ADAPTIVE CONSTRAINT AND 3D SKETCH-BASED DEFORMATION FOR INTERACTIVE FREE FORM SURFACE STYLING

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Keywords: Physical-based modelling, adaptive constraint, free form sketching, local deformation.

Abstract: This paper tries to answer to the increasing demand in the domain of conceptual design for more intuitive methods for creating and modifying free-form curves and surfaces. This is done by addressing the issue of physical-based shape control by free hand spline sketching instead of the tedious mathematical parameters adjustment. We present a novel approach capable of matching the designer's requirements in terms of quality and accuracy of the produced model. The algorithm adopts a simple 3D sketching technique and a finite element deformation method to create free-form models. In the method proposed the user applies interactive sculpting to modify a surface in a predicable way. Our algorithm automatically extracts the key points from sketched target curve and adaptively distributes the external-force constraints which impose the force energy on the corresponding control vertexes along their normal. We have limited the influence of these constraints to a localized area by attaching an influence factor to each control vertex of the parent surface. The smoothing function introduced later further solves the transition interval and it provides for symmetry features. This proposed method is finally implemented in a 3D scene environment and the results show how the designers intuitively and exactly control the shape of the surface.

1 INTRODUCTION

Efficient and intuitive shape manipulation techniques are vital to the success of geometric modeling, computer animation, physical simulation and other computing areas. Recently considerable achievements have been reached through the adoption of Free-Form Deformation (FFD) and Extended Free-form Deformation (EFFD). These embed the whole object into a tensor product volume, and the volume can be deformed by means of spline control points while the embedded object is deformed accordingly. Unfortunately, manipulation of splines is not intuitive. Although other physical-based manipulation approaches improve the natural operation and a new medial Axial Deformation method (AxDf) is being currently proposed to achieve better deformation results, the degree of freedom available to control the shape is still limited.

The technique presented here supports fully interactive and intuitive shape control, ranging from free-form surface creation to predictable shape deformation. We proposed three surface generation modes based on easy freehand sketching. During the implementation of the deformation, our method adaptively extracts force constraints and it automatically adjusts the corresponding control vertices in response to the external force distribution. Furthermore, a series of linear influence functions are introduced to improve the continuity and the symmetry.

The rest of the paper is organized as follows: in section 2 we present the previous works. Section describes the parent surface creation and relevant concepts. In section 4 we detail the implementation of the algorithm showing how to control the deformation process. Section 5 describes some experimental results. Finally in section 6 we conclude with a summary and describe the directions of future work.

2 PREVIOUS WORKS

The first modeling deformation technique introduced into the CAD/CAM field was the method relying on

Han L., De Amicis R. and Conti G. (2006).
ADAPTIVE CONSTRAINT AND 3D SKETCH-BASED DEFORMATION FOR INTERACTIVE FREE FORM SURFACE STYLING.
In *Proceedings of the First International Conference on Computer Graphics Theory and Applications*, pages 392-399
DOI: 10.5220/0001352803920399

global and local deformations (Barr, 1984). This method and its improvements (Güdükbay, 1990) can provide support for regular deformations such as twisting, tapping, bending, rotating and scaling. However the method does not easily yield arbitrary shapes and, further, it involves tedious and unintuitive geometric operations. Free-Form Deformation (FFD) (Sederberg, 1986) tackles the issue of generating more complex objects through geometric modeling. Specifically a geometrical element such as a point, a line, a plane etc. is chosen together with special weight factors and by taking their weighted average to express a complex shape. Then, to induce deformations within such complex shape, those control points are moved, while the local object points' coordinates are deemed to remain unchanged: i.e. the topological structure of the deformed object remains unchanged (Bechmann, 1994). In fact, FFD is one of the most versatile and powerful deformation tools, however it is not easy for the user to exactly predict the deformation to exactly reach a desired effect. Further exact placement of object points is hard to achieve. In literature (Kalra, 1992; Lamousin, 1994; Griessmair, 1989; Coquillart, 1991; Chadwick, 1989) it is possible to find FFD improved in terms of shape control functions, whose results have been exploited in several domains including human body animations and dynamic flexible deformations. However, while these approaches increase control flexibility, on the other hand they require the solution of complex nonlinear equations with numerical methods.

Another approach which promotes an easier and more intuitive interface is the so-called Extended Free-Form Deformation (EFFD) technique proposed in (Coquillart, 1990). With EFFD, instead of starting with the FFD's set of parallelepipeds control points, the user configures the initial lattice of control points taking into account the approximate shape of the intended deformed shape. However, the user must know the general shape before starting to model, and the interface is still a direct representation of the underlying mathematics.

Thanks to the introduction of constraint points and radius the authors in (Borrel, 1994) present a good technique for local deformation which was further improved by (Xiaogang, 2000) to the extent which, not only it conducts to deformation of point constraints, but also lines and surfaces constraints. Léon et al. (Léon, 1997; Léon, 1995; Léon, 1991) have linked the control polyhedron of a surface to the mechanical equilibrium of a bar network by using the force density concept. Although its effect on the deformation is very satisfactory in terms of aesthetic feeling, it often needs the solution of high-order systems of linear equations which generally need demanding complex computations.

3 SURFACE CREATION AND RELEVANT CONCEPTS

In the approach implemented we adopt a physical-based method that incorporates both external force energies and internal deformation distributions into the parent NURBS geometric surface.

During the implementation both the "parent surface" creation by user interactive sculpting and the "target surface" construction through spline-driven approach underline the physical meaning and predictable motion features.

3.1 The Creation of Parent Surface

The so-called "parent surface" is the surface which will be affected by the deformation. As mentioned earlier, it can be obtained in three different ways:

1. *Geom-filling mode*: the designer is allowed to sketch two or more 3D curves which serve as the constrained boundary of the surface.
2. *Skinning mode*: the designer sketches a surface by using the well-known concept of extrusion. He/she first draws a free-form 3D curve, then the curve is attached to the pointer and when the pointer is moving, the process of surface generation starts and the shape is immediately shown.
3. *Revolving mode*: the designer can generate a surface by revolving a curve around one axis.

In this process, the technique developed supports fully freehand curve sketching, and as a result, the NURBS parent surface is constructed by a "multi-patch" which is composed of a compatible network of iso-parametric curves as it is shown in formula 1, where *numRow* and *numCol* represent the number of iso-parametric curve *C(u,v)* in *U* and *V* directions.

$$S\left(\sum_{i=1}^{numRow} C_i(u,v);\ \sum_{j=1}^{numCol} C_j(u,v)\right); \qquad (1)$$

In the following section, we will further describe how the constraint-based resultant surface is finally reconstructed by combining multi-patch with so-called "physical force" distribution technique.

3.2 Relevant Concepts

Before illustrating further details of the approach we first introduce the mathematical representation behind the process presented in the following sections.

Bound curve and Target curve

Let C: $\varphi\ (u, v) = 0$ be a sketched closed-curve in 3D space. It will be used for deciding the region to be deformed. The influence factor $E\ (Q_j)\ (0 \le j \le Nt)$ is attached to each control vertex Q_j within the parent surface $S\ (u, v)$, where Nt is the number of the control vertex in parent surface. If the control vertex Q_j lies inside the bound curve, E is equal to 1 and it can be influenced by force constraints, otherwise E is set to 0 and it will thus keep a "static" status;

$$E(Q_j) = \begin{cases} 1 & \varphi(u_j, v_j) \le 0 \\ 0 & \varphi(u_j, v_j) > 0 \end{cases} \quad (2)$$

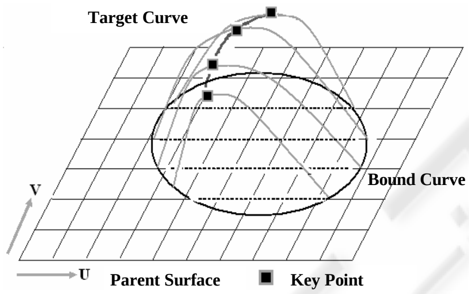


Figure 1: Target curve (in purple) influences only the area which is inside of the bound curve (in dark)

Likewise the sketched target curve is used to define the resultant shape by $\Psi\ (u, v) = 0$. A series of force energies are adaptively produced through the key points on this curve (see Figure 1).

The next section will illustrate how we effectively obtain these force energies and how they influence the whole parent surface.

Linear force energy fi (Ki ,P).

We define K_i as the key points on target curve and $D\ (K_i)$ as the projection distance from K_i to the parent surface $S\ (u, v)$ along the normal N_i (see Figure 2 - left). Q_j is the closest control vertex to the projected point P which is used for determining the corresponding curve on the parent surface. In this way, the energy of each force $f_i\,(K_i\,,P)$ will be distributed among the vertices on the corresponding curve. Therefore, the parent surface will be gradually approximated to the leading target curve (see Figure2 - right).

$$f_i\,(K_i\,, P\,) = E(Q_j)D(K_i) = \begin{cases} D(K_i) \\ 0 \end{cases} \quad (3)$$

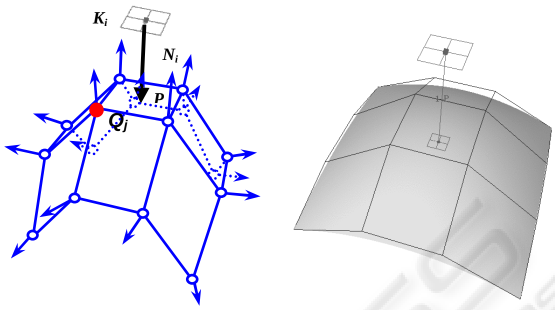


Figure 2: (Left) the multi-patch structure of a surface. K_i is the key point which imposes the force energy f_i to the patch, and Q_j is the closest vertex to the projected point P. (Right) the resultant surface under the influence of the force f_i.

The force intensity "α"

Within our model, "α_i" represents the contribution of the i^{th} force energy to the parent surface $S\ (u, v)$. If the projected point P lies in one patch, the force will be distributed among the neighboring four vertices (see Figure 3);

$$\alpha_j\ (u_j, v_j) = \alpha_0\ x_b\ y_b \quad (4)$$

$$F\ (Q_j) = \alpha_j(u_j, v_j) f_i(K_i, P) = \alpha_j(u_j, v_j) E(Q_j) D(K_i) \quad (5)$$

$$\delta F_i(C(u,v)) = \sum_{t=1}^{Np} F(Q(u_t, v_t)) \quad (6)$$

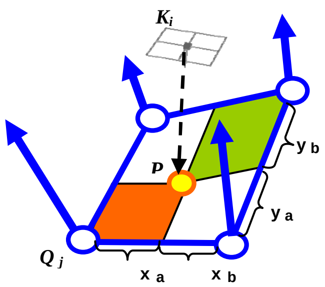


Figure 3: Force Intensity distribution in one patch. P is the projected points from key point K_i; then as the intensity of the force to the closest vertex Q_j, "α_j" is varied according to the extent of area $x_b\ y_b$

Here x_a, x_b, y_a and y_b are defined as the distance from P to the four neighbor vertices, and the unit of the intensity "α_0" is set to "1". Then the force exercises its effect inversely to the extent of the area.

Therefore the force's influence on the control vertex Q_j can be described as $F(Q_j)$ (see formula 4, 5). In formula 6, $\delta F_i(C(u,v))$ represents the force's influence on the whole curve, where the *Np* is the number of control vertex on this curve.

Resultant Surface

Finally we call D_L the replacement function, which represents the extent to which the parent surface is influenced by the force *f*. We assume ***Nc*** as the number of curves and ***Nt*** as the number of the control vertices on the parent surface, ***m*** is the number of the force constraints. Then the resultant surface *S' (u, v)* is obtained as:

$$D_L(u,v)=\sum_{i=1}^{m}\sum_{k=1}^{Nc}\delta F_i(C_k(u,v))=\sum_{i=1}^{m}\sum_{j=1}^{Nt}\alpha_j(u_j,v_j)\bullet E(Q_j)\bullet D(K_i) \quad (7)$$

$$S'(u,v)=D_L(u,v)+S(u,v)$$

4 SKETCH-BASED LOCAL DEFORMATION

4.1 Local deformation algorithm

The algorithm followed briefly depicts the implementation of local deformation where applicable through the help of pseudo code description.

Step1: The user creates a free form surface *S (u, v)* in the preferred mode (e.g. by geom-filling, skinning or revolving);

Step2: The user draws a bound curve φ *(u, v)* and consequently the system calculates the influence factor $E(Q_j)$ for each vertex.

Step3: The user sketches the target curve Ψ *(u, v)*;

IF (Over-constrained) *then Goto* Step *5*;

IF (Under-constrained) *or* (Well-constrained)

1. The system predicts the motion tendency of the target curve "*_DiR*" and it determines the number of force constrains "*m*"
2. Switch (*_DiR*)

   Case (U direction):

   The curves in *V direction* evolve by repositioning control vertexes according to each force constraint;

   Case (V direction):

   Likewise, the curves in *U direction* evolve by repositioning control vertexes.
3. The system resolves the transition intervals and it improves the symmetry.

*Step4***:** The system renders the resultant surface

*Step5***:** End

In the following sections we will detail how to effectively obtain the key points on the sketched target curve and how to classify three different constraints configurations to further improve boundary features of resultant surface.

4.2 The number of force constraints "m"

Since the designer's sketching activity produces only an approximation of the desired shape, it is important that the resultant surface captures the "shape" features of the leading target curve. However, in the free-form domain, the number of the constraints is usually unknown. Most current approaches provide only a solution that is a result of a predetermined criterion.

We instead propose a method which adaptively provides such criteria through the prediction of the motion of target curve (see Figure 4).

We then adopt the partial derivatives θ_1 and θ_2 (see equation 8). As shown in Figure 4 we can easily get the points P_s (u_s, v_s) and P_e (u_e, v_e) by projecting K_s and K_e onto the parent surface *S (u ,v)*. Then the span of patches can be obtained, where *Cs* and *Ce* are respectively the curve position in the V direction while *Rs* and *Re* are the curve position in the U direction.

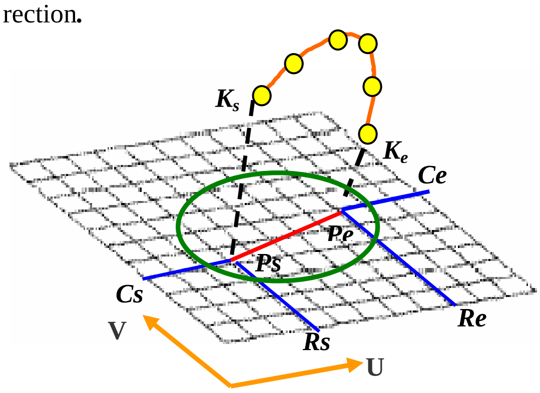


Figure 4: The Parent surface with bound curve (in green) and target curve (in orange); the yellow circles represent the key points which are adaptively produced by considering the value of "m".

$$\theta_1 = \frac{\partial \psi}{\partial u};\quad \theta_2 = \frac{\partial \psi}{\partial v};$$
$$m = \begin{cases} Ce - Cs & ; \ \theta_1 \geq \theta_2 \\ Re - Rs & ; \ \theta_1 \prec \theta_2 \end{cases}$$
$$Re, Rs, Cs, Ce \quad \in Integer \qquad (8)$$

When $\theta_1 \geq \theta_2$, the target curve is leading towards the *V* direction. Therefore the number of key points (constraints number) on the target curve "*m*" is determined by the difference between *Ce* and *Cs*. Vice versa, when $\theta_1 < \theta_2$, "*m*" is valued by the difference between *Re* and *Rs*. In this way the key points on the target curve will be adaptively produced and they will impose the force's spring to the surface.

4.3 Improvement of the boundary feature of the resultant surface

During the deformation process, we have excluded the option of fixing all the control vertices outside the bound curve and operating only on those inside. However this choice could still result in an inaccurate and insufficient deformed shape around the bound curve. Furthermore, the leading target curve may result over-constrained or just show unacceptable undulations.

To avoid these issues, we propose ***two means*** to improve the quality of the result of the deformation.

First, we classify the constraints into three cases:

- Over-constrained: if the target curve completely lies outside the bound curve.
- Under-constrained: if the target curve partly lies inside the bound curve.
- Well-constrained: if the target curve lies well inside the bound curve.

When the configuration is over-constrained, the parent surface will not be affected. Conversely when the configuration is under-constrained or well-constrained, we will use the aforementioned Formula 8 and four extremes (see Figure 5) to calculate the adaptive constraints.

Secondly, we introduce two factors to resolve the undulations near the bound region.

1) Approximation Scale

We provide the scale factor "λ" (Li, 2005), through which the users can interactively adjust the degree of approximation to the target curve as detailed in Formula 9.

$$\lambda \ \ f_i(K_i, P) = \lambda \ \ E(Q_j) D(K_i) = \begin{cases} \lambda \ D(K_i) \\ 0 \end{cases} \quad 0 \leq \lambda \leq 1 \qquad (9)$$

2) Relaxation Interval.

The so-called Relaxation Interval is used to provide the transition parts, from two ending points on the target curve to the parent surface.

We define them through computing the minimum bounding box of bound curve, and then four extremes can be obtained: *MinRow*, *MaxRow*, *MinCol* and *MaxCol*. As shown in Figure 5-top, the relaxation intervals T_{P1}, T_{P2} are valued by the span of the patches $|Re - MaxRow|$ and $|Rs - MinRow|$. The force $f_1(K_s, P)$ and $f_m(K_e, P)$ will gradually decrease to reach zero within these two parts as it is shown in Formula 10 and Formula 11.

$$\{\delta F_1(C_r(u,v))\}_{r=Rs}^{Minrow} = \sum_{r=Rs}^{Minrow} \sum_{j=1}^{Np} \alpha_j(u_j, v_j) \frac{f_1(K_s, P)(r - Minrow)}{|Rs - MinRow|} \qquad (10)$$

$$\{\delta F_m(C_r(u,v))\}_{r=Re}^{Maxrow} = \sum_{r=Re}^{Maxrow} \sum_{j=1}^{Np} \alpha_j(u_j, vj) \frac{f_m(K_e, P)(Maxrow - r)}{|Re - MaxRow|} \qquad (11)$$

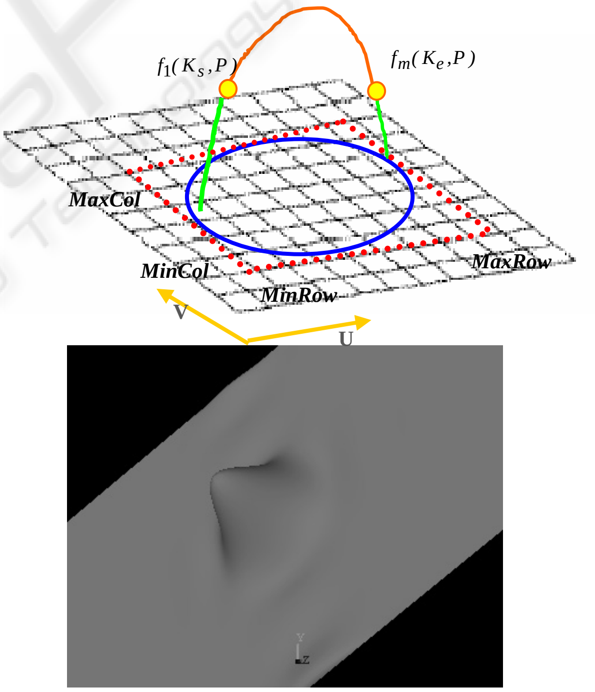


Figure 5: (Top) the Relaxation Interval T_{P1} and T_{P2} in green line. (Bottom) an example of dealing with relaxation interval.

4.4 The smoothing function for symmetry and discontinuity features

Since the target curve used to drive the deformation process of the surface might be characterized by a sharp line behavior (see Figure7-left), we propose a smoothing function to improve the symmetry feature of the deformed surface. This provides strong visual impact of the quality of the surface within such areas.

Without the need for any new patches insertion, we maintain the same topology by symmetrically distributing the external force influence to the corresponding curve (see Figure.6).

$$Tolerance = \frac{Np}{2\|C(u,v)\|} \qquad (12)$$

$$\delta F_i(C(u,v)) = \sum_{t=1}^{Np} F(Q(u_t,v_t)) = \sum_{t=r}^{1} \frac{\lambda E(Q_t) D(K_i)\ \alpha_t(u_t,v_t)\ t}{Tolerance} + \sum_{t=r}^{Np} \frac{\lambda E(Q_t) D(K_i)\ \alpha_t(u_t,v_t)\ t}{Tolerance}$$

$$Q_t \in C(u_t,v_t) \quad 1 \le t,\ r \le Np \qquad (13)$$

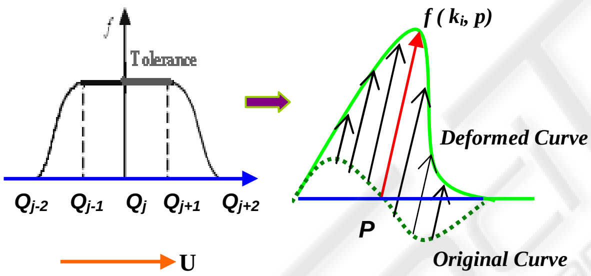


Figure 6: The force f is symmetrically distributed along the curve; (left) the “tolerance” serves as a step; Q represents different vertex in this curve. (Right) the deformed curve is produced by symmetrical force distribution.

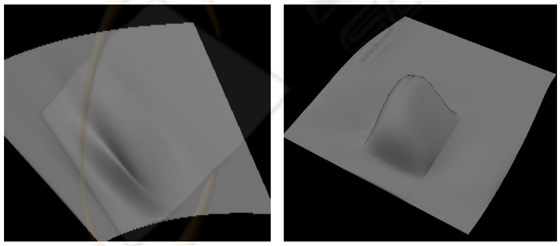


Figure 7: before smoothing (left) and after smoothing (right)

The details are shown in formula 12 where the value $\|C(u,v)\|$ is the length of curve *C*, while *Np* is the number of control vertices on each curve. The *tolerance* factor is used to determine the step of the distribution, along the corresponding curve.

From formula 13, we can achieve symmetric space deformation by symmetrically and gradually distributing $f_i(K_i,P)$ to different control vertex Q_t on the parent surface. The results can be compared in Figure 7.

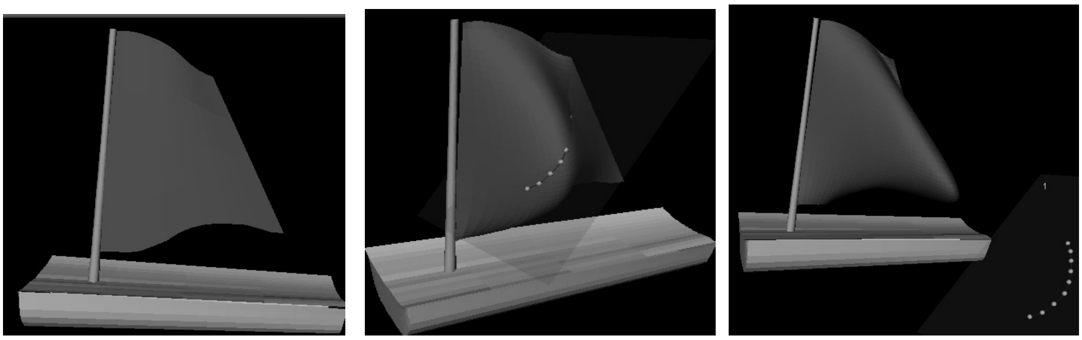
5 EXPERIMENT AND RESULTS

We have implemented our method in C++ with OpenGL and OpenInventor 4.0 on a Pentium 4 1.6GMhz with 512MB of RAM. This implementation provides real-time feedback (approx 20 frames per second for average 30,000 vertices) with a sequence of deformations.

In order to improve the interaction for the required shape, we have developed a 3D dragger metaphor, which can be freely controlled in 3D space. This is used for handling the plane in which the object lies. So that the user is capable of dynamically controlling the target curve and parent models to reproduce a series of results. Meanwhile in our application, all the objects can be adjusted by freely “oversketching”.

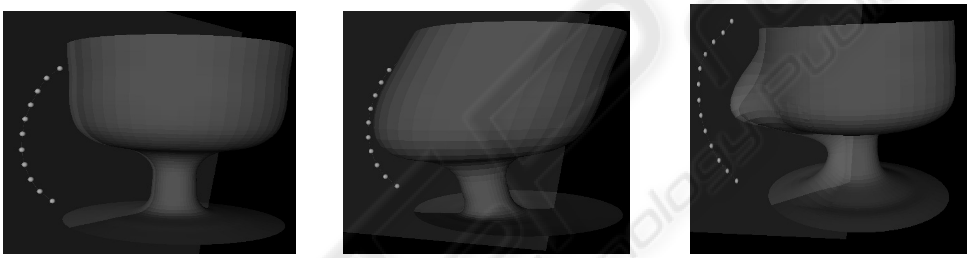
Furthermore, we apply two methods to limit the influence of the force to the surface. The first is that the local area is directly obtained by projecting the target curve onto the parent model. In this way a series of springs are produced in the parent model which are going to respond to the energy strains from the target curve. In the second method, we directly define a local region by sketching a bound curve as aforementioned. The comparison is shown in the following figures.

Our experiments indicate that our method is intuitive and effective for creating and editing a large variety of free form shapes (see Figure 8, 9, 10).



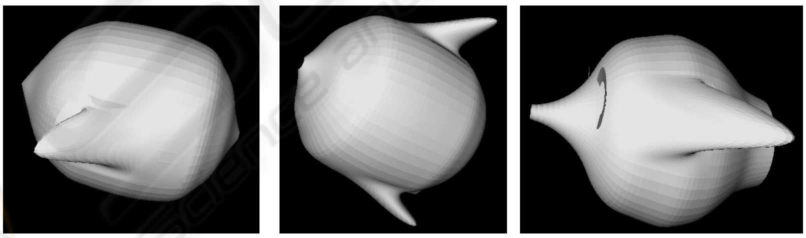
(a) *(b)* *(c)*

Figure 8: Dynamical shape control by spline-driven deformation method where the parent surfaces are respectively generated by geom_fill, skin, and revolving. (a) The red sail is selected as the sensitive surface which is going to be deformed. (b) The local area is automatically obtained by projecting target curve (blue spline) onto the surface. When the target curve is close to the parent model the target curve imposes high force intensity to the local area. (c) When the target curve is moving away from the parent model, the influenced region becomes smaller but the force energy becomes stronger and consequently the surface will be dynamically adjusted in response to the energy distribution.

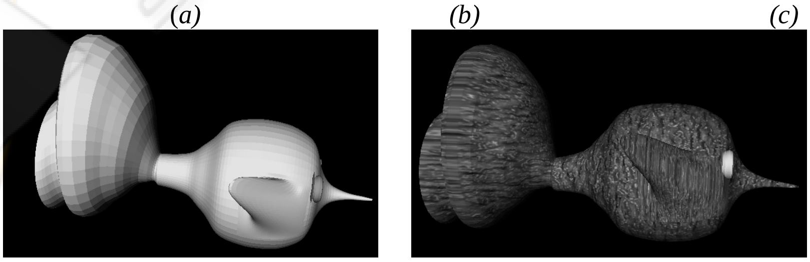


(a) *(b)* *(c)*

Figure 9: Three stages of the operation: (a) Before the deformation. (b) Without a predefined local region: the key points in the target curve (blue balls) produce force springs in the surface and only impose strain to these sensitive springs. However the influence can not be strictly localized. (c) With the predefined local region, the force's influence can be well localized.



(a) *(b)* *(c)*



(d) *(e)*

Figure 10: (a) (b) (c) with the predefined local region we can properly control the result of the deformation. (d) We provide interactive shape control which allows to re-deform any selected parts. (e) The texture is applied and its mapping is dynamically changed with the user interaction.

6 CONCLUSION AND FUTURE WORK

In this paper, we present a physical-based deformation method. When working with our deformation method, the designer does not need to manipulate some non-intuitive mathematical shape parameters, such as control points and control vectors. Instead, he/she can work with the point constraints and spline-based constraints, therefore designers can easily and intuitively control the resultant shape.

The potential function is centered at the constraint and it symmetrically distributes the so-called force energy. Compared with other deformation methods, this approach has the following advantages: intuition, locality and simplification since this method combines shape creation and deformation. Finally, it is possible to use various intensities and smoothing functions to enrich the quality and accuracy of the deformation.

Although our method is intuitive and less computationally challenging for free form surface modeling and styling, it still needs some time to create sophisticated models; and there is a limitation in our deformation technique when we want to change the topology of the model, such as creating a hole.

In the future work, we will further investigate intelligent operations for shape editing and multi-surfaces modeling based on 3D sketching; such as surface splitting and stitching. We also plan to improve the connectivity and continuity between different surfaces based on declarative constraints.

ACKNOWLEDGEMENT

This research presented in this paper is a part of EU project “IMPROVE” and of the Part of the project InSIDe.

REFERENCES

Barr, A. H.,1984 , “Global & local deformations of solid primitives,” *Computer Graphics*, 18(3), 21-30.

Güdükbay, U. and Üzgüç, B., 1990, “Free-form solid modeling using deformations,” *Computer Graphics*, 14(3/4), 491-500.

Sederberg, T. W. and Parry, R.,1986, “Free-form deformations of solid geometric models,” *ComputerGraphic*, 20(4), 151-160.

Coquillart, S., 1990, “Extended free-form deformation: A sculpting tool for 3D geometric modeling,” *Computer Graphics*, 24(4), 187-196.

Bechmann, D., 1994, “Space deformation models survey,” *Computer & Graphics*, 18(4), 571-586.

Kalra, P., Mangili A. and Thalmann, N., 1992, “Simulation of facial muscle actions based on rational free-form deformation,” *Computer Graphics Forum*, **2**(3), 59-69.

Lamousin, H. J. and Waggenspack, W. N., 1994, “NURBS based freeform deformation,” *IEEE Computer Graphics & Applications*, 14(6), 59-65.

Griessmair, J. and Purgathofer, W., 1989, Deformation of solids with trivariate B-spline,” *Proc. EUROGRAPHICS’89*, 137-148.

Coquillart S. and Jancene, P., 1991, “Animated free-form deformation: an interactive animation technique,” *Computer Graphics*, 25(4), 23-26.

Chadwick, J. E., Haumann, D. and Parent, R. E., 1989, “Layered construction for deformable animated characters,” *Computer Graphics*, 23(3), 243-252.

Borrel, P. and Rappoport, A., 1994, “Simple constrained deformations for geometric modeling and interactive design,” *ACM Transactions on Graphics*, 13(2), 137-155.

Xiaogang, J., Youfu L. and Qunsheng, P. , 2000, “General constrained deformation based on generalized metaballs,” *Computer & Graphics*, 24(2), 219-231.

Léon, J. C. and Veron, P., 1997, “Semiglobal deformation and correction of free-form surface using a mechanical alternative,” *The Visual Computer*, 13(3), 109-126.

Léon, J. C. and Trompette, P. , 1995, “A new approach towards freeform surfaces control,” *C.A.G.D*, 12(4), 395-416.

Léon, J. C., 1991, “Modé lisation des courbes et des surfaces pour la CFAO,” hermès, paris.

Li, Han, Giuseppe, Conti, Raffaele, De. Amicis (2005), “Freehand 3D curve recognition and oversketching,” *Eurographics UK Chapter 2005*,187-193.

Chesutet, V. and Catalano, C.E., Pernot, J. P. “ 3D Sketching with Fully Free Form Deformation Features for Aesthetic Design.” *EUROGRAPHICS Workshop, Sketch-based Interfaces and Modeling*, 2004, 9-18.

Michalik, P. and Brüderlin, B.D., “Constraint-based Design of B-spline Surface from Curves.” *ACM Symposium on Solid Modeling and Applications*, 2004, 213-220.

DIETZ, U. , “Creation of Fair B-Spline Surface Fillets” *In Creating Fair and Shape Preserving Curves and Surfaces. B.G. Teubner, Stuttgart*, 1998. 2, 3, 8

Fontana, M., Giannini, F., Meirana, F., “Free Form Features for Aesthetic Design.” *Int. Jou. Shape Modelling, vol. 6, n°2*, 2000, 273-302.