Integrated system for skin deformation

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Abstract

In this paper, we present an integrated system for skin deformation that is able to handle deformations due to both the skeleton animation and collisions. This method is based on a physically-based deformation of a skin surface linked to a reference shape; the reference shape is animated with a geometric deformation. Collision detection has been implemented to avoid penetration. Our method for collision response consists of a kinematical correction of positions and forces during the simulation. The resulting model of the skin deformation enables an efficient simulation and interaction of the skin with deformable objects. Results are presented at the end of the paper as examples.

***Keywords**: Skin deformation, Collision response, Skeleton animation, Grasping objects, Physically-based deformation.*

1. INTRODUCTION

Simulation of the body deformation has many applications. In addition to uses in entertainment industry, applications of animation of human beings are becoming quite important in the fields of ergonomics, medicine, biomechanics, and the like. In computer graphics, animation of a human being is a key challenge. At first, humans have been represented as simple articulated bodies made of segments and joints with a kinematics based model to simulate them. More recently, deformable models that use physically-based deformation or geometric deformation have been proposed to improve the realism of the skin behavior.

Today, most of the skin deformation methods use a skeleton that is represented with a tree-structure hierarchy of rigid segments connected by flexible joints. The problem of skin deformation consists of how to modify the skin shape in response to changes in the hierarchy. Many methods have been proposed. We can classify these methods in two categories: geometric deformation methods and physically-based methods. Geometric deformations directly deform the geometric model of a 3D-object in different ways: (1) by modifying the parameters that define the model of an object [6], (2) by applying a mathematical transformation on the object [1]. In physically-based methods [5][8][11], the simulation system computes the evolution of the skin using a modeling of its mechanical behavior. These deformation techniques are useful to deform an object according to a natural phenomenon.

Few skin deformation methods handle deformations due to both the skeleton animation and collisions. Our main contribution is to propose a system for the skin deformation that handles these two types of deformations. Our method combines the geometric and the physically-based deformations. The skin is attached to a reference shape, and the deformation of the reference shape is simulated with a geometric method. The behavior of the skin is defined by the physical model, which is based on the application of the forces over all the points constituting the skin mesh. In our system, we consider three forces: (1) anchorage force to attach the skin to the reference shape, (2) elasticity force and (3) curvature force. During the simulation process, a collision library computes the collided vertices. The collision response produces the correction of the position and the forces of the colliding vertices.

We present in the first section, a review of the existing methods for the body deformation. In the next section, we give a description of our skin deformation model. Then, we present the system integration for the skin and collision library. At the end of the paper, results are presented in examples.

2. BACKGROUND

Body deformation is a very challenging task. A variety of approaches have been proposed for deformable animation of articulated characters. These approaches can be classified into two groups: geometric deformation and physically-based deformation.

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2.1. GEOMETRIC DEFORMATION

Moccozet *et al.* [1][2] animated a polygonal hand placed over a hierarchy using Dirichlet free-form deformations to model the wrinkling of the palm and undersides of the fingers due to joint flexion. This method consists of deforming the predefined skin with a space-filling function whose purpose is to deform the skin surface in response to the movement of the hierarchy.

Implicit surfaces have been widely used to simulate the skin surface. Some type of implicit surface like blobs [17], convolution surfaces [18] or soft objects [20] have received increasing attention in Computer Graphics. Shen *et al.* [6] have developed in the Body Builder, a system for interactive design of human bodies. To represent bones, muscles and fat tissues, they employ ellipsoidal metaballs. To obtain the skin, an implicitly defined surface is computed from metaballs.

Sheepers *et al.* [3] have developed a geometric method for muscle deformation. Muscle bellies are represented by ellipsoids and deformations are provided by scaling the three major axes of the ellipsoids, simulating compression and extension motion.

2.2. PHYSICALLY-BASED DEFORMATION

Wilhelms *et al.* [5][14][15] have proposed a hybrid method to model the skin surface. The internal components (bones, muscles and tissue model) are directly modeled with triangle meshes or ellipsoids. A pre-defined skin is attached to the underlying bone, muscle and tissue model. The skin is approximated by a 2D mass-spring network whose nodes are inter-connected and anchored to the internal components by spring to muscles.

Porcher *et al.* [7] have developed a particle system for real-time muscle animation. To physically simulate deformations, they used a mass-spring system with a kind of springs called "angular springs" which were developed to control the muscle volume during simulation.

Turner *et al.* [16] have developed the LEMAN system to construct and animate 3D characters based on the elastic surface layer model. The skin surface is implemented as a simulation of a continuous elastic surface discretized using a finite difference technique. The surface is represented as a mesh of 3D mass points attached to the muscles.

James *et al.* [8] have developed a finite element method to simulate the real-time deformation of objects. Some of their methods can be applied for the skin deformation. They described the formulation of the boundary integral equation for the static, linear elasticity as well as the related technique for the discretization of the Boundary Element Method.

Keeve et al. [24] have presented an anatomy-based 3D finite element tissue model. In order to get a more realistic model of the elastomechanics they have developed a non-linear tissue model using the principal of Virtual Displacements described by the Total Lagrange Formulation

Our main contribution is to propose an integrated system for skin deformation in which this skin deformation is driven by the skeleton animation and the collision detection. The proposed skin model is able to combine direct surface deformations due to skeleton animation together with indirect one, as it is required to perform contact reaction in environment interactions.

3. SKIN MODEL

We consider two kinds of deformations. Global deformation consists of modifying the skin shape in response to the changes in skeleton position. Local deformation is the modification of the skin shape in response to the local constraint such as collision response. To take into account these two deformations, we have developed a multi-layer approach. Our layered construction is based on three interrelated levels:

- The first layer is the hierarchy of articulated skeletons composed of line segments whose movements are pre-specified.
- The second layer is used for the global skin deformation. This layer computes the body surface generated from the skeleton by a geometric method. This body surface will be used as an anchor surface for the skin mesh in the third layer. Any modification on the surface generated at this layer will modify the skin computed in the third layer. The reference shape has been generated with metaballs [6] for the body and with DFFD method [1] for the hands.
- The third layer is used to compute the local deformation. The skin is modeled by a mesh linked by springs to the reference surface of the body computed in the second layer. The skin is adapted to the local constraints such as the collisions with a physically-based deformation. The deformation is computed with a particle system.

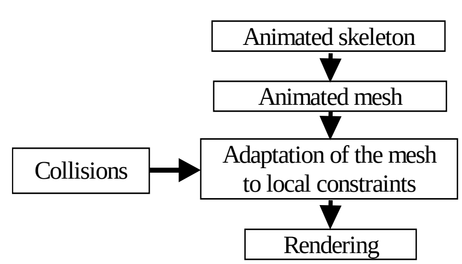

Figure 1: the skin deformation method with the three layers.

As mentioned earlier, our system is based on the application of the forces over all the points that compose the skin. We have defined three forces applied on particles.

- The first one is used to link the skin mesh to its reference shape computed with metaballs. A spring with zero rest-length links each vertex to its anchor and keeps the skin in contact with the body surface.
- The second interaction links each particle to its neighbors by springs. This interaction is mainly used to simulate the elasticity of the skin.
- This third interaction controls the bending effect of the skin.

The resulting force applied on each particle X_i is:

$$f_R(X_i) = f_A(X_i) + f_E(X_i) + f_C(X_i)$$

3.1. ANCHOR INTERACTION

The elasticity force is used to anchor the skin to the reference shape. Each vertex is connected to its anchor by a spring with zero-rest length. In the following equation, X_i is the current position of the particle and X_{rest} is the anchor position of the particle. *Ke* is the coefficient of the spring.

$$f_A(X_i) = K_E(X_{rest} - X_i)$$

3.2. ELASTICITY INTERACTION

To simulate the elastic effects between the particles on the skin mesh, we have used linear springs. Skin elasticity is modeled with a network of springs. The main advantage of this method is its speediness. The skin surface is discretized into vertices linked to their respective neighbors by springs, forming a structure with the topology of a triangular mesh. Mesh deformation produces a force proportional to their elongation along their current orientation.

$$f_E(X_i) = K(l_{rest} - l_i)$$

K_E is the coefficient of elasticity, l_{rest} is the rest length of the spring, l_i is current length of the spring.

3.3. CURVATURE INTERACTION

Previous models deal only with the in-plane elasticity. Another kind of elasticity, dealing with the surface curvature and bending has to be defined. Curvature elasticity is good approximation to simulate the thickness of the skin. The thinner the skin is, the more it can be folded. The most common way to measure curvature in an irregular mesh is to consider the angle θ formed by two triangles (A C B) and (C D B) around an edge (B C). We compute four forces F_A, F_B, F_C and F_D applied on A, B, C and D.

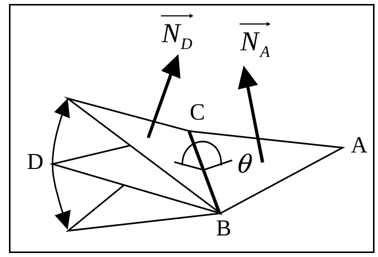

Figure 2: Curvature along the edge (BC)

In the first step, we compute F_D and F_A. These two forces generate opposed momentums around the edge, which globally act to unfold the two adjacent triangles. The two forces F_D and F_A is aligned to the triangle normals $\overrightarrow{N_D}$ and $\overrightarrow{N_A}$ respectively. We give here the equation of these forces:

$$\overrightarrow{F_D} = \frac{f(\theta)}{|D - D'|} \overrightarrow{N_D}$$

$$\overrightarrow{F_A} = \frac{f(\theta)}{|A - A'|} \overrightarrow{N_A}$$

A' and D' are respectively the orthogonal projection of A and D on the segment $\overline{BC}$. The two other forces are computed using the equilibrium equation of all the forces: $\overrightarrow{F_A} + \overrightarrow{F_B} + \overrightarrow{F_C} + \overrightarrow{F_D} = 0$. $f(\theta)$ is the momentum of the curvature force.

4. SYSTEM INTEGRATION

In this part, we will give a description of the implementation of the whole system. This system is composed of three layers (Figure 3).

- The lowest layer is the simulation library described in the previous section. The main task of this layer is to compute the mechanical behavior of the skin and the deformable objects. This layer includes the mechanical model of the skin, the collision detection library, and the "Runge-Kutta" algorithm.
- The next layer is used to manage the objects and the meshes. It is composed of a mesh library and a material library. The material library is used to

manage the mechanical properties of the skin such as elasticity, weight, and curvature.

- The topmost layer is in an interface between the 3D Studio Max [12] and the simulation library. This layer is composed of functions needed by 3D Studio Max for the user interface and the plugin functionality. Our system has been developed as a plugin to 3D Studio Max.

In the next section, we will give a description of the lower layer. This layer includes (1) the numerical integration, (2) the collision detection and response, and (3) the mechanical models of the skin.

4.1. THE NUMERICAL INTEGRATION METHOD

As already mentioned, the physical model is based on the application of the forces over all the points that compose the mesh, generating new positions. Adding all the applied forces, we obtain a resultant force for each particle on the deformable mesh. Vertex displacement of the skin is computed with a quasi-static method. Quasi-static system is a sequence of static simulation performed over time. For each simulation step, we compute the equilibrium state of the forces applied to the skin. Quasi-static simulations are useful for approximating the physically-based response of the models for which we can assume that the effects of inertial force can be neglected. In the case of the skin deformation, vibrations and deformations due to the skin mass are negligible.

Among the different numerical integration methods available in the literature, we have chosen to implement a 4th order Runge-Kutta method [21], adapted in order to provide an evaluation of the simulation errors for each simulation step.

4.2. COLLISION DETECTION AND RESPONSE

4.2.1 Collision Detection

A collision detection engine has been developed to compute the collisions and self-collisions between all the objects in the structure.

For each simulation step, the collision detection is performed for all the objects. This collision detection algorithm, formerly presented in [9], is based on a geometrical surface region hierarchy and takes advantage of surface curvature within and between adjacent surface regions for optimizing self-collision detection.

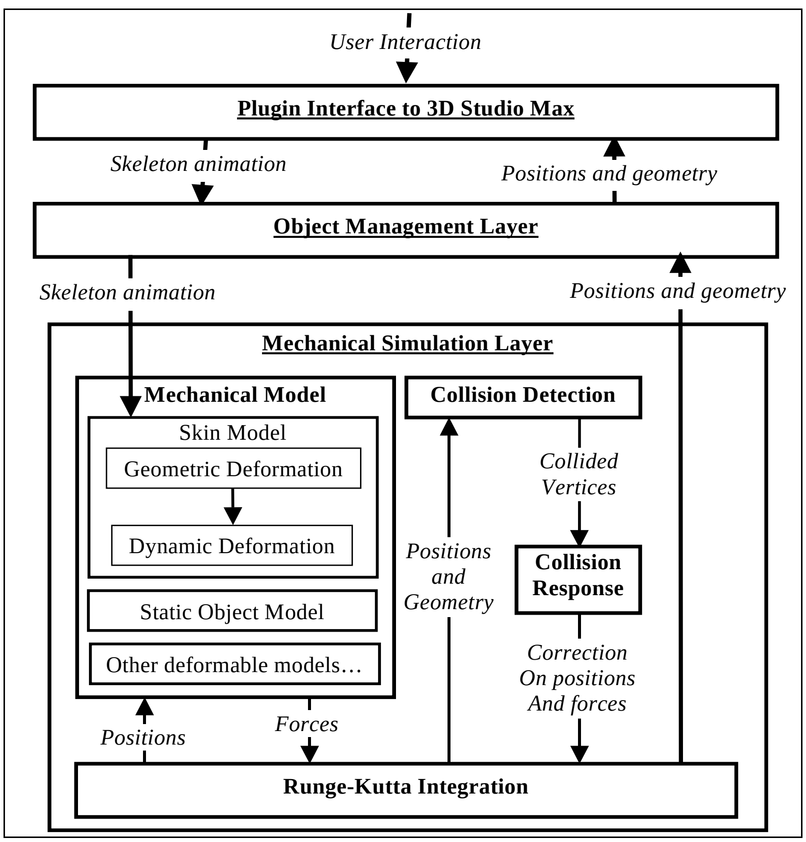

Figure 3: Data flow of the system

The collision detection engine provides for each simulation step, location of collided surfaces.

4.2.2 Collision Response

Collision response is mainly used to impose a minimum distance between the two surface elements in contact. We handle collision constraints using the kinematical correction on the constrained elements. Rather than computing "collision forces" through inverse kinematics from the momentum conservation law, we directly integrate the constraints by position corrections on the concerned vertices accordingly to the momentum conservation. Thus, we avoid dealing with the high reaction forces that alter the mechanical simulation. Positions are corrected according to the mechanical conservation laws to fit the constraints precisely. The kinematical correction is described as below:

- An immediate correction of the position of the concerned vertices, taken into account before the dynamical simulation process, is aimed at reflecting the immediate effects of the constraint.
- A force correction will attenuate or cancel the force difference between the constrained vertices, in order to maintain the imposed kinematical constraints. This correction is made during the Runge-Kutta integration.
- A position adjustment is made on new positions after the integration.

The figure below gives an overview of the collision response method.

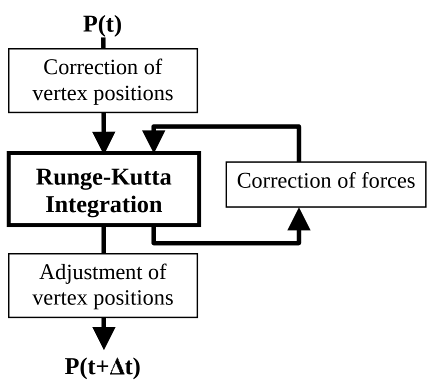

Figure 4: Collision response

The collision response is composed of two components: reaction and friction. A contact surface is defined parallel to the two object surfaces at the contact points. The reaction force is orthogonal to the contact surface, while the friction force is parallel, and usually oriented along the relative speed between the two object contact points. Correction for reaction forces is used to impose minimum distance between the two surface elements in contact. Correction for friction forces acts against the sliding effect between the objects.

5. SOME RESULTS

To illustrate the application of the methods described here, we present three examples of the skin deformation. These examples illustrate the skin deformation from the interactions with rigid and deformable objects.

5.1. CONTACT WITH OTHER OBJECTS.

The figure “Figure 5” shows an example of the skin deformation of the finger. On the left image, the animation has been computed without any collision detection and the skin deformation. On the right image, we can see that our method has deformed the finger and the surface to avoid the penetration of the object through the skin mesh. The reference shape (first layer of our simulation method) has been computed using DFFD method [1] previously developed in our lab.

The user can specify the properties of skin locally. The human body is a collection of soft and firm components. In some region, bones are flush against the skin; in some others, they are more distant to the skin. By defining properties locally, we can simulate the behavior of these different regions of the skin.

Regarding the system performance, we have made some tests on PC, with a 400 MHz Pentium II processor. For a simulation of the hand with 3000 polygons, we have reached the performance of one image calculated on each second.

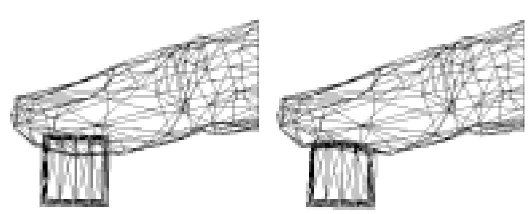

Figure 5: Skin deformation on finger

The figure below illustrates another example of the skin deformation. Our system is able to handle the skin deformation of the whole body. The body is composed of 12 000 polygons.

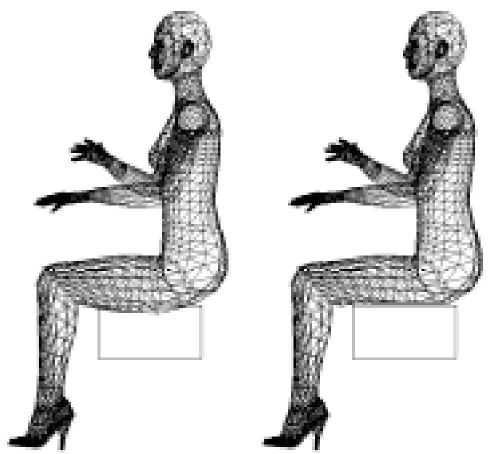

Figure 6: skin deformation on rigid object

5.2. GRASPING OBJECTS

Actually, most of researches on grasping objects use some techniques [22] [23] that consist on attaching geometrically the grasping object to the hand. The grasping task is mainly made by geometric methods. When the correct gesture to touch the object has been done, the transformation matrix between the object and the hand is recorded. This matrix is then used to compute the new position of the grasping object so that the object follows the hand in orientation and position.

The figure below shows a hand grasping a cube. The cube deformation is simulated with a simple spring-mass system.

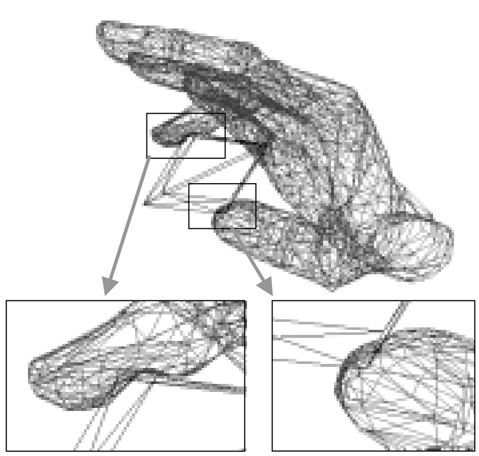

Figure 7: grasping a deformable object

In our case, the grasping task is simulated with a physic-based method. During the grasping task, the shape of finger skin and the deformable object are adapted to local collision. When a deformable object is grasped, the collisions on it and on the skin will lead to deformation of both the object and the skin. The grasping task is possible thanks to the friction between the skin and the deformable object. This friction avoids these objects to slip on each other.

Moreover, by computing the elongation of the springs used to attach the skin to the reference shape, it is possible to define which region of the skin is in contact with the grasped object and with which force. It may be compared to the tactile sensors of robots or the human sense of touch.

6. CONCLUSION

In this paper, we have presented a new method for the skin deformation. Our method combines the global deformations (based on a geometric deformation) and the local deformations (based on a physically-based method). This combination allows simulating many cases of deformations. It can be used for the skin deformation in response to the skeleton movements and the collisions with other objects. In comparison to the existing methods, our system is able to handle the collision detection and response. Until now, collision detection was used for specific applications such as simulation surgical operations. By using collision response, it is possible to improve the realism of the body deformations. Moreover, by simulating the contact between the skin and the object with physically-based method, our system is able to simulate grasping objects. We believe that it can be used to improve the behavior of synthetic human grasp.

7. ACKNOWLEDGEMENTS

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