A SURVEY OF SELF-COLLISION DETECTION FOR DYNAMIC CLOTH INTERACTION IN VIRTUAL ENVIRONMENT

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ABSTRACT
Simulating the natural motion of cloth is a main component in virtual character animation. In cloth simulation, there are many researchers interest to study the structure and their characteristics. It is because cloth has a few unique features consist of flexible, elastic and easy to pleat and shape. Their characteristics are very complex to simulate and difficult to elaborate and making their prediction. This paper presents a research survey on self-collision detection for cloth simulation within the computer graphics research community. This research has variety of techniques have been suggested by numerous researchers. This paper tries to provide a comprehensive survey of all self-collision detection techniques from a unified viewpoint. So that the explanation and discussion will cover various topics such as issues, designs and performances.

Categories and Subject Descriptors
I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism– Animation

General Terms
Algorithm, Performance and Theory

Keywords
Cloth simulation, Self-collision Detection

1. INTRODUCTION
Virtual environment application is a complex system that consists of computer graphics fundamental components and various kinds of interactions. One of the crucial components to produce realistic virtual environment application especially for surgery simulation and entertainment industries is self-collision detection. In virtual environment application, we need to apply self-collision detection technique to ensure virtual objects such as cloth or hair is free from having self penetration.

In general, we can see that the self collisions scene only occur in deformable objects. To be specific, it is a situation of collision that happens within the virtual objects itself. Therefore, deforming objects require highly mathematical computation.

Collision detection can be segregated into two main divisions. The first division is known as inter-collision detection. It refers to the detection process of two objects both for solid and deformable bodies. Second division is self-collision. Collision detection on the other hand has three components namely collision detection, collision determination and collision response. The first component which is collision detection is a process to report boolean information whether two objects come into contact. Likewise, contact determination also provides boolean report with detailed information such as vertex, edge and surface. The last component is collision response that may involve some physics law. Applying proper response requires consideration on the object surface orientation. For a situation where the objects surfaces have no topological connections, applying correct response to the suitable surface might be complicated and computationally expensive.

As far as the collision detection system is concerned, the 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 the computation. Self-collision detection considers both intersection of surfaces comprising the objects and other objects (refer Figure 1). Durupinar [2] 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. As mentioned by Volino et al. [3], collision handling algorithm is usually inefficient if the algorithm tends to consider the adjacency features. More time will be spent to calculate the sub area where collision is going to occur.

2. LITERATURE REVIEW

As mentioned in the previous section, self-collision detection usually relates to flexible objects. For example for cloth modeling, Baraff and Witkin [4] proposed a technique that is able to handle large time steps (refer Figure 2). 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.

Durupinar [2] suggested a unique technique which made the construction of 3D garments from 2D platform possible (see Figure 3). Using several steps such as cutting, smoothing the garments boundary, seaming and scaling, the simulation of complete garments can be achieved realistically.

Lafleur et al. [5] on the hand initiated a repulsive force that able to avoid the surface of flexible object from having contact. The strategy was quite straightforward. First we need to divide the volume into small adjacent non-overlapped cell that enclose one particular surface. Once the algorithm identified that a point had crossed into the cell boundary, thin repulsive force was then imposed.

Continuing his previous dedicated work in 1995, Provot [6] proposed an improvised solution to semi rigid mass-spring cloth. The aim of the improvement was to build a real garment on synthetic human model (see Figure 4). To achieve that, several collision handling strategies had been taken into account, starting from detecting collision until the procedure to maintain the consistency of both detected collision and appropriate response.

Figure 2. Top row- Cloth draping on cylinder. Second row- Sheet with two fixed particles. Third row- Shirt on twisting. Bottom row- Walking man [4]

Figure 3. Shows a woven cloth emphasizing the difference between the front and back side. [2]

Figure 4. Garment constructions [6]

Figure 5. A tabletop consisting of 1600 particles draped on a sphere in real-time [7]
An alternative way to handle the rubbery looking of cloth model was presented by Lv et al. [1]. 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 (see Figure 7). Furthermore, to ensure that the process can be done efficiently, most of the unwanted particles were removed.

2.1 Self-collision Detection Techniques

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) (see Figure 8 to Figure 11). 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.

To avoid the penetration, Lv et al. [1] 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. [7] 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 [6] proposed the new technique that grouped the particles together. Huh et al. [16] proposed the same technique with Provot [6] that divided the particle into collision cluster and avoid possible subsequent collisions. Lv et al. [1] apply the bounding sphere hierarchy and direction boxes of the hierarchy tree without updated.

Choi and Ko [15] handle the collisions using voxel-based collision detection that inspired from Zhang and Yuen [12]. 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. [1] applied hierarchy bounding sphere to prune most of the unwanted particles in self-collision detection. Figure 12 shows the pruning-bounding sphere that bound the particles completely. To prune unwanted particles, Lv et al. [1] create another bounding sphere which more smallest sphere that can bound the moving track of particle (see Figure 13).

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.

The computer graphics community only became interested in cloth modeling in the late 1980’s [17]. They are focused on the problem of simulating the complex shape, deformable of fabric and clothing in three dimensions. Cloth modeling techniques are usually classified into three categories: geometrical, physical and hybrid. Physical techniques represent cloth models as rectangular grids with points of the intersections. The following table (Table 1) shows the comparison of physical methods since 1986 until present day. We identify different techniques mentioned by previous researchers based on several features such as parameters being considered, used techniques and level of techniques.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Technique</th>
<th>Level</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feynman [18]</td>
<td>Minimization Force</td>
<td>realistic</td>
<td>Elasticity, Bending, Gravity</td>
</tr>
<tr>
<td>Terzopoulos et al. [19][20]</td>
<td>Elasticity, Lagrange’s</td>
<td>increasing stability</td>
<td>Density, Damping, Metric, Curvature tensor</td>
</tr>
</tbody>
</table>

Figure 12. Pruning-bounding sphere [1]

Figure 13. Process of self-collision detection [1]
<table>
<thead>
<tr>
<th>Kurihara et al. [21]</th>
<th>Reaction constraint method</th>
<th>clock time 3 seconds</th>
<th>constrained force, damping, inelastic collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ng et al. [22]</td>
<td>Minimization Force Multigrid</td>
<td>very realistic motion</td>
<td>Elasticity, Bending, Gravity</td>
</tr>
<tr>
<td>Lv et al. [1]</td>
<td>particle-based cloth model</td>
<td>very efficiently</td>
<td>adjoining particles, neighboring grids</td>
</tr>
<tr>
<td>Lafleur et al. [5]</td>
<td>processing dynamic cases, flexible objects, Forces</td>
<td>realistic cloth motions</td>
<td>triangle surface, velocity vectors</td>
</tr>
<tr>
<td>Baraff [23]</td>
<td>handle large time steps</td>
<td>slightly better than O.n1.5/ performance</td>
<td>Energy, Force, Derivatives, Shear, Bend Forces, Damping</td>
</tr>
<tr>
<td>Provot [6]</td>
<td>semi rigid mass spring cloth</td>
<td>lower than the time required</td>
<td>Curvature, Contact and friction</td>
</tr>
<tr>
<td>Fuhrmann [24]</td>
<td>triangulated mesh, mass-spring system</td>
<td>realistic cloth motions</td>
<td>Particle primitive distances, corresponding normals</td>
</tr>
<tr>
<td>Volino [25]</td>
<td>hierarchical algorithms, curvature</td>
<td>very efficient and robust system</td>
<td>Edge, Surface, Polygons</td>
</tr>
<tr>
<td>Yoo-Joo Choi [26]</td>
<td>particle-based physical model</td>
<td>very realistic motion of clothes</td>
<td>Interaction, Post-Buckling Instability, Damping</td>
</tr>
<tr>
<td>Bridson et al. [27]</td>
<td>robust geometric collision algorithm</td>
<td>Fast</td>
<td>contacts, kinetic friction, static friction</td>
</tr>
<tr>
<td>Breen et al. [28]</td>
<td>physically-based for variety of woven fabrics</td>
<td>Middle</td>
<td>particle systems, Kawabata Evaluation, physically-based modeling</td>
</tr>
<tr>
<td>Volino [29]</td>
<td>Versatile and Efficient Techniques</td>
<td>Fast</td>
<td>Elastic, shearing strain</td>
</tr>
<tr>
<td>Heidelberg et al. [30]</td>
<td>new image-space technique</td>
<td>best performance 40.0ms</td>
<td>Volume-of-Interest, images or layers of depth values, (front-face, back-face)</td>
</tr>
</tbody>
</table>

| Cyril Ngo Ngoc et al. [31] | Kawabata Evaluation System (KES) | highly influenced | traction, bending, shearing |
| Thanh et al. [32]          | high resolution mass-spring system | reduce the simulation time drastically | Hierarchy decomposition methods, Energy minimization |
| Bridson et al. [27]        | Mixed explicit/implicit time integration scheme | Fast | Velocities |

Figure 8 until Figure 10 show number of techniques which have been illustrated in timeline diagrams since 1985 to 2007. The diversity of techniques covers various applications, domains and issues in cloth simulation research area.
3. CONCLUSION

Cloth simulation is a popular computer graphic area that has received a lot of attention from many researchers. It is important because it adds to the realism of a graphically generated environment. For example, *The Incredibles*, (see Figure 11) employed cloth simulation to cloth the animated characters, “Monster & Co.” from Pixar or “Shrek” from DreamWorks. ClothReyes is a commercial fabric simulation plug-in for 3ds Max. A moment ago, simple cloth simulations have been used in computer games as well.

In computer animation, even something as simple as a draped cloth can start to make an interesting character animation. Figure 12 shows a ghost created by draping a cloth over a sphere. The cloth drapes and flows around this sphere in a satisfying way.

![Figure 10. Series of cloth simulation techniques since 2003 – 2007](image)

![Figure 11. ClothReyes fabric simulator plug-in. On the right from Pixar’s *The Incredibles*](image)

![Figure 12. Draping a cloth over a sphere.](image)

We explained several self-collision techniques for virtual environment application. The explained techniques cover various topics and applications as shown in table and diagrams. Our current research at the moment is focusing on physical technique and most of the works are initiated by [1, 4, 6].

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5. REFERENCES


