Determination of Force Fields for Ode-based and Skeleton Driven Character Animation

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Abstract: In the existing work, character modelling and animation are two separate tasks. After a character model is built, a lot of time and efforts are still required to animate the character model. Ordinary differential equation-based surface modelling and animation using physically based deformable curves to define and deform skin surfaces of 3D character models. With such a technique, character modelling and animation can be integrated into a unified framework by introducing time-dependent varying force fields into ordinary differential equations. This paper addresses the issue of determination of the force fields and proposes three models, i. e. linear transformation model, interpolation model and extrapolation model, to obtain time-dependent varying force fields. Some application examples are presented which demonstrates the force fields obtained from the three models create believable skin deformations of character models.

1 INTRODUCTION

Skin deformation plays a very important role in realistic character animation. Various techniques of animating skin deformation have been developed. These techniques can be divided into three groups: skeleton-driven, physics-based and data-driven ones.

Among various skeleton-driven techniques, skeleton subspace deformation (SSD) is the most popular and widely used one. It was investigated by Thalmann et al., (1988), Lander, (1998; 1999), Weber, (2000), Wang and Phillips, (2002), Mohr and Gleicher, (2003), Yang et al., (2006) and Kavan et al., (2005).

Physics-based techniques were investigated by a lot of researchers such as Chen and Zeltzer, (1992), Wilhelms and Van Gelder, (1997), Scheepers et al., (1997), Jane and Allen, (1997), Nedel and Thalmann, (1998), Nedel and Thalmann, (2000), Aubel and Thalmann, (2001), Capell et al., (2002), Maryann et al., (2002), James and Pai, (2002), Larboulette and Cani, (2004), Guo and Wong, (2005), Venkataraman et al., (2005), Teran et al., (2005) and Capell et al., (2007).

Data-driven techniques were proposed to improve the skeleton subspace deformation by some researchers such as Lewis et al. (2000), Allen et al., (2002), Mohr and Gleicher, (2003), Kurihara and Miyata, (2004), Rhee et al., (2006), and Weber et al., (2007).

In addition to the above approaches, curve-based surface modeling has also been introduced. The examples include Shen and Thalmann, (1994), Singh and Fiume, (1998), Pyun et al., (2004), Hyun et al., (2005), Yoon and Kim, (2006), Nealen et al., (2007), and Gal et al., (2009).

Although curve based surface deformations become more active in recent years, how to introduce the underlying physics into curve based surface manipulation for more realistic deformations remains an open problem.

Ordinary differential equation-based surface modelling uses the same methodology as that of beam bending and can be regarded as physics-based. It integrates modelling and animation into a same framework by introducing time-dependent varying force fields.

Skin deformations of character models using ODE curve-based surface modelling and animation combine the strengths of skeleton-driven, physics-based, and data-driven techniques together. It also takes advantage of the high efficiency of curve-based surface modelling.

Due to the importance of force fields in ODE-based surface modelling and animation, this paper

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will address the issue how to determine the force fields.

2 MATHEMATICAL MODELS

The determination of time-dependent varying force fields is to change the force field at the rest pose to those at required poses. In this section, we propose three models: Linear transformation model, interpolation model, and extrapolation model.

2.1 Linear Transformation Model

The linear transformation model uses the same methodology as that of the skeletal subspace deformation to transform a force field at the rest pose to the required poses.

A force field consists of sculpting forces at the curve vertices. Therefore, we achieve the linear transformation of a force field by considering a sculpting force acting at a curve vertex $\mathbf{V}_{mni}$. The sculpting force acting at the vertex at the rest pose can be represented by $\mathbf{P}_{rmni}$ in the global coordinate system. Here the subscript r is used to indicate the rest pose.

First, we transform this sculpting force into the local coordinate system of the jth bone. The geometric transformation matrix from local to global coordinate system for the jth bone at the rest pose can be written as $\mathbf{M}_{rj}$.

Next, the bone is translated and rotated. The sculpting force defined in the local coordinate system of the jth bone is transformed back to the global coordinate system at the new pose. And a weight w_j is applied to scale the sculpting force to create realistic skin deformation. The geometric operation transforming the sculpting force back to the global coordinate system is described by the matrix $\mathbf{M}_{gj}$ where the subscripts gj indicate the geometric transformation from the jth transformed bone to the global coordinate system.

If there are J bones whose movements have the influences on the curve vertex $\mathbf{V}_{mni}$, the resultant sculpting force at the curve vertex $\mathbf{V}_{mni}$ should be the sum of those caused by each of the bones which can be written as

$$\mathbf{P}'_{rmni} = \sum_{j=1}^{J} w_j \mathbf{M}_{gj} \mathbf{M}_{rj}{}^{-1} \mathbf{P}_{rmni} \tag{1}$$

2.2 Interpolation Model

The interpolation model requires knowing the force fields at the rest pose and the final pose. Then the difference between the two force fields is found and the linear interpolation operation is used to find the force fields at the poses between the rest and final poses.

Assuming that $\mathbf{P}_{mn}^{r}$ and $\mathbf{P}_{mn}^{fr}$ is the force fields at the rest post and final pose, respectively, we first transform these two force fields to the pose θ and obtain the transformed force fields $\breve{\mathbf{P}}_{mn}^{r\theta}$ and $\breve{\mathbf{P}}_{mn}^{fr\theta}$. Then, we determine the force field at the pose θ using the following linear interpolation

$$\mathbf{P}_{mn}^{\theta} = \breve{\mathbf{P}}_{mn}^{r\theta} + \frac{\theta}{\theta_f} \breve{\mathbf{P}}_{mn}^{fr\theta} \tag{2}$$

where θ_f is the rotation angle from the rest post to the final pose.

2.3 Extrapolation Model

The determination of the force field using the extrapolation model is similar to that using the interpolation model. Both models use the skin shape at the rest pose. However, the extrapolation model used the skin shape at the pose adjacent to the rest pose. That is to say, we use the pose adjacent to the rest pose to replace the final pose in the interpolation model. Accordingly, equation (2) can be used to determine the force fields at any poses beyond the rest and adjacent poses by replacing the subscript and superscript f with the subscript and superscript a which indicates the pose adjacent to the rest pose.

3 APPLICATION EXAMPLE

The three models proposed in above section were used to determine the force fields of human fingers, a horse front leg, and a horse rear leg. The obtained force fields $\mathbf{F}(u)$ were incorporated into the following equation

$$D \frac{d^4 \mathbf{C}(u)}{du^4} = \mathbf{F}(u) \tag{3}$$

where

$$D = \frac{Eh^3}{12(1-\nu^2)} \tag{4}$$

Solving Eq. (3) subjected to the following boundary constraints where $\mathbf{S}(u,v_j)=\mathbf{C}(u)$

$$
\begin{aligned}
u=0 \quad & \mathbf{S}(u,v)=\mathbf{B}_0(v) \quad \frac{\partial \mathbf{S}(u,v)}{\partial u}=\mathbf{D}_0(v) \\
u=1 \quad & \mathbf{S}(u,v)=\mathbf{B}_1(v) \quad \frac{\partial \mathbf{S}(u,v)}{\partial u}=\mathbf{D}_1(v)
\end{aligned} \tag{5}
$$

we obtain the mathematical expression of a surface which is used to create skin deformations of these models.

3.1 Deforming Human Fingers with Linear Transformation Model

The linear transformation model was used to determine the force fields of human fingers whose skin shape at the rest pose is shown in Figure 1a. The obtained results were shown in b-d of Figure 1.

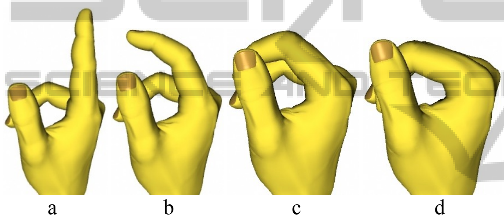

Figure 1: Skin deformation of human fingers from the linear transformation model.

3.2 Deforming a Horse Front Leg with Interpolation Model

In this subsection, we used the interpolation model to determine the force fields of a horse front leg at any poses between the rest pose and final pose. The skin shapes at the rest pose was indicated in Figure 2a and that at the final pose was presented in Figure 2e. The deformed skin shapes created were demonstrated in Figures 2b, 2c, and 2d.

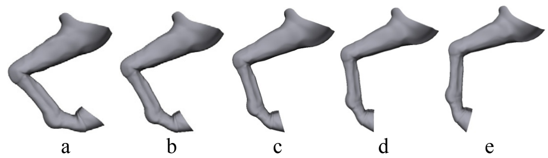

Figure 2: Skin deformation of a horse front leg from the interpolation model.

3.3 Deforming a Horse Rear Leg with Extrapolation Model

Finally, the extrapolation model was employed to determine the force fields of a horse rear leg at the poses beyond the two adjacent poses. The skin shapes at the two adjacent poses were given in Figures 3a and 3b. The deformed skin shapes created were depicted in Figures 3c, 3d and 3e.

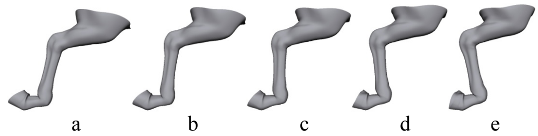

Figure 3: Skin deformation of a horse rear leg from the extrapolation model.

4 CONCLUSIONS

How to determine time-dependent varying force fields for ordinary differential equation-based surface modelling and animation has been addressed in this paper. We proposed three models to generate time-dependent varying force fields. They are linear transformation model, interpolation model, and extrapolation model.

In order to demonstrate the effectiveness of the proposed three models, we present some examples of skin deformations of character models. These application examples indicate that the force fields determined by the proposed three models create believable skin shapes.

Our future work is to introduce time-dependent varying force fields into dynamic ordinary differential equations which involves a time variable and considers dynamic effects of skin deformations.

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