Advanced ODE Based Head Modelling for Chinese Marionette Art Preservation

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Abstract

Puppetry has been a popular art form for many centuries in different cultures, which becomes a valuable and fascinating heritage assert. Traditional Chinese marionette art with over 2,000 years history is one of the most representative forms offering a mixture of stage performance of singing, dancing, music, poem, opera, story narrative and action. Apart from a set of string rules which controls the dynamics, head carving skill is another important pillar in this art form.

This paper addresses the heritage preservation of the marionette head carving by digitalizing the head models with a novel modelling technique using ordinary differential equations (ODEs). The technique has been specially tailored to suit the modelling complexity and the need of accurate description of shapes. It offers smoothly sewing ODE swept patches to represent the distinct features of a marionette head with sharp variance of local geometry. Such features otherwise are difficult to model and capture accurately, which may require a great effort and tedious hand-crafting of an experienced modeller, when using other representation forms like polygons.

Keywords: ODE based swept surface, marionette head modelling, culture heritage preservation

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Introduction

Chinese marionette is one of the most historical folk arts, where a number of marionette theatres across the country still perform many secular stories. For marionettes, the head carving is of irreplaceable cultural and artistic values. For example, Figure 1 shows Zhong Kui, a god who exorcises ghosts and evil spirits, with a panther-like head, ring-like eyes and curly whiskers, presenting exaggerated facial details. The carved head shape and painting provides unique facial features and defines the characterisation well.

"Puppet head making procedures such as carving and painting need one to keeping working at the workbench for more than ten hours a day and few young people could endure this kind of loneliness." said Huang Qinghui, a marionette head carving master. To rectify the situation that the art form is dying, it is an urgent task to develop digital achieves of marionette with 3D modelling and animation techniques, which would give new life to the historic art forms.

Figure 1: An example of famous Chinese marionette characters, "Zhong Kui drunk" [1]

Our work aims to develop suitable digital modelling techniques to capture and restore puppetry heads as computer generated models, which then can be viewed from different angles and edited easily with software tools. Such development will assist design and automate machine manufacturing as well as to create a representative archive of a selection of real hand carved heads.

It will be set as a foundation stone for future digital production of marionette using computer animation techniques.

With the primary concern of being able to represent the head shape accurately as well as being able to edit the model with an elegant user-centred approach, the ODE based modelling techniques are selected, which have been developed in the past two decades to model complex curve surface and offer smooth transition between neighbouring patches.

In summary, this work has the following contributions:

- Introduce novel ODE based modelling technique to model marionette head;
- Design the process of modelling marionette head where a template is developed to standardise the design and to follow the principle in traditional hand carving;
- Summarise the refinement techniques for ODE based modelling, where we have developed a method to insert ODE surface patches, which can refine the shape locally.

Related work

Head Modelling

So far, few works have addressed the related techniques of marionette heading carving and its digital replication. Due to extremely complex biomechanical structures of human faces and people's visual familiarity with human faces, modelling and animating realistic human faces remains one of greatest challenges in Computer Graphics. There are substantial research works related to facial modelling and expression capture. They may shed some insight on the development of marionette head modelling techniques. The techniques of constructing human facial models generally fall into four categories: parameterised facial models [2-4], physics-based facial models [5-7], performance-driven facial models [8-10], and example based facial models [11-14].

Parameterised facial models [2-4] generated facial shapes through a set of parameters that control facial features with the advantages of low computational costs. But these models require animators to specify the shape parameters with care, to avoid incorrect shapes or other spurious effects. Physics-based facial models [5-7] altered facial shapes by simulating the physical behaviours of facial skin and muscles, which can produce realistic facial expressions. Performance driven facial models [8-10] animated facial expressions using motion-captured data from real actors' performances which can generate natural and lifelike behaviours. Such method is often laborious and requires special techniques to prepare the data and models. Example based facial models [11-14] created new facial models from a number of known range scans or images that were captured from real faces or sculptures. Such models were generally confined by the shape space of available face examples.

Swept Surface \Modelling

A number of surface modelling methods exist and are widely used in computer graphics including NURBS and subdivision surfaces, among which, swept surfaces is a simple and efficient technique. In swept surface modelling, a curved surface can be represented with a small set of parameters which are most likely presented as boundary curves and tangent information at the boundary.

The generation of a swept surface has been studied for many years. Since Bloor et al.'s pioneering work made use of the Partial Differential Equations (PDEs) in blend surface generation in 1989 [15], the benefits of using differential equations for surface modelling have been gradually recognised by researchers. Such techniques were adopted to address a variety of geometric modelling problems, such as the free-form surface design, complex shape modelling and skin deformation in computer animation [16-17].

ODE swept surfaces are generated through the following steps. 1). Formulate a vector-valued ordinary differential equation (ODE), 2). Determine proper boundary conditions consisting of boundary curves and boundary tangents, 3). Find the solution of the vector-valued ODE to create a profile curve called a generator, 4). Sweep the profile along the boundary curves and satisfy the boundary tangents at the same time by introducing the solution into the boundary conditions. By altering the equations and the boundary data set, users can adjust the differential properties and shapes of the generated surface. This gives a choice of editing surfaces at a high level rather than direct manipulating individual vertices of a polygon mesh.

By studying the existing works and comparing different technologies, we decided to use ODE based swept surface as a fundamental construction bricks to model marionette heads. This work is inspired by You's research [18] on ODE based geometric parameterisation and modelling which accelerated the computing with analytical solutions of an ODE to formulate a set of profile curves as bone structures for a swept surface. In our implementation, we are able to create and edit the geometric shapes and facial feature details of a marionette head with newly developed numerical tools and software based on ODE modelling techniques.

Modelling marionette head

Although an experienced modeller can develop a proper 3D facial model of a character based on a few reference images using cutting edge software, it is still a common practice in character design to start with a hand sculpted model which is scanned into the computer for latter editing and refinement. We can follow suit to generate a marionette head model in computer by scanning a real carved shape, but the scanned data would require a lot of work to refine the mesh structure, remove noise and fill holes caused by occlusion in scanning. Such model may lack flexibly for further editing, design and recreation. Moreover, it requires special knowledge and skills of a modeller as a laborious and time-consuming task.

We want to develop a useful tool to enable normal users with basic computer operation skills to create the model of a marionette head from scratch so most public can engage with the process to create their own marionette characters. It is also important that the final model is friendly for machining, that is, the accuracy and smoothness is expected. Therefore, a careful designed process of using parameterised models may be appropriate.

The advantage of our method is as follows: 1) the surface model is light weight analytical model which makes the representation both efficient and numerically robust; 2) because the generation of swept surface depends on the profile curves and boundary curves, we can easily produce surface deformation to represent marionette’s exaggerative art effect by changing them further in the future; 3) because it is possible to control both shape and tangent conditions of a swept surface at the boundary curves, the smoothness of the model thus can be guaranteed, which is also one notable feature of traditional Chinese marionette head besides its exaggerative artistic style.

Facial Patches

Traditional Chinese marionette head models are smooth and slippery with exaggerative characteristics reflected by the shape variation and different painting. When carving the face, the craftsmen pay much attention to several particular parts: "Five Shapes and Three Bones", which refers to two eyes, the mouth, two nostrils (five shapes) and brow bone, malar bone and chin bone (three bones)[19].

To follow the similar principle of shaping the marionette head, we divide the head model into several patches, which are related to the division of "Five Shapes and Three Bones". Each patch as a fundamental element of modelling the head can be modelled as a single swept surface. As in Figure 2, the patches related to two eyes (patch 6, 7), two nostrils (patch 3, 4) and the month (patch 8, 9) are given special attention in modelling to form unique shapes related to the character. Boundaries which separate different patches are coincident with the main “three bones” (as highlighted in red lines), which provide the base shape information of the overall head.

It is noted for some marionette characters, ears are also one of the important facial features. Therefore, the head sculptures should include them and the additional facial patches are required to model them. Often, two surface patches are used for each ear. For some marionette character, three heads may present as a single piece of carving which give different emotional expressions of the character in performance by switching the head facing. It is straightforward to duplicate our facial patch partition to the other two faces. To keep consistency and avoid confusion, in the rest of the paper, the following discussion of modelling method is based on the facial patch partition as in figure 2.

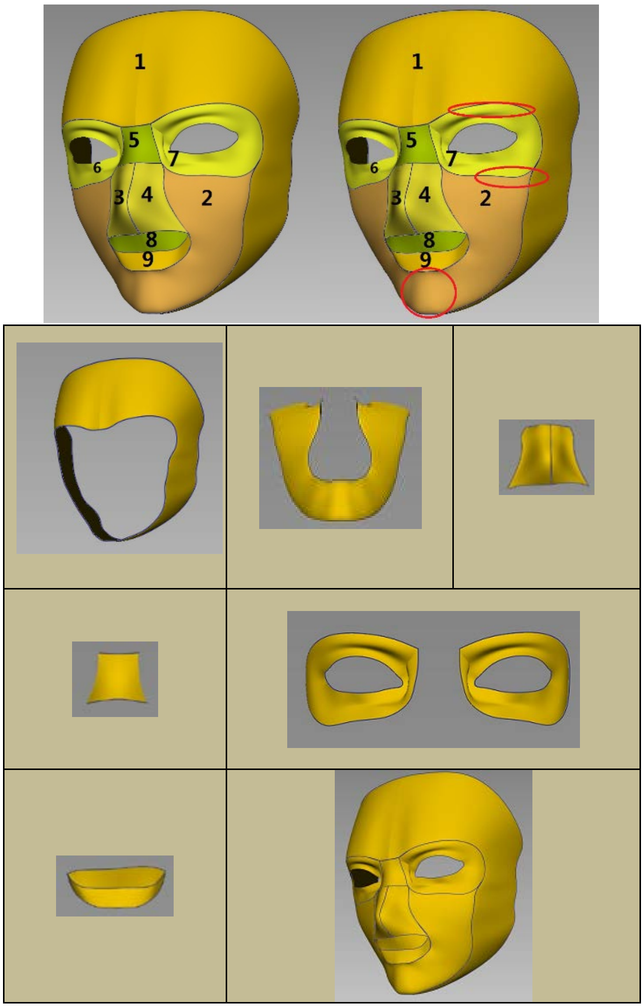


Figure 2: Facial patch partition

ODE based swept surface

You et al. has develop a useful techniques of generating ODE based swept surface to model various object in [20]. A swept surface $\vec{S}=\vec{S}(u,v)$ is created as sweeping a profile curve $\vec{P}=\vec{P}(u,v)$

along two boundary curves and subjected to the constraints of boundary tangents. When modelling Chinese marionette head models with five shapes, the adjacent shapes will keep both positional and tangential continuities to create smooth transitions between them. ODE swept surfaces are especially suitable for such a modelling task. When the ODE profile curve sweeps to generate a swept surface, the four constraints are satisfied: two as point constraints on boundary curves ($\vec{B}_1$ and $\vec{B}_3$) and two tangents constraints as $\vec{B}_2$ and $\vec{B}_4$ defined at the boundary curve. The four constraint equations at the two boundaries are as follows:

$$
\begin{aligned}
u=0: \quad & \vec{B}_1(v)=\vec{S}(0,v); \quad \vec{B}_2(v)=\frac{\partial \vec{S}(0,v)}{\partial u}; \\
u=1: \quad & \vec{B}_3(v)=\vec{S}(1,v); \quad \vec{B}_4(v)=\frac{\partial \vec{S}(1,v)}{\partial u};
\end{aligned} \tag{1}
$$

where $u,v \in [0,1]$ are the surface parameters, $\vec{B}_1$ and $\vec{B}_3$ represent the boundary curves, $\vec{B}_2$ and $\vec{B}_4$ represent their tangents.

We define the profile curve by solving a vector-valued 4-th order ordinary differential equation (ODE) as shown in equation (2), which is related to the deformation of a flexible elastic beam. Usually, the higher the order of an ODE is, the smoother the transition between the two adjacent surface patches is. A second order ODE can guarantee the 0-order continuity of the position constraints at the boundary, and a four order ODE can ensure the tangential continuity at the boundary. In some application, a sixth order ODE is required to handle curvature continuity. We find the 4-th order ODE is sufficient for our modelling where increasing the order of ODE may increase the modelling complexity and require more computing.

$$
\vec{a}_1 \frac{d^4\vec{P}(u)}{du^4} + \vec{a}_2 \frac{d^2\vec{P}(u)}{du^2} = 0 \tag{2}
$$

where $\vec{P}(u)$ presents the profile curve; $\vec{a}_1$ and $\vec{a}_2$ are vector-valued material constant parameters which are specified by user for surface shape control.

By assuming that the profile curve $\vec{P}(u)$ takes the form of

$$\vec{\vec{P}}(u) = e^{\vec{r}u} \tag{3}$$

The complementary solution of Eq. (2) can be obtained:

For $\vec{a}_1\ \vec{a}_2 > 0$

$$\vec{\vec{P}}(u) = \vec{c}_1 + \vec{c}_2 u + \vec{c}_3 \cos(\vec{a}u) + \vec{c}_4 \sin(\vec{a}u)$$

For $\vec{a}_1\ \vec{a}_2 < 0$

$$\vec{\vec{P}}(u) = \vec{c}_1 + \vec{c}_2 u + \vec{c}_3 e^{\vec{a}u} + \vec{c}_4 u e^{\vec{a}u}$$

For $\vec{a}_2 = 0$

$$\vec{\vec{P}}(u) = \vec{c}_1 + \vec{c}_2 u + \vec{c}_3 u^2 + \vec{c}_4 u^3 \tag{4}$$

, where $\vec{c}_1, \vec{c}_2, \vec{c}_3, \vec{c}_4$ are unknowns which are determined with boundary constraints, and $\vec{a}$ is related to $\vec{a}_1$ and $\vec{a}_2$ with $a_x = \sqrt{|a_{1x} / a_{2x}|}$, $a_y = \sqrt{|a_{1y} / a_{2y}|}$ and $a_z = \sqrt{|a_{1z} / a_{2z}|}$.

Each equation of Eq. (4) represents a profile curve. As an example, we will use the first equation of Eq. (4) to discuss the creation of a boundary constrained swept surface. We use $\vec{a}$ stand for $\sqrt{|\vec{a}_2 / \vec{a}_1|}$, then the first equation of Eq. (4) can be simplified by

$$\vec{\vec{P}}(u) = \vec{c}_1 + \vec{c}_2 u + \vec{c}_3 \cos(\vec{a}u) + \vec{c}_4 \sin(\vec{a}u) \tag{5}$$

The four unknown variables $\vec{c}_1, \vec{c}_2, \vec{c}_3, \vec{c}_4$ in Eq. (5) can be determined by satisfying constraint equations Eq. (1). To give an example, substituting a solution of the profile curve $\vec{\vec{P}}(u) = \vec{c}_1 + \vec{c}_2 u + \vec{c}_3 \cos(\vec{a}u) + \vec{c}_4 \sin(\vec{a}u)$ when $\vec{a}_1\ \vec{a}_2 > 0$ into Eq. (2), we can have the surface equation as

$$\vec{S}(u,v) = \begin{pmatrix} \vec{c}_1(v) + \vec{c}_2(v)u + \vec{c}_3(v)\cos(\vec{a}u) \\ + \vec{c}_4(v)\sin(\vec{a}u) \end{pmatrix} \tag{6}$$

, when $u=0$ and $u=1$, the boundary constraints need to be satisfied. It leads to the following expressions of $\vec{c}_1, \vec{c}_2, \vec{c}_3, \vec{c}_4$ as

$$\begin{aligned}
\vec{c}_1(v) &= \vec{b}_0\left(\vec{b}_1\vec{B}_1(v) + \vec{b}_2\vec{B}_2(v) + \vec{b}_3\vec{B}_3(v) - \vec{b}_4\vec{B}_4(v)\right) \\
\vec{c}_2(v) &= \vec{b}_0\left(\vec{b}_5\vec{B}_1(v) + \vec{b}_3\vec{B}_2(v) - \vec{b}_5\vec{B}_3(v) + \vec{b}_3\vec{B}_4(v)\right) \\
\vec{c}_3(v) &= \vec{b}_0\left(\vec{b}_3\vec{B}_1(v) - \vec{b}_2\vec{B}_2(v) - \vec{b}_3\vec{B}_3(v) + \vec{b}_4\vec{B}_4(v)\right) \quad \text{and} \\
\vec{c}_4(v) &= \frac{\vec{b}_0}{\vec{a}}\left(-\vec{b}_5\vec{B}_1(v) + \vec{b}_1\vec{B}_2(v) + \vec{b}_5\vec{B}_3(v) - \vec{b}_3\vec{B}_4(v)\right)
\end{aligned}$$

$$\begin{aligned}
\vec{b}_0 &= \frac{1}{2 - 2\cos\vec{a} - a\sin\vec{a}} \\
\vec{b}_1 &= 1 - \cos\vec{a} - \vec{a}\sin\vec{a} \\
\vec{b}_2 &= \cos\vec{a} - \vec{a}\sin\vec{a} \\
\vec{b}_3 &= 1 - \cos\vec{a} \\
\vec{b}_4 &= 1 - \vec{a}\sin\vec{a} \\
\vec{b}_5 &= \vec{a}\sin\vec{a}
\end{aligned}$$

, where the components of $\vec{a}$ are defined as $a_x = \sqrt{|a_{1x}/a_{2x}|}$, $a_y = \sqrt{|a_{1y}/a_{2y}|}$ and $a_z = \sqrt{|a_{1z}/a_{2z}|}$. By using 3D modelling software, boundary points can be obtained by selecting the points on boundary curves manually or extracted uniformly from boundary curve sketched on model. For more information and numerical methods about ODE based surface, please refer to [18] and [20].

Types of ODE surfaces

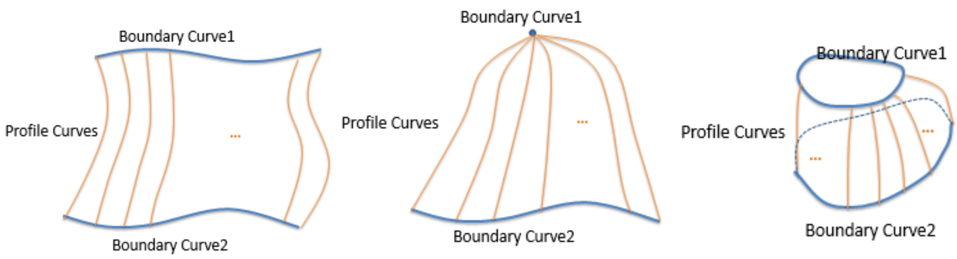
In general, using different boundary curves, we can classify the type of ODE based swept surface into two main types. Type-I swept surface is created with two open boundary curves as shown in Figure 3: (a), where the profile curves $\vec{\bar{P}}(u)$ at $v=0$ and $v=1$, form two open edges. A degeneration surface of Type-I, Type-I-A, as shown in Figure 3: (b), is reported in [20] to generate a sewing patch with three edges. For Type-I-A, one boundary curve shrinks into a single point, the point coordinates are the same when parameter v increasing from 0 to 1, but the tangent which still varies when v change values remains a function of v.

Type-II swept surface is created with two closed boundary curves which form two loops, as shown in Figure 3: (c), where the profile curves $\vec{P}(u)$ (at $v=0$ and $v=1$) are coincident. The swept surface of this type can be seen as a revolution surface or generalised cylinder. Two degeneration types of Type-II surface are of particular interest for our patch modelling. One degenerate type Type-II-A is that when the inner boundary shrinks into a fold line, as shown in Figure 3: (d). Each end of the line is linked to the outer boundary and this patch is identical to two patches of Type-I. This example can be illustrated in the two patches formed the two lips in the facial patches in the section of "Facial Patches" as shown in Figure 2 as well. Type-II-B is a surface where the inner ring shrinks into a single point but its tangent keeps changing continuously when parameter v varies. An example of Type-II-B is illustrated as in Figure3: (e).

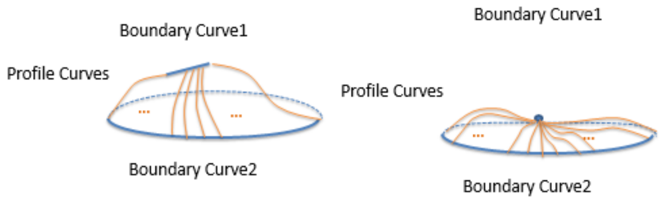
For Type-II-B surface, we can define the tangent of the inner boundary $\vec{B}_2(v)$ as the projection of a vector from the inner boundary point $\vec{B}_1$ to a point on the outer boundary $\vec{B}_3(v)$ on the tangent plan at point $\vec{B}_1$, which is shown in Figure 3 :(e):

$$\vec{B}_2(v) = \alpha\left\{(\vec{B}_3(v) - \vec{B}_1) - \left[(\vec{B}_3(v) - \vec{B}_1)\cdot\vec{N}\right]\vec{N}\right\}$$

where α is a user control ratio and $\vec{N}$ is the normal vector of the given tangent plan. By doing so, the location of the inner boundary and the normal vector provide useful handles for us to alter the shape of a given patch locally.



(a) (b) (c)



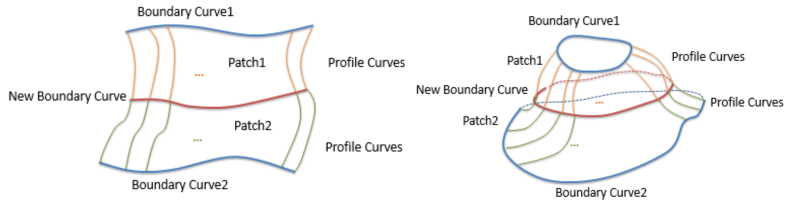
(d) (e)

Figure 3: Type-I and Type-II and their degeneration

Editing and local refinement of marionette head model

Primarily the shape of a marionette head sculpture can be adjusted by editing the boundary conditions, including altering the locations of vertices on a boundary curve and changing the length and orientation of tangent distributed along the boundary curve. The shape can also be refined by altering the details and types of profile curves which are controlled by parameter $\vec{a}_1$ and $\vec{a}_2$ of the ODE (see equation 2). The related techniques have been discussed with details in [21].

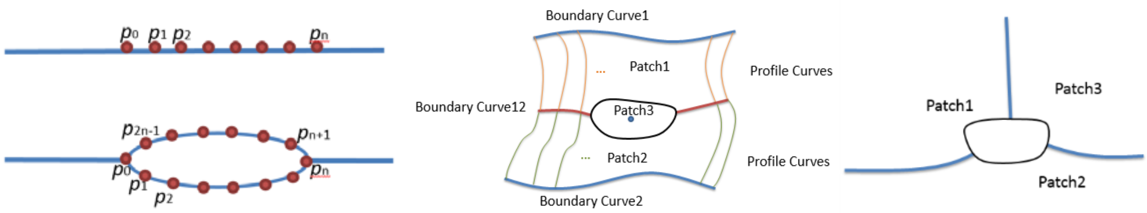
To locally refine the sculpture shape, we propose to subdivide existing surface to refine the shape locally within a patch or close to a boundary region. For both Type-I and Type-II patch, it is straightforward to divide an existing patch into two. As shown in Figure 4, for a known surface patch with boundary conditions, all the points on the profile curves with same u value $u = u_0$ form a new curve and its tangent is known as $\frac{\partial \vec{S}(u_0, v)}{\partial u}$. Using these as a new boundary curve and its tangent plus the known boundary conditions of the existing patch, it will form two patches whose shapes are coincident with the old patches. The patch shape can then be refined by editing the boundary conditions as discussed before. By repeating the process, a patch can be divided into as many sub-patches as possible. When changing the boundary condition, only those sub-patches sharing this boundary are deformed.



(a) (b)

Figure 4: Examples of divide a patch into two for Type-I and Type-II

We can also increase a new patch at a boundary to refine the shape, which enables us to refine local shape near the three bones. To do that, we first duplicate points at a section of boundary, so the single boundary line of this section becomes a fold ring. We then separate the duplicated boundary to form a ring-like shape. As the alternation to the boundary, a hole will appeal between the two neighbouring patches. Using the created ring-like boundaries as an outer boundary and their centre as a degenerated inner boundary, we can create a Type-II-B patch as a new inserted one which fills the hole. This process is shown in Figure 5(a). It is noted the reverse operation can be taken to remove the inserted patch.



(a) (b)

Figure 5: Examples of insert Type-II-B patch and star joint

To ensure the patch shape is consistent before and after inserting such a new patch, we constraint the points of the ring to the original patch and their tangents are from the same tangent plane. The selected boundary section has points $p_0, p_1, p_2, ..., p_n$. The point list becomes $p_0, p_1, p_2, ..., p_n, p_{n+1}, ..., p_{2n-1}$, where point p_{n+i} shares the same location of p_{n-i}. We then draw a closed curve on the original patch and intersect with the boundary at p_0 and p_n, and therefore, p_0

and p_n as two initial sampling points divided the closed curve as two parts each of which is then divided into *n* sections equally in length by inserting *n*-1 sampling points. Starting from p_0 on the boundary section, we map the boundary curve points p_{i+1} to the sampling points p'_{i+1} one by one counter-clock-wisely. The tangent on the new boundary point p'_i can be estimated as

$$\frac{\partial \vec{S}}{\partial u} = \vec{N}(p'_i) \times (p'_{i+1} - p'_i)$$

where $\vec{N}(p'_i)$ is normal vector of the surface patch at point p'_i. We define p'_{2n} as p'_0 to get the tangent at point p'_{2n-1}.

For a star joint of several boundaries, as shown in Figure 5(b), using the same technique proposed in You's paper [20], we can construct a surface patch to fill the hole.

With the refinement function, we greatly enhance the flexibility when editing a marionette head to better capture shape at local area and increase the complexity of the model. Examples of refined patch lay-out are shown in Figure 6, as illustrated, more patches are used near the areas related to "five shapes and three bones" to produce and control variations at these areas.

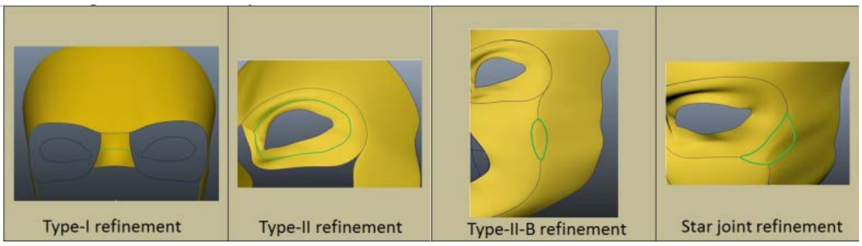


Figure 6: Use CV curves to identify and adjust boundary curves

Marionette head modelling

There are two major ways to create the marionette heard. One is that when a real sculpture model is available, a scanned polygon mesh can be transformed into our facial ODE patches with least square optimisation by minimizing the difference of the two shapes, which can follow the same technique as in You's paper [18].

In a far general case, if only reference images exist or the model has to be designed from scratch, the following steps will be followed.

1. Start from a template with standard partition as shown in Figure 2;
2. Alter the boundary curves of the template model to approximate the wanted shape roughly, where special attention is paid for areas related to "three shape and three bones";
3. Refine the sculpture shape locally by inserting new boundary curves(dividing a patch into two) or inserting new patches, where nice details about the main facial features are created, such as possible fold and wrinkles;
4. Adjust the boundary curves related to the new inserted patches from step 3;
5. Remove the unwanted patches if necessary;
6. Go back to step 3 and refine the model, or if wanted, go back to step 2 to change the outline of the model unless satisfied with the shape;
7. Finalise the sculpture and the model is ready for use.

One benefit of our method is that the main surface patches which represent two eyes, two nasals and month can be reused by sewing them to a new model with slightly alternation of the boundary conditions, which is normally hard to achieve with other modelling techniques. One example is shown in the head sculpting of Monkey King[1] (see Figure 8, top row) where different shapes of months and eyes are used to present different facial expression where the remaining facial parts are the same.

We have designed a plugin for Maya2014 which offers a user-friendly interface generated with Qt. It is called ODE Based Marionette Head Designer, as shown in Figure 7. The core ODE function is

[1] The Monkey King, also known as Sun Wukong is a Chinese Epic Heroes in Journey to the West. Its marionette head model is distinguished with a monkey face and special blinking eyes.

implemented by C++ programming. This interface allows users to retrieve previously stored marionette models from a database, edit ODE facial patches and direct manipulate the boundary curves and boundary tangent.

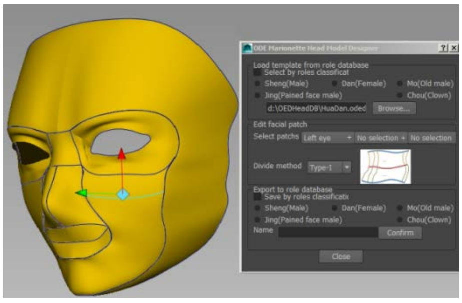


Figure 7: ODE Based Marionette Head Designer

Results and discussion

By using proposed method, the heads model with substantial complexity of different marionette roles are created, which are shown in Figure 8. Normally a head model will take at least about ten thousands polygons to approximate the shape. If the polygon numbers are less, the shape of the model will be degenerated and its smoothness will not be preserved. With our ODE based approach, a small fraction of data is required to store the model. For example, only few hundreds of vertices are used to store the boundary conditions for forming the shapes of Figure 8.

Figure 8: Heads model of different marionette roles

Generally speaking a human face is symmetrical, but that is not necessarily the case for marionette head design, because there are some specific characters in traditional Chinese marionette, which have asymmetric faces associated to particular emotional state or characteristics, for example, some evil characters may show a twisted smile. If a marionette head is symmetric, the modelling work can be halved by only sculpturing one half and mirroring the other half.

The type and appearance of marionette characters may vary a lot. Different patch segmentation for a template may be used, for example a bird head would be different from a human head. The user can design his template profile. However, we find our template works well with design for most known characters. However, if a different curving skills or tradition are used, the selection of patches may vary as well. Discussion of the making and selection of template profile is out of the scope of this paper.

One main principle of our modelling is that because the swept surface is generated by sweeping a curve along known boundaries, we identify the boundary constrains with respect to the main facial features, summarised as “three shape and three bones”. Manipulating the sweeping curve and related boundary conditions, we create different surfaces, which are patches to form our marionette head.

5. Conclusion

The traditional puppetry art has a long history and contains rich cultural elements of different nations. If this gem of traditional folk art fails to be handed down to future generations, it will be a great loss. We have designed novel techniques to model the marionette head carving with ODE based surfaces, which are specially tailed to meet the requirement of preserving the facial feature nicely. The method is designed for ease of use which can engage young generations without special trainings to create their own marionette character with assistance of computers.

We have created a facial patch template to standardise the modelling process, where an ODE surface patch or a small set of ODE surface patches are used to represent the main facial features as demonstrated in Figure 4 and Figure 8. Although different template may be used by different designer to suit their own way of modelling, we would consider the generation of a template database will greatly easy the design effort. In particularly, once the template is chosen, a selection of elements model like facial main features of eyes, nose and mouth can be selected from existing models to assemble a new model, which will greatly improve the modelling efficiency and simplify the modelling process.

Our work aims to develop suitable digital modelling techniques to capture and restore puppetry heads in computer. Based on the developed techniques in this paper, in the future we want to develop a more powerful software tool, which can facilitate the design and manufacturing of Chinese marionette. The digital modelling techniques of marionette will become a foundation stone for marionette-style computer animation, which would increase the appearance of marionette at modern media and distribution platform, like sharing videos at YouTube and Facebook. This will contribute to the preservation of this cultural treasure of art.

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References

[1]Zhong Qui Drunk, Quanzhou Marionette Theatre
Availvable from: http://www.cnqzmt.com/products_detail/&productId=16accce7-5d9e-4692-9073-72f12cc13d47.html

[2]Parke F. Computer generated animation of faces. *In Proceedings of the ACM Annual Conference* 1972; 1:451-457.

[3]Parke F. A parametric model for human faces. *No. UTEC-CSc-75-047*. UTAH UNIV SALT LAKE CITY DEPT OF COMPUTER SCIENCE 1974.

[4]Parke F. Control parameterization for facial animation. *Computer Animation'91*. Springer Japan 1991; 3-14.

[5]Platt S, Badler N. Animating facial expressions. *ACM SIGGRAPH computer graphics* 1981; **15**(3): 245-252.

[6]Sifakis E, Neverov I, Fedkiw R. Automatic determination of facial muscle activations from sparse motion capture marker data. *ACM Transactions on Graphic* 2005; **24**(3): 417-425.

[7]Sifakis E, Selle A, Robinson-Mosher A, Fedkiw R. Simulating speech with a physics-based facial muscle model. *In Proceedings of the 2006 ACM SIGGRAPH/Eurographics symposium on Computer animation.* Eurographics Association 2006; 261-270.

[8]Williams L. Performance-driven facial animation. *ACM SIGGRAPH Computer Graphics* 1990; **24**(4): 235-242.

[9]Weise T, Li H, Van Gool L, Pauly M. Face/off: Live facial puppetry. *In Proceedings of the 2009 ACM SIGGRAPH/Eurographics Symposium on Computer animation* 2009; 7-16.

[10]Weise T, Bouaziz S, Li H, Pauly M. Realtime performance-based facial animation. *ACM Transactions on Graphics (TOG)* 1981; **30**(4):77.

[11]Blanz V, Vetter T. A morphable model for the synthesis of 3D faces. *In Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, ACM Press/Addison-Wesley Publishing Co., 1999;87-194.

[12]Blanz V, Basso C, Poggio T, Vetter T. Reanimating faces in images and video. *Computer graphics forum,* Blackwell Publishing, Inc, 2003; **22**(3):641-650.

[13]Li H, Weise T, Pauly M. Example-based facial rigging. *ACM Transactions on Graphics (TOG)* 2010; **29**(4): 32.

[14]Seol Y, Seo J, Kim P, Lewis J, Noh J. Artist friendly facial animation retargeting. *ACM Transactions on Graphics (TOG)* 2011; **30**(6): 162.

[15]Bloor M, Wilson M. Generating blend surfaces using partial differential equations. *Computer-Aided Design* 1989; **21**(3): 165-171.

[16]Bloor M, Wilson M. Using partial differential equation to generate free-form surfaces. *Computer-Aided Design* 1990; **22**(4): 202–212.

[17]Zhang J.J., You L. Fast surface modelling using a 6th order PDE. *Computer Graphics Forum*. Blackwell Publishing Inc 2014; **23**(3): 311-320.

[18]You L, Yang X, Pachulski M, Zhang J.J. Boundary constrained swept surfaces for modelling and animation. *Computer Graphics Forum.* Blackwell Publishing Ltd, 2007; **26**(3): 313-322.

[19]Lin C. On patterns and innovations of puppet head carving in Quanzhou. *Journal of FUJIAN arts (Chinese)* 2013; **1**:63-63.

[20]You L, Ugail H, Tang B, Jin X, You X, Zhang J.J. Blending using ODE swept surfaces with shape control and C^1 continuity. *The Visual Computer* 2014; **30**(6-8), 625-636.

[21]You L, Yang X, You X, Jin X, Zhang J.J. Shape manipulation using physically based wire deformations. *Computer Animation and Virtual Worlds* 2010; **21**(3-4), 297-309.

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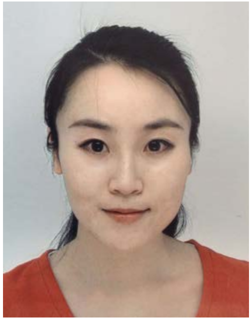

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