulation. Since all particles are on the surface, all particles may potentially collide with each other. Cloth self collision is much more complex. The most accurate methods for resolving this entail using polygon intersection tests for every section of the cloth. This is probably too slow for most applications.

One method of approximating self collision is to give each node a repulsive force to all other non-neighboring nodes. This works well unless extreme forces are applied to a section of the cloth, in which case cloth nodes can pass through, creating a section of cloth locked into itself by having nodes on either side of another section, each trying to get away from the intersection line. However, in practice, this usually resolves itself quickly, as it's usually a corner that passes through. The corner will have less nodes pushing away from the cloth than the other side, allowing the other side to pull the nodes through with the same force.

To avoid the penetration, Lv et al. [13] implemented pruning method as an efficiency self collision detection. For wrinkle model cloth, each of their particles are linked each other by massless spring that have three type of spring such as structural, shear and flexion. So, the internal forces applied to all spring nodes on cloth model linking to its neighbors. External forces are like gravity, viscous damping, wind etc., which interact with outside object. Sugihara et al. [30] proposed an algorithm that combining the hierarchical structures and particle systems to simulate cloth simulation and it seems the algorithm is really times consuming. To solve this problem, his proposed algorithm considers the invisible particles and changing the topology in the future.


Provot [15] proposed the new technique that grouped the particles together. Huh et al. [38] proposed the same technique with Provot [15] that divide the particle into collision cluster and avoid possible subsequent collisions. Lv et al. [13] apply the bounding sphere hierarchy and direction boxes of the hierarchy tree without updated.

Choi and Ko [17] handle the collisions using voxel-based collision detection that inspired from Zhang and Yuen [35]. The cloth particle and solid triangle were register to the corresponding the voxel based on their spatial coordinates and perform the collision detection for each voxel. To test the self-collision detection, this technique checks the particle-particle pairs and adds the repulsive proximity force between the colliding when the particles too close. In order to speed up the interference test, hierarchically with bounding volume can be applied.
Lv et al. [13] applied hierarchy bounding sphere to prune most of the unwanted particles in self-collision detection. Figure 7 shows the pruning-bounding sphere that bound the particles completely. To prune unwanted particles, Lv et al. [13] create another bounding sphere which more smallest sphere that can bound the moving track of particle.

![Figure 7. Process of self-collision detection](image)

This algorithm does not need to updating the bounding volumes and updating the direction boxes of the hierarchy tree because it require much time. So, the bounding volumes are the pruning bounding sphere has the centers as a particles and their radii are fixed on the hierarchy.

6 CONCLUSION

We explained some of an algorithm that is able to simulate a piece of real time cloth. Our current research at the moment is focusing on physical technique and most of the works are initiated by [13, 12, 15].

Moreover, in order to speed up the process of interference detection, hierarchically with bounding volume can be applied. There are several techniques that have been used by previous researchers to reduce the number of detecting collision in cloth simulation [39, 31, 32, 33, 34, 35, 36, 37, 30, 16, 38, 13]. The latter is described in section 5.1.

Finally, we are currently extending our cloth-to-cloth collision detection fast for the thin cloth, which was very difficult to produce using the previous methods.

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