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Real-time Animation of Dressed Virtual Humans

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Abstract

In this paper, we describe a method for cloth animation in real-time. The algorithm works in a hybrid manner exploiting the merits of both the physical-based and geometric deformations. It makes use of predetermined conditions between the cloth and the body model, avoiding complex collision detection and physical deformations wherever possible. Garments are segmented into pieces that are simulated by various algorithms, depending on how they are laid on the body surface and whether they stick or flow on it. Tests show that the method is well suited to fully dressed virtual human models, achieving real-time performance compared to ordinary cloth-simulations.

1 Introduction

One of the most challenging areas in research is in the development of a robust methodology for simulating clothes in real-time. In order to define a cloth simulation system that is able to simulate complex garments realistically, whilst maintaining a reasonable computation time, a deeper study of the cloth model and the identification of its behaviour at different levels are necessary.

This study is not intended to integrate yet another more precise physical model of a garments behaviour, but rather focus on the real-time constraints for the simulation and the visual cloth motion features to which an observer is sensitive. Most of the existing approaches use a general-purpose simulation method using collision detection and physical simulation for the whole garment. Unfortunately, simulations that simply calculate all potentially colliding vertices may generate a highly realistic movement, but do not provide a guaranteed frame time. A new simulation model should be implemented that avoids heavy calculation of the collision detection and particle system wherever possible.

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Our assumption is that the whole cloth does not need to be simulated with a general-purpose simulation method; instead many optimizations can be made. For example, the trouser will never collide with the arms. Collision detection may be simplified by restricting the collision detection to only potentially colliding surfaces. Also, stretched garments do not need to be simulated with a complex physical method. It can be simply simulated by keeping an offset between the garment and the underlying skin surface. We aim to develop a hybrid approach exploiting the merits of both the physics-based and geometric deformations and predetermined conditions between the cloth and the body model. The method is based on a multi-layer approach where each layer is simulated by its own dedicated method. A pre-processing stage aims to define the three regions corresponding to stretch, loose and floating clothes. During the real-time simulation, they will be animated using different methods.

The paper is organized as follows: The first section reviews previous work on real-time cloth simulation. In the second section we will provide an overview of the method, then, we will describe in detail the garment design and segmentation, and the three cloth layers used for the simulation. In the last section, we will present

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the results of our method when applied to virtual humans.

2 Previous work

Extensive research has been carried out in cloth simulation. Several of them have focused on the quality of garment simulation, where constraint of real-time was not a priority. Their aim was to develop a physics-based method that is able to simulate the dynamics of cloth independent of its use whether as clothing or other situations like in furnishing tablecloth. They integrated complex collision detection and they were able to simulate the physical behaviour of garments [1], [2], [3], [4].

Other research has focused on the real-time aspect of the animation of deformable objects using physical simulation.

Baraff et al. [5] have used the Implicit Euler Integration method to compute the cloth simulation in real time. They stated that 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, suggesting the possibility of real-time animation of simple objects.

Meyer et al. [6] and Desbrun et al. [7] have used a hybrid explicit/implicit integration algorithm to animate real-time clothes, integrated with this is a voxel-based collision detection algorithm. Their method seems to be limited by the maximum number of polygons they can animate in real-time.

Other research has focused on the collision detection, stating that it is one of the bottlenecks to real-time animation. Vassilev et al. [9] proposed to use the z-buffer for collision detection to generate depth and normal maps. Computation time of their collision detection does not depend on the complexity of the body. However, the maps need to be pre-computed before simulation, restricting the real-time application.

Another approach presented by Grzeszczuk et al. [10] uses a neural network to animate dynamic objects. They replaced physics-based models by a large neural network that automatically learns to simulate similar motions by observing the models in action. Their method works in real-time. However, it has not been proven that this method can be used for complex simulation such as cloth.

James et al. [11] have also worked on real time simulation; their paper describes the boundary integral equation formulation of static linear elasticity as well as the related Boundary Element Method discretization technique. Their model is not dynamic, but rather a collection of static postures, limiting its potential applications.

Debunne *et* al. [12] have recently introduced a technique for animating soft bodies in real time. However, their method works on volumetric meshes. Therefore, it is not applicable to thin objects such as cloth.

Some other researchers have used geometrical approaches [13] [14] [15] [16]. Geometrical models do not consider the physical properties of the cloth, therefore providing techniques that produce fast results. However, these techniques are not able to reproduce the dynamics of clothes. Moreover, geometrical techniques require a considerable degree of user intervention. They can be regarded as a form of advanced drawing tools.

Hybrid approaches try to combine geometrical and physical deformations. Kang et al. [17] [8] improved the visual quality of the garments of small number of polygons by tessellating the triangles. With a wrinkled cubic spline curve, their tessellation algorithm is able to simulate the wrinkles. Oshita et al. [18] use a similar approach. Both these methods are mainly applicable to

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whilst a skirt will float around the legs. The first part of the study is to identify all the possible categories:

- Garment regions that stick to the body with a constant offset. In this case, the cloth follows exactly the movement of the underlying skin surface.
- Garment regions that flow around the body. The movement of the cloth does not follow exactly the movement of the body. In case of a long skirt, the left side of the skirt can collide with the right legs.
- Garment regions that move within a certain distance to the body surface are placed in another category. The best examples are shirtsleeves. The assumption in this case is that the cloth surface always collides with the same skin surface and its movement is mainly perpendicular to the body surface.

These three categories are animated with three different cloth layers. The idea behind the proposed method is to avoid the heavy calculation of physical deformation and of collision detection wherever possible, i.e. where collision detection is not necessary. The main interest of our approach is to pre-process the target cloth and body model so that they are efficiently computable during runtime. The skin and the garment are divided into a set of segments and the associated simulation method is defined for each. For each layer, we propose solutions and explain why they have been chosen.

4 Body and garment segmentation

Any simulation of clothes requires choosing a body model and designing the garments. This section provides a description of the body model and the way it is deformed as the skin deformation is an important component of our cloth deformation model. A description of the garment segmentation is also supplied.

4.1 Body model preparation

We start from a body model that is described by a polygonal mesh, which can be animated using skeletal deformation [19]. The first step in body model preparation is to define the attachment of the skin surface to the joints of a skeleton, i.e. which vertex belongs to which joint. In our current implementation, this is done using an external application [20]. This attachment information is later used for skeletal deformation. Next, the skin mesh is segmented using the weight values defined in the attachment information. Each triangle belongs to the joint corresponding to the highest weight. During the segmentation, vertices that are located on the boundaries of segments are duplicated. They share the same attachment information. At the end, each segment is attached to the corresponding joint on the H-ANIM skeleton [21]. The result of the segmentation is an H-ANIM compliant human body model.

4.2 Skeletal deformation

The skeletal deformation uses vertex weights. Vertex weights are what tie the joints and the mesh together. Each vertex in the mesh is tied to any number of joints. Each vertex-joint relationship has a scalar weight. The position of vertices is calculated using the weight values and the transformation matrix of the joints. The skeletal deformation is also used to compute the normal to the mesh surface. With the Cosmo3D library [24], these normals need to be updated whenever the mesh is deformed.

On the skin mesh, the movement of vertices that belong to a single joint is not calculated but automatically moved as they are attached to the joint. Duplicated vertices that are on the boundaries have the same position as they share the same attachment information. Thus, the boundaries among segments are not visible. The result is a segmented body that appears as a seamless body in the rendering view port. This method combines the speed of the deformation of segmented bodies with the visual quality of seamless bodies.

4.3 Garment design

The garment creation is done using our in-house software [22]. The garment designer is assisted in drawing 2D patterns and defining seaming lines on the borders of the garment patterns, referring to the polygon edges that are to be joined during the garment construction process. The patterns are then tessellated into a triangular mesh and are placed around the 3D virtual body (Figure 9(a) on color section). Next, the remaining garment shape is computed, as illustrated in Figure 9(b) on color section. The shape of the body model guides the surface of the cloth as a result of the collision response.

4.4 Segmentation of the cloth

As described in the previous section, we use a multi-layer approach. The cloth is segmented into one of the three layers. Each layer contains vertices that belong to

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the same behaviour category. These cloth layers are simulated using different methods. From the garment in its rest shape on the initial body, the distance between the garment and the skin surface is used to determine to which category the cloth triangles belong. Associated with each segment are distances from the skin surface that are used to determine the category. Each segment falls into one of three categories: tight, loose and floating clothes. Cloth vertices that are located closely to the skin surface belong to the first or the second layer. Cloth vertices that do not collide with any skin surface belong to the third layer (Figure 9(c) on color section). Once the automatic segmentation is done, the user can adjust it if necessary.

When the garment is composed of several layers, our simulation method severely limits its target and only the outermost garment is animated. As soon as the garment segmentation is completed, hidden layers and the skin parts that are covered by the outer layer are automatically removed. Figure 9(d) on color section shows the body model after such optimization on the initial model illustrated in Figure 9(b) on color section. Since they will never be visible during the real-time simulation, their deformation does not need to be computed.

5 Layer 1: "Stretch clothes"

Tight clothes keep constant distances with the underlying skin surface. The deformation of this layer follows the deformation of the underlying skin. We choose to use the skin deformation method to animate this layer. This method does not involve any collision detection or physical deformation. It has no impact on the calculation time. Therefore, it is necessary to construct the skeletal information of this cloth layer. This information is defined by mapping the attachment information of the underlying skin to these cloth vertices. Each vertex of the garment mesh is associated to the closest triangle, edge or vertex of the skin mesh.

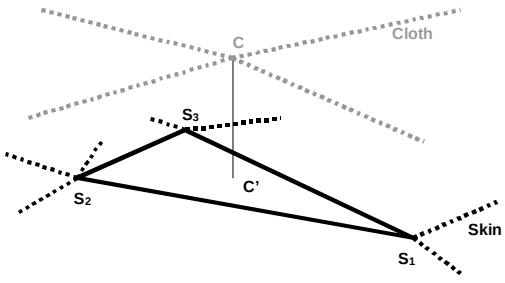


Figure 1: *Mapping of attachment information*

In the Figure 1, the garment vertex C is in collision with the skin triangle $S_1S_2S_3$. We define C' as the closest vertex to C located on the triangle $S_1S_2S_3$. We then define the barycentric coordinates of C' with S_1, S_2 and S_3. The attachment information of C is calculated by combining the attachment information of S_1, S_2 and S_3 weighted with the barycentric coordinates.

6 Layer 2 "Loose cloth"

For loose clothes, the relative movements of clothes to the skin remain relatively small, keeping a certain distance from the skin surface. To get an intuitive understanding of such cases, consider the movement of sleeve in relation with the arm: for a certain region of the garment, the collision area falls within a fixed region of the skin surface during simulation. With this in mind, the scope of the collision detection can be severely limited. A basic assumption made is that the movement of the garment largely depends on that of the underlying skin and yet it should not follow the skin surface rigidly. It is necessary to simulate the local displacement of the garment from the skin surface.

Two different methods have been developed, one for cloth deformation on the limbs (trousers and sleeves), the other one for the deformation of cloth on the trunk.

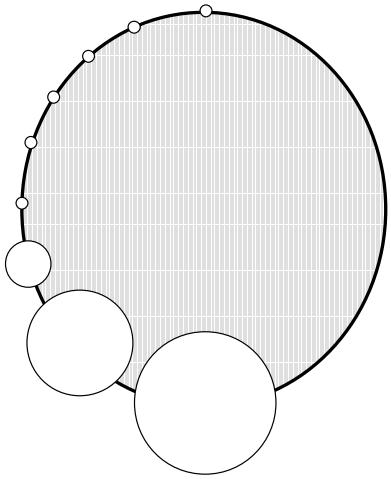
6.1 Sleeves and trousers

In this approach, we use the assumption that cylinders can approximate the limbs. Each vertex is kept on a disc that is attached to the skin.

- Initially, the position of the disc centres are calculated using the attachment information defined in the pre-processing stage. They are obtained by mapping the attachment information of the underlying skin to the cloth vertices (see Section 5). The axe of the discs is parallel to the limb joint.

- During simulation, the movement of the vertices on their disc follows the equation of the rigid body motion. Vertices move independently to each other. Using the 2nd Newton's law, velocity and position are easily calculated with gravity force. In case a vertex leaves its disc, a kinematic correction [2] is applied to the velocity and the position to put the vertex back on the disc surface. The Figure 2 shows a cross-section of a limb with a garment.

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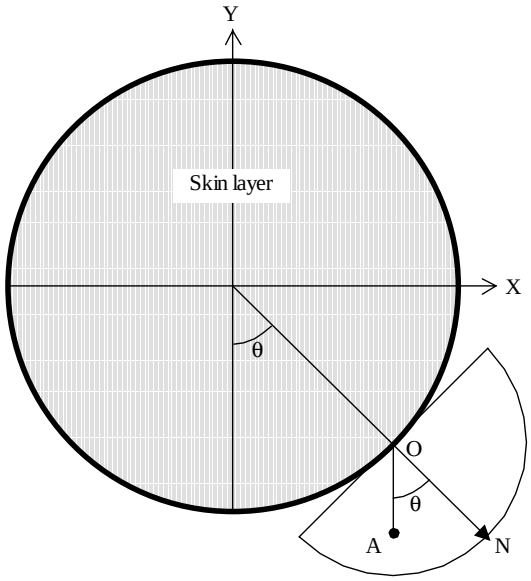


Figure 4: *Computation of the disc diameter*

This method ensures that the rest shape of the garment takes the shape of real garment hanged on a limb. All the discs containing the vertices are parallel to their corresponding limb joints. This ensures that every vertex of the same limb will fall down to the same side on the limb, even in case the direction of the limb is almost vertical. If the limb is perfectly vertical, the result is unpredictable. However, this case never happens in practice.



Figure 5: *deformation of sleeves*

In this method, no collision detection on surfaces is necessary. Our particle system is very simple, each vertex moves independently. Therefore, the acceleration applied on vertices is constant. The stability of the system does not depend on the time step duration. The resulting motion of the garments provides the appearance of dynamic movements as well as the shape of real clothes. An example of a sleeve deformation is shown on Figure 5.

6.2 Clothes on the trunk

The hybrid technique described in Section 6.1 works well if the skin surface can be approximated by a moderately thin cylinder and the movement of the garment is more or less perpendicular to the skin surface. This assumption is true for the arms and legs; the friction prevents the garments to move along the limbs. In such cases, vertices are considered to move independently of each other. However, such an assumption cannot be made for garment regions around the trunk where, unlike the arm, the movements of the garment are driven not only by the torso but also by the potentially complex movement of the shoulder and the arm. To get an intuitive understanding of the problem, consider a shirt worn by a virtual human who is raising its arms. The whole garment around the torso part moves along the vertical direction as the arms are raised. This implies the necessity to simulate the elastic property of the tissue. Therefore, a dedicated method for cloth deformation on the trunk has been developed.

A simplified mesh composed of 42 nodes is animated using a simplified mass-spring system. The movement of these nodes is driven by two interactions: gravity and springs in connection with neighbouring nodes. Each of these nodes is a control point used to deform the cloth mesh on the trunk. Figure 10 on color section shows an overview of the simplified mesh. These control points are uniformly placed on the trunk, they form a grid of 3x4x3 points. Six additional control points are attached to the shoulder. These control points maintain the grid mesh on the trunk and prevent the mesh from falling due to the gravity. Each control point is included in a half-sphere that is attached to the skeleton. The collision detection algorithm verifies if each control point is contained within its corresponding hemisphere. In case the control point is not in its hemisphere, a kinematical correction is applied on the position and the speed.

The cloth mesh is deformed with the Freeform Deformation method [26] using the position of the nodes of the simplified mesh. Our implementation uses a 3x4x3 control point lattice for the FFD and uses Bernstein polynomials as the basis functions. The example in shows the grid, composed of the 36 green nodes. The weight values associated to the vertices, deformed by the FFD, are pre-calculated.

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7 Layer 3 "Floating cloth"

Layer 3 is composed of vertices that freely float around the body. This will take care of cases, such as a large skirt floating around the legs. Any part on this skirt can collide with any part of the leg. The simulation of this layer uses a classical approach with particle system and collision avoidance.

- **Particle system**: We use a simple mass-spring system. The simulation is performed using the Implicit Euler Integration proposed by Barraf et al. [5] and Volino et al. [1]. The garment is modelled by a simple mass-spring system. We consider two interactions: gravity and forces applied by the springs joining the particles.
- **Collision response**: Calculating collision detection between the cloth and the skin mesh would not be feasible in real-time, therefore we use a simplified model of the body. Given the assumption that the floating clothes are mainly skirts, the collision detection is calculated for the legs only and two cylinders model each leg. By simply calculating the distances between the skirt and the four leg segments, the collision detection can be performed. It is possible to further optimize by restricting the number of collision distances that we compute for each segment. During the pre-processing stage, a list of possible colliding vertices is defined for each segment. This list is defined by calculating the distance between the vertices and the legs and the normal orientation for each vertex on the skirt. The collision response consists of applying a kinematical correction to the position and velocity of the colliding vertices.

8 Deformation on layer boundaries

Vertices located at the boundaries of layers need to be animated with a hybrid method in order to keep a smooth deformation on these boundaries.

On the layer 3, vertices that belong to the boundary are used as anchors to keep the floating garment on the hips. These vertices are solely deformed by the neighbouring layer. This implies that the layer 3 is deformed at last because it uses the resulting

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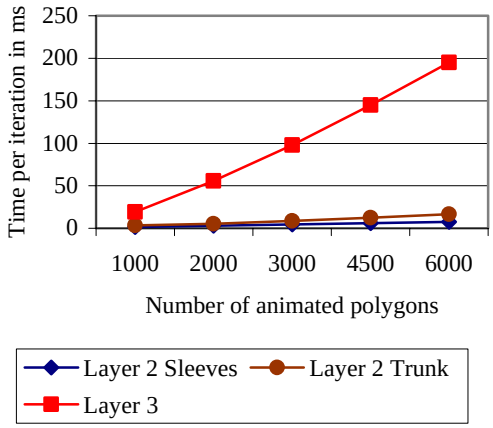


Figure 6: *Computing time per iteration versus number of triangles.*

The Figure 8 summarizes the performances of these three animations.

Nb. of Polygons	Skirt and Jacket	Dress	Trouser and Pullover
Original model Cloth & Body	8413	5887	7445
After optimization Cloth & Body	4874	4526	5187

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