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Shape modeling for animated characters using ordinary differential equations

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ABSTRACT

In this paper, we develop a new approach to animate skin deformation of character models. It aims to combine the strengths of joint-based approaches, physics-based algorithms and curve-based surface modeling methods together for efficient and realistic animation of skin deformation. We first transform the deformation of skin surfaces of character models into that of the curves defining the skin surfaces, and introduce a mathematical model consisting of a vector-valued fourth order ordinary differential equation and boundary conditions to describe the curve deformation. In order to achieve capacity and high animation efficiency, we propose an efficient finite difference solution of the mathematical model, and apply our proposed solution to animate skin deformation of character models. The application examples demonstrate that our proposed approach can create realistic skin deformations for real-time character animation.

1. Introduction

Skin deformation plays a very important role in creating realistic and efficient character animation. How to create high-fidelity skin deformations quickly is one of the most challenging areas of computer animation. To this end, various skin deformation techniques have been developed. Among them, joint-based [1], physics-based [2], and example-based techniques [3] are widely applied, and curve-based surface modeling [4] also has some applications.

Joint-based techniques are the most popular in the animation industry because they seem intuitive. However, the animator must spend time and effort to manually manipulate the skin surface in relation to the motion of the skeleton. This is because the relationship between skin deformation and skeleton movement must be manually tuned by applying proper weights. Physics-based approaches consider anatomy and biomechanics and can create more realistic skin deformations. However, they involve a lot of numerical calculations, and reduce the efficiency of animating skin deformations. Example-based methods use example skin shapes to improve the realism of skin deformations. Although they do not require any manual skills to specify the weights required by skeleton-based techniques, sufficient example skin shapes must be used to achieve realistic skin deformations. Curve-based surface modeling transforms modeling and deformations of surfaces into those of curves. It is very efficient but requires investigations into the relationships between surfaces and the curves defining the surfaces.

As discussed above, there is not one complete method for skin deformation that can meet all the requirements of the animation industry like realism, effectiveness and less computational time. Each method has its strengths and weaknesses. This paper aims to combine the strengths of joint-based approaches, physics-based algorithms, and curve-based surface modeling methods, and uses two example skin shapes for efficient and realistic animation of skin deformations. It uses surface curves to define the skin shape, example skin shapes and the underlying physical law of curve deformations to improve realism, and employs curve shape changes to drive skin deformations for reducing computational cost. In order to maximize the capacity of our proposed approach, an efficient finite difference solution of the proposed mathematical model is developed. It can effectively tackle the problems of line distribution forces in local regions and/or concentrated forces which are difficult to solve with analytical approaches.

Our proposed approach first transforms a skin surface into a set of curves defining the skin surface. Then, the forces acting on the set of curves which drive the skin surface to deform from an initial pose to a final pose are determined using our proposed physics-based deformation algorithm similar to that of beam bending.

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Next, the forces at any poses between the initial and final poses are obtained using interpolation. With the obtained forces, our proposed physics-based algorithm will generate the deformation of all the curves and create the deformed skin surface.

2. Related work

Skin deformation techniques can be classified into three major categories: surface-based, volume-based and curve-based techniques [5].

Among various surface-based techniques, joint-based techniques deform skin surfaces through the transformations associated with the joints of the skeleton of a character model. Since the transformations do not involve the physics of skin deformations, skin shapes are achieved by manually applying appropriate weights to modify the transformations [6–13].

With volume-based techniques, biomechanics and anatomical structures are introduced to develop more accurate models and to achieve realistic skin deformation. These models usually comprise a skeleton, muscles, other tissues, and skin. The involvement of muscles and other tissues causes volumetric deformation [14–16].

Curve-based techniques [17–21] use the curves on skin surfaces to define character models. When animating skin deformation, these curves are deformed and the deformed curves are used to change skin surfaces into other shapes.

Example-based techniques are surface-based. In example-based techniques [10,22–26], the artist models different shapes and poses of the characters or reconstructs them from the data consisting of range scans of a human body in a variety of poses. New poses are interpolated from these poses.

Physics-based techniques can be surface-based or volume-based. They used anatomy, elastic mechanics, or biomechanics of skin deformation originating from the movements of muscles and tendons [27–33].

Recently, Kavan and Sorkine developed a closed form skinning method that combines joint-based techniques with physics-based techniques. This method minimizes an elastic energy function to optimize skinning weights [34].

The work given in this paper aims to take advantage of the strengths of skeleton-based skinning, physics-based approaches and curve-based surface modeling, and use two example skin shapes to improve realism and efficiency of animating skin deformations. In what follows, we first discuss the relationships between skin surfaces and curves defining the skin surfaces. Then we introduce curve-based static skin deformations. Next, we present a number of examples of skin deformations with our proposed approach followed by a conclusion.

3. Defining geometric models

Geometric models can be defined by four types of surfaces in Autodesk Maya: polygons, subdivision surfaces, patch modeling and with curves. In Autodesk Maya, a surface model can be changed into a wireframe model or created from a set of curves through skinning these curves. Curves can also be represented by Bézier, B-spline and NURBS.

In addition, the solution to a vector-valued fourth order ordinary differential equation subjected to suitably specified boundary conditions also gives a curve. Different from Bézier, B-spline and NURBS curves, the curves created by the solution to a vector-valued fourth order ordinary differential equation can be regarded as physics-based since the differential equation can be derived from the same methodology as that of beam bending. In the subsections below, we will use such curves to define surface models.

3.1. Basic principle

For curve-based surface modeling, the shape of a surface can be described by the curves on the surface. In order to use surface curves to animate a surface, we must find out the relationships between surface curves and the surface described by these curves. They include how to obtain the surface curves describing a surface from a polygon model, and how to transfer the deformations of the surface curves to the polygon model. We will discuss these two issues in the following subsections.

3.2. Converting a polygonal model into a curve defined surface model

First, we divide a model into different parts or surface patches (complicated parts should be decomposed into two or more simpler surface patches). Second, we create the curves defining each part or surface patch. To do this, we draw a rough central curve within each of the parts or surface patches. Then, some points at equal intervals are selected on the curve. From each point, we create a plane perpendicular to the curve. We use this plane to find out the intersecting points between the plane and the part or surface patch which forms a curve on the part or surface patch. With this method, we obtain all the curves defining the part model or surface patch and the central curve determined from the curves as shown in Fig. 1a. Then we transform these curves into those in the direction of the arm as indicated in Fig. 1b. Using the above curve creation method, we obtained the curves defining a human arm, human hand and complete human model with segments as shown in Fig. 1.

3.3. Converting a curve defined model back to a polygonal model

After the curves describing a polygon model are obtained, we can deform these curves and transfer the deformations of these curves to the polygon model to achieve the new shape of the polygon model. With this method, we can animate a polygon model efficiently.

There are two approaches which can be used for this purpose. One is to create a new model from these curves through the skinning method available in Maya software package and the other is to relate all surface points of the polygon model to these curves [20,21]. In this paper, we have used both approaches to generate deformed models.

4. Static skin deformation

In addition to the relationships between surface curves and the surface described by these curves, another main issue is how to deform the curves describing the surface realistically.

For static deformations, the mathematical model will consists of a time-independent vector-valued fourth order ordinary differential equation and boundary conditions. The purpose of introducing a fourth order ordinary differential equation to describe the deformations of curves is that the equation is similar to that of beam bending and it considers physical properties with an externally applied force to change the shape of curves. Therefore, it can produce more realistic deformation of curves than purely geometric shape manipulation.

Since the finite difference solution of the ordinary differential equation dealing with static deformations is very efficient and it has a capacity in tackling the problems of line distribution forces in local