Character Modeling using Physically based Deformable Curves

L. H. You[1], E. Chaudhry[1], X. Jin[2], X. S. Yang[1] and Jian J. Zhang[1]
[1]National Centre for Computer Animation, Bournemouth University, Poole, Dorset, U.K.
[2]State Key Lab of CAD & CG, Zhejiang University, Zhejiang, China

Keywords: Character Modelling, Physically based Deformable Curves, Sculpting Forces, Ordinary Differential Equations, Analytical Solution.

Abstract: Curve and physically based surface modelling techniques are becoming more and more active in geometric modelling of three-dimension (3D) objects since the former can create 3D models easily and quickly and the latter can produce more realistic appearances. In this paper, we present a curve and physically based surface modelling technique to create 3D models of virtual characters. This technique is based on physically based curve deformation. With such a technique, a character model is created from a number of surface patches. Each surface patch is obtained from physically based deformable curves. We introduce sculpting forces into a vector-valued ordinary differential equation to control the physically based deformations of curves. By describing concentrated sculpting forces with a sine series, we present an efficient analytical solution of the ordinary differential equation which can determine physically based curve deformations quickly. An example of character modelling is presented to demonstrate the application of our proposed technique.

1 INTRODUCTION

Virtual characters are widely applied in many industries. Currently, the most popular modelling techniques of virtual characters are polygon, NURBS and subdivision.

A lot of literature addresses polygon modeling such as Autodesk Maya Press (2006), Russo (2005), Apostol (2012), Patnode (2008) and Flaxman (2008).

NURBS tools can be found in various 3D modelling and animation software packages. There are many publications talking about NURBS such as Piegl and Tiller (1997), Reese (2000), Rogers (2000), and Farin (2001).

Subdivision modelling (Cashman 2012) depends on subdivision schemes. Approximating schemes include Catmull and Clark (1978), Doo and Sabin (1978), Loop (1978), Peters and Reif (1997), Habib and Warren (1999), and Kobbelt (2000). Interpolating schemes include Dyn and Levin (1990) and Zorin et al., (1996) etc.

Curve-based surface modelling creates free-form surfaces from some characteristic curves. It was investigated by Singh and Fiume (1998), Igarashi et al., (1999), Karpenko and Hughes (2006), Nealen et al., (2007), Liu et al., (2008), and Gal et al., (2009).

In addition to purely geometric modeling, physics-based modeling methods have been investigated by Terzopoulos and Fleischer (1988), Terzopoulos and Qin (1994), Xie and Qin (2004), Choi et al. (2004), Müller et al., (2005), Nealen et al., (2006), McDonnell and Qin (2007), and Swanson et al. (2009).

The work presented in this paper aims to combine the high efficiency of curve-based surface modelling with physically based shape deformation together and develop a new technique of character modelling.

2 MATHEMATICAL MODEL AND ANALYTICAL SOLUTION

A character model can be decomposed into a number of parts and some surface patches. Each of the parts and surface patches can be created separately. The parts can be produced by connecting its surface patches together, and the whole character model can be built by assembling these parts. In this section, we discuss the mathematical model of curve-based surface modelling and the solution of the mathematical model.

H. You L., Chaudhry E., Jin X., S. Yang X. and J. Zhang J..
Character Modeling using Physically based Deformable Curves.
DOI: 10.5220/0004297601190122
In *Proceedings of the International Conference on Computer Graphics Theory and Applications and International Conference on Information Visualization Theory and Applications* (GRAPP-2013), pages 119-122
ISBN: 978-989-8565-46-4

2.1 Mathematical Model

In order to maintain a smooth transition at the interface between two adjacent character parts, the position and first derivative of the two adjacent surface parts should keep the same at their joint interface. A character part has two ends which are at $u=0$ and $u=1$, respectively. Both ends are the two interfaces of the part. If we assume that the vector-valued position function and first partial derivative to be met by the character part are $\mathbf{C}_0(v)$ and $\mathbf{D}_0(v)$ at one end $u=0$ and $\mathbf{C}_1(v)$ and $\mathbf{D}_1(v)$ at the other end $u=1$, the surface $\mathbf{S}(u,v)$ of the part should satisfy the following boundary constraints

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

where $\mathbf{C}_i(u)=\left[C_{ix}(u) \quad C_{iy}(u) \quad C_{iz}(u)\right]^T \quad i=(0,1)$, $\mathbf{D}_i(u)=\left[D_{ix}(u) \quad D_{iy}(u) \quad D_{iz}(u)\right]^T \quad (i=0,1)$, and $\mathbf{S}(u,v)=\left[S_x(u,v) \quad S_y(u,v) \quad S_z(u,v)\right]^T$.

The surface $\mathbf{S}(u,v)$ of the character part can be created by a set of curves between two interface curves $\mathbf{C}_0(v)$ and $\mathbf{C}_1(v)$ and satisfying the constraints of the first partial derivatives $\mathbf{D}_0(v)$ and $\mathbf{D}_1(v)$, and the shape of the character part can be achieved by deforming the curves.

According to the concept of physics-based geometric modelling, a geometric object possesses material properties and geometric attributes such as length, width and thickness. For the physics-based geometric modelling of a curve with an elastic and isotropic behaviour, the material properties are Young's modulus E and Poisson's ratio ν, and the geometric attribute is the thickness h.

The lateral deformation of a curve is similar to the bending of an elastic beam. Therefore, the governing equation of the lateral deformation of a curve can be derived with the same methodology as that of the bending of an elastic beam which can be described by

$$D\frac{d^4\mathbf{C}(u)}{du^4}=\mathbf{F}(u) \tag{2}$$

where

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

and $\mathbf{C}(u)=\left[C_x(u) \quad C_y(u) \quad C_z(u)\right]^T$ is a vector-valued deformation function of the curve, and $\mathbf{F}(u)=\left[F_x(u) \quad F_y(u) \quad F_z(u)\right]^T$ is a vector-valued function of sculpting forces.

The solution to equation (2) represents an arbitrary 3D curve. At the two ends of the curve, the curve should satisfy boundary constraints (1) at a certain position $v=v_i$. When v changes from 0 to 1, a set of curves are generated which define a 3D surface $\mathbf{S}(u,v)$. Therefore, equations (2) and (1) form the mathematical model of a 3D surface describing a part of character models. In the following section, we discuss how to solve the mathematical model.

2.2 Analytical Solution of Mathematical Model

Equation (2) is a vector-valued nonhomogeneous fourth order ordinary differential equation. According to the knowledge of ordinary differential equations, the general solution of Eq. (2) consists of two parts: the complementary solution and the particular solution which can be written as

$$\begin{aligned} \mathbf{C}(u) &= \mathbf{d_0}+\mathbf{d}_1 u+\mathbf{d}_2 u^2+\mathbf{d}_3 u^3+\frac{2}{D\pi^4} \\ & \sum_{n=1}^{\infty}\frac{1}{n}\Big[\sum_{i=1}^{I}\mathbf{p}(u_i,v_j)\sin n\pi u_i\Big]\sin n\pi u \end{aligned} \tag{4}$$

The following work is to generate a 3D surface $\mathbf{S}(u,v)$ from the curve (4) and boundary constraints (1). At the position v_j, the surface becomes a curve defined by Eq. (4). Therefore, boundary constraints (1) can be changed into

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

Inserting Eq. (4) into the above boundary constraints, we can determine all the four vector-valued unknown constants $\mathbf{d_0}$, $\mathbf{d}_1$, $\mathbf{d}_2$ and $\mathbf{d}_3$, and obtain the mathematical expression of the curve.

Since v_j can be any values within the range [0, 1], we change v_j into v, and obtain the mathematical representation of a 3D surface which will be used to create various surface patches between two boundary curves in the following section.

3 APPLICATION EXAMPLE

In this section, we use our proposed technique to build a horse model. A house is first decomposed into parts. These parts are body, ears, legs and tail. Taking one leg of the horse whose profile curve is shown in Figure 1a as an example, we further decompose the leg into 4 surface patches. Then we draw the five boundary curves shown in Figure 1b.

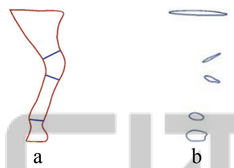

Figure 1: Creation of boundary curves of a horse leg.

From the first and second curves from the top in Figure 1b, we create the first surface patch shown in Figure 2a. The second, third and fourth patches are from the second and third boundary curves, the third and fourth boundary curves, and the fourth and fifth boundary curves, respectively. These three created surface patches are given in Figures 2b 2c, and 2d, respectively.

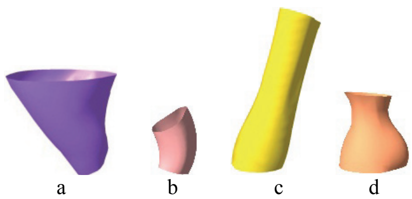

Figure 2: Surface patches of a horse leg.

Then we put the four surface patches together and build the horse leg model shown in Figure 3a. Similarly, we obtained the other three legs which are shown in Figures 3b, 3c and 3d, respectively.

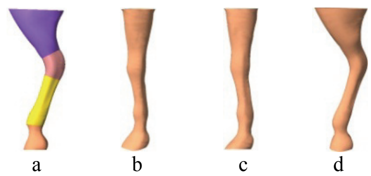

Figure 3: Creation of horse legs.

With the same method, the other parts of body, ears, and tail were produced and depicted in Figures 4a, 4b, 4c and 4d.

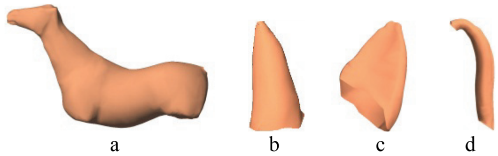

Figure 4: Creation of horse body, ears and tail.

The last step of the horse modelling is to assemble all parts together. For the surface patches which share common boundary curves and the first partial derivatives, the positional and tangential continuities are maintained automatically. However, for the surface patches which intersect each other, we first determine the intersecting curves between them. Then, two curves which are on the intersecting surface patches and close to the intersecting curves are determined. And a blending surface between these two curves is created to smoothly connect the two intersecting surface patches together. With the above treatment, we built the horse model and depicted it in Figure 5.

Figure 5: Created horse model.

4 CONCLUSIONS

A new modelling technique of character models has been proposed in this paper. This technique aims to combine curve-based surface modelling and physically based deformations together, and creates free-form surfaces using physically based deformable curves. A vector-valued fourth order ordinary differential equation involving concentrated sculpting forces is introduced to achieve physically based deformable curves, and sharing of boundary curves and the first derivatives by two adjacent patches is used to obtain the positional and tangential continuities of two adjacent patches at the shared boundary curves.

In order to make the proposed technique build character models efficiently, we transformed concentrated sculpting forces into an analytical mathematical expression and derived the analytical solution of the vector-valued fourth order ordinary differential equation by means of the analytical mathematical expression of concentrated sculpting forces.

We have applied our proposed technique in the modelling of a horse model which demonstrates the effectiveness of our proposed technique in character modelling.

ACKNOWLEDGEMENTS

This research is supported by the grant of UK Royal Society International Joint Projects / NSFC 2010.

REFERENCES

Autodesk Maya Press. 2006. *Learning Autodesk Maya 8|Foundation +DVD*. Sybex, Bk & DVD edition.

Russo, M. 2005. *Polygonal Modeling: Basic and Advanced Techniques*. Wordware Publishing Inc.

Apostol, K. 2012. *Polygonal Modeling*. Salupress.

Patnode, J. 2008. *Character Modeling with Maya and ZBrush: Professional polygonal modeling techniques*. Focal Press.

Flaxman, T. 2008. Maya 2008 *Character Modeling & Animation: Principles/Practices*. Charles River Media.

Piegl, L. Tiller, W. 1997. *The Nurbs Book*. Springer.

Reese, A. 2000. *NURBS Modeling in 3D Studio Max*. US Imports & PHIPEs.

Rogers, D. F. 2000. *An Introduction to NURBS: With Historical Perspective*. Morgan Kaufmann.

Farin, G. 2001. *Curves and Surfaces for CAGD*, Fifth Edition: A Practical Guide. Morgan Kaufmann.

Cashman, T. J. 2012. Beyond Catmull–Clark? A survey of advances in subdivision surface methods. *Computer Graphics Forum 31(1)*: 42-61.

Catmull, E., Clark, J. 1978. Recursively generated B-spline surfaces on arbitrary topological meshes. *Computer-Aided Design 10(6)*: 350-355.

Doo, D., Sabin, M. 1978. Behavior of recursive division surfaces near extraordinary points. *Computer-Aided Design 10(6)*: 356-360.

Loop, C. 1978. *Smooth Subdivision Surfaces Based on Triangles*, M.S. Mathematics thesis, University of Utah.

Peters, J., Reif, U. 1997. The simplest subdivision scheme for smoothing polyhedra. *ACM Transactions on Graphics 16(4)*: 420-431.

Habib, A., Warren, J. 1999. Edge and vertex insertion for a class C^1 of subdivision surfaces. *Computer Aided Geometric Design 16(4)*: 223-247.

Kobbelt, L. 2000. √3-subdivision. *Proceedings of ACM SIGGRAPH*, pp. 103-112.

Dyn, N., Levin, D. 1990. A butterfly subdivision scheme for surface interpolation with tension control. *ACM Transactions on Graphics 9(2)*: 160-169.

Zorin, D., Schröder, P., Sweldens, W. 1996. Interpolating Subdivision for Meshes with Arbitrary Topology. *Proceedings of ACM SIGGRAPH*, pp. 189-192.

Singh, K., Fiume, E. 1998.Wires: a geometric deformation technique. In *Proceedings of SIGGRAPH 98*, pp. 405-414.

Igarashi, T., Matsuoka, S., Tanaka, H. 1999. Teddy: a sketching interface for 3D freeform design. *In Proceedings of the 26th annual conference on Computer graphics and interactive techniques (SIGGRAPH 99)*, ACM Press/Addison-Wesley Publishing Co., p. 409-461.

Karpenko, O. A., Hughes, J. F. 2006. Shape modeling and textures: SmoothSketch: 3D free-from shapes from complex sketches. *ACM Transactions on Graphics (SIGGRAPH 06) 25(3)*: 589-598.

Nealen, A., Igarashi, T., Sorkine, O., Alexa, M. 2007. FiberMesh: Designing freeform surfaces with 3D curves. *SIGGRAPH 07 and ACM Transactions on Graphics 26(3)*: #41, 1-9.

Liu, L., Bajaj, C., Deasy, J. O., Low, D. A., Ju, T. 2008. Surface Reconstruction From Non-parallel Curve Networks. *Computer Graphics Forum (EUROGRAPHICS 2008) 27(2)*: 155-163.

Gal, R., Sorkine, O., Mitra, N. J., Cohen-Or, D. 2009. iWIRES: An analyze-and-edit approach to shape manipulation. *ACM Transactions on Graphics (SIGGRAPH 09) 28(3)*: #33, 1-10.

Terzopoulos, D., Fleischer, K. 1988. Modeling inelastic deformation: viscoelasticity, plasticity, fracture. *SIGGRAPH 88 and Computer Graphics 22(4)*: 269-278.

Terzopoulos, D., Qin, H. 1994. Dynamic NURBS with geometric constraints for interactive sculpting. *ACM Transactions on Graphics 13(2)*: 103-136.

Xie, H., Qin, H. 2004. A Physics-based Framework for Subdivision Surface Design with Automatic Rules Control. *In Proceedings of the 10th Pacific Conference on Computer Graphics and Applications*, pp. 304-315.

Choi, K.-S., Sun, H., Heng, P.-A., Zou, J. 2004. Deformable simulation using force propagation model with finite element optimization. *Computers and Graphics 28(4)*: 559-568.

Müller, M., Heidelberger, B., Teschner, M., Gross, M. 2005. Meshless deformations based on shape matching. *SIGGRAPH 05 and ACM Transactions on Computer Graphics 24(3)*: 471-478.

Nealen, A., Müller, M., Keiser, R., Boxerman, E., Carlson, M. 2006. Physically based deformable models in computer graphics. *Computer Graphics Forum 25(4)*: 809-836.

McDonnell, K. T., Qin, H. 2007. A novel framework for physically based sculpting and animation of free-form solids. *The Visual Computer 23(4):* 285-296.

Swanson, K. W., Brakke, K. A., Breen, D. E. 2009. Physics-based Surface Modeling using Quasi-Static Liquids. *Computer-Aided Design and Applications* 6(1-4): 1-11.