Facial Model Improvement Using 3D Texture Mapping Feedback

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Abstract

We present a method for improving a 3D facial model by interactive feedback of mapping a texture obtained from a 3D scanner. The method is based on extracting features from both 3D model and texture, and deforming a generic head model. Feature texture area is first mapped onto the corresponding part of a generic head model. The generic model is then reconstructed depending on the result of texture mapping feedback. The difference of our approach with existing methods is that we model components of a face, e.g., mouth, eyes, nose etc., using customized 3D curves; this helps in preserving the shapes of features during interactive modifications. A Java 3D implementation is also developed following the proposed method.

1. Introduction

Interactive three-dimensional (3D) human facial modeling has a wide range of applications from surgical training to video games. Many of these applications require deforming human facial models. Deformation, or modification of 3D model, belongs to the main techniques used in 3D computer graphics. It consists of editing the shapes of 3D models, and providing a general modification of a 3D model such as twisting, bending and stretching.

Currently, 3D facial modeling is receiving significant attention among the computer vision and computer graphics communities and has several important applications, such as virtual reality, facial animation and plastic surgery. The following demands have to be observed based on the cited application: easy handling of the object for user, quality of deformation/modification result, and speed of the process. A facial model with well-structured information is useful for further reconstruction and could make future work more efficient, compared with a facial model with only raw data. We may acquire human facial model and textures using a 3D scanner, *e.g.* Rotating Arm Scanner from Zoomage® [2]. However, the human face is a very irregular structure, which varies from person to person. It is inefficient and time-consuming to obtain 3D models for many different people. On the other hand, different faces share common facial features, for example, the eye contour is approximately an ellipse; the lip contour consists of several parabolic curves. The spatial relationship among facial organs such as eyebrows, nose, eye and mouth is relatively invariant. A typical approach is to start with an existing generic facial model without any distinctive features, and modify it gradually to precisely match a specific person's face. Lee *et al*. [4] started with a generic facial model and reconstructed it from information of three head photos (left, front and right). This approach needs to generate texture from two input images and fit it onto the 3D model. Simmons *et al*. [10] introduced a method for 3D model creation that "morphs" a canonical anatomically based model. This approach is complicated for the human head model since it requires "morphing" in a bone-muscle-skin hierarchy.

In this paper, we propose a new method to deform a generic 3D facial model in order to fit a person's face precisely. We develop several deformable templates for 3D curves of organs (mouth, eyes etc.) on the face and change the shape of 3D model by modifying the parameters associated with these templates. To obtain visual feedback of the model reconstruction for evaluation purpose, facial texturing is performed by setting up the correspondence between feature points on both 3D model and the texture image. The procedure of facial model deformation and texturing is interactive and user-friendly.

The organization of the remaining sections is as follows: Related work is presented in Section 2. In Section 3, we give a brief overview of our system. Section 4 is dedicated to the texture mapping with feature points and the reconstruction process from the feedback of texture mapping. Experimental results are explained in Section 5. Finally conclusion and future work are described.

2. Related Work

Free Form Deformation

Free Form Deformation (FFD) is a technique for deforming solid geometric models in a free form manner [28, 29]. The FFD method deforms an object by first assigning to each of its points within the deformation lattice a set of local coordinates. MacCracken and Joy presented a general FFD method [1]. Kalra *et al*. [9] proposed the option of including rational basis function in the formulation of deformation.

Facial Action Coding System (FACS)

Facial Action Coding System (FACS) is the most widely used and versatile method for measuring and describing facial behaviors. Ekman and Friesen [30] developed the ordinal FACS by determining how the contraction of each facial muscle changes the appearance of the face. FACS measurement units are Action Units (AUs), which are single muscles or clusters of muscles. Platt and Badler [31] presented a facial animation system based on the FACS.

MPEG-4 Facial Deformation

MPEG-4 is an ISO/IEC standard developed by MPEG (Moving Picture Experts Group). The new MPEG-4 standard includes support not only for video and audio, but also for synthetic interactive graphics, in particular, representation of human face and bodies. Important components in the specification of MPEG-4 are Facial Animation Parameters (FAPs) and Facial Definition Parameters (FDPs). Escher *et al.* [32] presented a method to perform facial deformation for MPEG-4.

Muscle-based Deformation

In the Facial Action Coding System (FACS), a technique for the extraction of facial parameters is presented. Action Units (AUs) is the basic element for describing facial deformation. Individual muscles or small groups of muscles are defined as AUs which distort the skin tissue. Computer model of muscles [33] for the human face are constructed to describe a facial model and assist facial deformation more efficiently.

Curve representation and modification on 3D model

Two of the most commonly used methods are triangular mesh and the design tool NURBS. Triangular mesh [11-15] is easy to construct and manipulate, but requires extensive computation and post-processing, such as mesh simplification [17]. B-spline surface model is being widely used for modeling 3D objects [18]-[21]. The non-uniform rational B-spline (NURBS) is adopted as a standard representation of curves and surfaces [22]. Park *et al.* [16] proposed an approach for constructing 3D model and performing parameterization automatically. However, since the definition of NURBS curve requires control points, knot vectors and weights, we still have to place many parameters to determine a 3D curve.

Triangle or polygon mesh is currently the most popular representation of 3D model. Some of the above deformation methods do not provide direct manipulation on 3D mesh, hence making them difficult to implement. MPEG-4 facial deformation needs the context of MPEG-4 standard and restricts the facial model in MPEG-4 environment. To use facial action coding system (FACS) for facial deformation, we will have to construct a relationship between a 3D model and FACS since Action Units (AUs) handle all the facial movement. In the case of muscle-based deformation, one has to build or import muscle models before directly controlling the 3D mesh's deformation. On the other hand, the other approaches, *i.e.*, free-form deformation (FFD) *etc.*, are capable of directly operating on 3D mesh triangles via pre-defined functions or formulae. But, making major modifications on the facial model, using FFD is tedious and not efficient. The more detailed the facial modification required, the longer the processing time needed.

In order to have a simple yet efficient solution, we use parameterized differentiable curves [23] instead. The advantage of parameterized differentiable curves is that fewer parameters are required yet the 3D shape is fairly well preserved. The contours of facial organs (mouth, eyes, *etc.*) can be represented by the combination of several parameterized curves using our method. To reshape the target facial organ, only the curve parameters have to be modified. Therefore, our approach tends to be efficient and straightforward. More details are discussed in the following sections.

3. System Overview

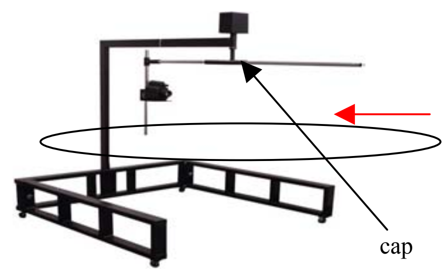


Fig. 1. Zoomage 3D scanner

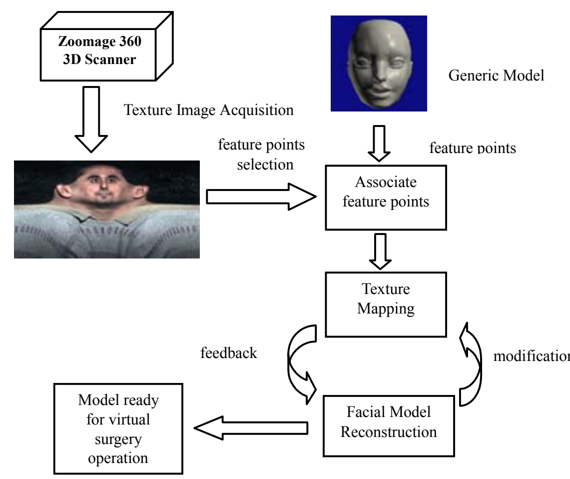


Fig. 2: System overview

The equipment for 3D texture acquisition is shown in Fig. 1. The Arm-Rotate model is especially designed for scanning a human head. A high-resolution camera is mounted on one end of the arm. A person sits right under the cap and the scanner rotates 360°. A sample texture image generated by the scanner is shown in Fig. 2. The range (3D) data obtained from the scanner is used to scale the detailed generic model.

The general idea of this system is shown in Fig. 2. There are 3 steps: texture acquisition, texture mapping and model reconstruction. The texture mapping step is divided into two phases. Feature points on both texture and model are picked out and associated one by one. Hence, we have a texture area which can be mapped onto the desired feature area of the 3D model in the second phase. After the correspondence between texture and model is determined, texture mapping is performed. As the result may be distorted because of poor match between an individual texture and a generic model, we modify the 3D model in order to achieve better matching and reasonable texture appearance on the model.

4. Facial Model Reconstruction

The ultimate goal of our work is to modify a generic model with the feedback of texture mapping on the 3D model. We consider the points on the contour of mouth, nose, eyes and ears etc. as the feature points.

4.1 3D generic model and texture preparation

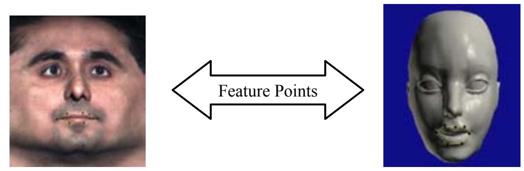
The generic model (Fig. 3) is created using a triangular mesh with no texture mapping on the surface; there are many more polygons (triangles) on the feature areas (eyes, mouth, nose and ears etc.) than in other parts (*e.g.*, forehead and cheeks). We scale the generic model using 3D scan data on a face. The advantage of using a generic model is that detailed mesh representation in features areas is possible without the need for accurate 3D scanning with occlusion avoidance.

4.2 Feature point selection

First, we select feature points by clicking on the 3D model, and locate all the control points along the contour of a feature (*e.g.*, mouth). Next, we mark control points on the texture image and extract an area as the Texture of Interest (TOI). Finally, the control points on both 3D model and TOI are associated one by one. Fig. 3 illustrates the process of feature point selection.

4.3 Texture mapping on 3D model

We adopt the shape-preserving parameterization method from [7], which is capable of preserving local geometry property such as length and angle. Next, we calculate the barycentric coordinates [27] of the flattened polygon for each point inside the contour. After selection of feature points described in the previous section, the correspondence between texture feature points and mesh feature points is set up. The other points on the texture contour are obtained by interpolation based on the known feature points. Finally, the barycentric coordinates calculated from the flattened polygon are applied to the texture polygon to get each interior point's texture coordinate. The underlying concept is to first flatten the 3D mesh into a 2D simple shape, and get a 2D flattened version of the surface. Now we have the mapping of every point on the 3D surface to its corresponding 2D flattened point. Given a texture image, we can map the points from the 2D flattened map to a point on the texture. Next, we would like to map the texture back to the surface. By our method, the texture mapping of feature points is satisfied while distortion is also reduced.



(a) (b)

Fig. 3: Feature point selection and association.

4.4 Modifying a generic face model

In Section 3.2 the user determines the contour of a facial feature; we then develop a template to represent the feature contour for further mesh editing. In our previous work, we proposed several 2D templates for facial features [8]. Our method is based on extending the approach in [8] to represent 3D templates. By using a mathematical representation of each facial feature we can control/modify its 3D shape without losing its intrinsic geometric properties. By contrast, using generic NURBS curves for all features can distort specific shapes of lips or eyes, for example, during editing.

Deformable 3D curve template

In [8], mouth features are represented by an open-mouth template and a closed-mouth template in 2D (Fig. 4). Each of the templates consists of several parabolic curves and is defined as follows:

$$p_i = h_i \left(1 - \left(\frac{q}{L_M} \right)^2 \right) \tag{1}$$

We extend this concept to 3D space. When we project a 3D curve onto the XY and XZ planes, the projections still have the shapes of parabolic curves. Hence, we have the new representation of mouth shape as:

$$\begin{aligned} x &= t \\ y &= w_i \left(1 - \left(\frac{t}{L_M} \right)^2 \right) \\ z &= h_i \left(1 - \left(\frac{t}{L_M} \right)^2 \right) \end{aligned} \tag{2}$$

Where, the parameter w_i describes the height of curve's projection on XY plane and h_i describes the height of curve's projection on XZ plane. L_M is the width of the mouth. With this parameterized 3D curve representation, the user can edit the mouth shape in 3D space by changing values of w_i and h_i.

Fig. 5 illustrates different views of a set of deformable curves generated by our template in 3D space. We have generated 3 curves by using the same width parameter L_M and various w_i and h_i (refer to Equation (2)). The curves described can be easily adapted to represent the contours of a human mouth in 3D.

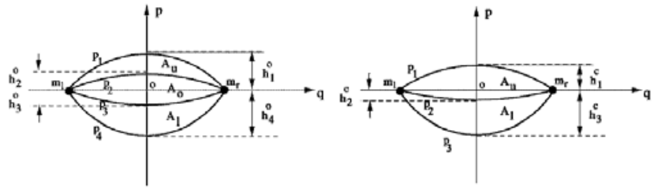


Fig. 4: Deformable template for open mouth (left) and closed mouth (right) in 2D.

Fig. 5: Deformable curve in 3D space

Mouth representation and modification

The mouth (open) can be represented by five curves (Fig. 6). All these curves are parameterized by our deformable template. This representation can accommodate both an open mouth and a closed mouth. Fig. 5 shows an open-mouth template; the closed mouth is obtained by merging middle curves 1 and 2 into one single curve. Since the lip contour is a combination of five different curves, we have to construct two partial curves (upper 1 and 2) and three complete curves (middle 1, 2 and lower). To achieve the objective of shape modification, one needs to adjust the associated curve parameters.

Eye representation and modification

The contour of eyes on a generic head model can also be represented by our formulae. Here we only present the open-eye case (Fig. 7), which combines two curves in Equation (2). The shape modification for eyes can be performed in a manner similar to the mouth.

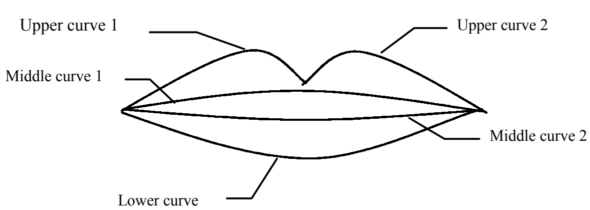


Fig. 6: Mouth representation by deformable templates

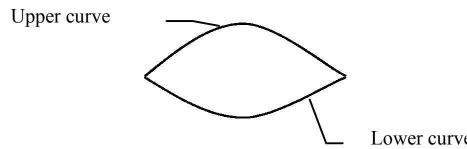


Fig. 7: Eye representation by deformable templates

4.5 Texture mapping feedback

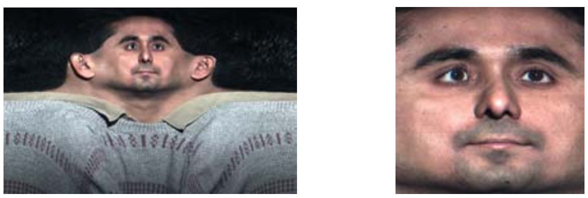
Our approach is based on user interaction and the model improvement is controlled by texture mapping feedback. There is no specific criterion to complete the process of shape adjustment, and the user determines when (s)he is satisfied by the texture mapping on a modified generic model. Experimental results in the next section describe implementation details of our strategy.

5. Experimental Results

We tested our technique on a generic head model with facial texture image acquired using the Zoomage® 3D scanner. The scanner creates a 360 degree texture image of a human head and we only have to work with the face region showed in Fig. 8 (b). Fig. 8 (c) gives the texture mapping result without interactive matching with the facial model. We describe experiments only in the mouth region because of limited space. The feature points on both 3D model and texture are selected interactively by a user, and the correspondence between them is setup accordingly (Fig. 9 (a)). (Note that only the lower lip is demonstrated here and the feature point selection for the upper lip is similar). Interactive texture mapping without using parameterized mouth contour is shown in Fig. 9 (b).

Fig. 9 (c) demonstrates a mouth texture mapped to the 3D mesh using our proposed 3D parametric model. Comparing Figures 9 (b) and 9 (c) we see that the mouth is reconstructed much better by the parameterized curve and the texture is mapped correctly. The curves in Figure 9 (c) are much smoother than in Figure 9 (b). Figure 10 illustrates texture mapping results of the eyes. In our implementation, parameters are modified by selecting the target curve and dragging the mouse to an appropriate position. On the other hand, the texture mapping result depends greatly on the texture feature point selection and the correspondence to the appropriate point on the 3D model. When the result does not improve any longer, the user might try to redo the feature point selection and correspondence. Figure 11 depicts the results of complete texture images mapping onto the generic facial model, with feature points on both mouth and eyes. The pictures are (from left column to right column): texture image, result without improvement, and result with improvement.

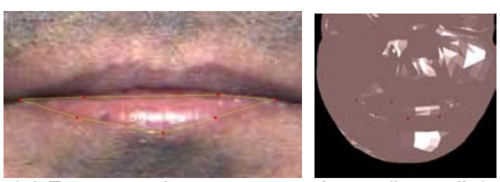
The effectiveness of our system was also evaluated from several aspects. We used ten judges to evaluate our implementation and give their evaluation marks on four aspects: ease of operation, texture mapping quality, speed, and visual improvement after using curve templates. The evaluation mark has five levels, *i.e.*, 1, 2, 3, 4, 5, which denote very unsatisfied, unsatisfied, neutral, satisfied, and very satisfied, respectively. The user can give any valid float point marks, *e.g.*, 3.5. The evaluation marks are shown in Table 1. In conclusion, our system has good performance on both ease of operation and speed. The textures mapping quality and model improvement are also acceptable by most of the users. This verifies that the ideas in this thesis have their advantages, and the implementation can be considered successful.



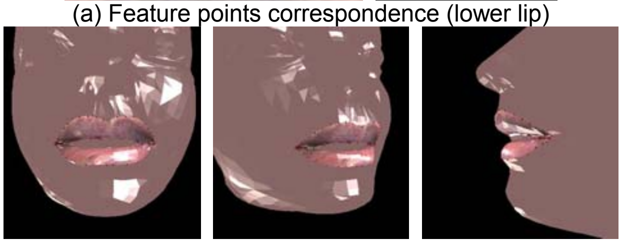
(a) Head texture from scanner (b) Facial texture

(c) Texture mapping without interactive modification.

Fig. 8. Facial texture and texture mapping without matching



(a) Feature points correspondence (lower lip)



(b) Without parametric mouth model

(c) With parametric mouth model

Fig. 9: Mouth reconstruction using feedback.

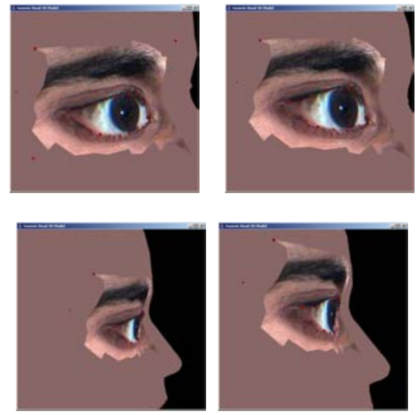


Fig. 10: Eye reconstruction using feedback
(left column: without parametric model; right column: with parametric model)

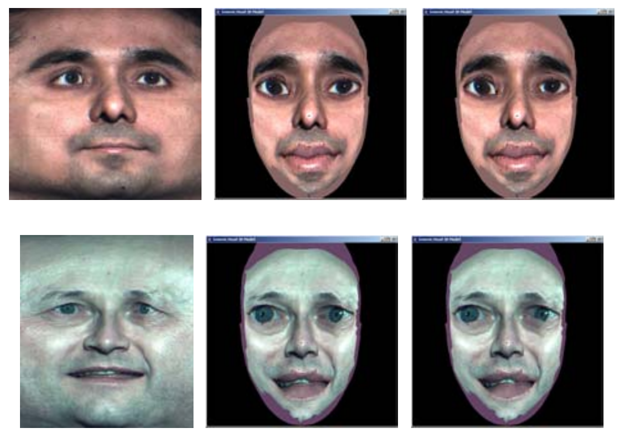


Fig. 11: Model improvement with complete facial texture mapping

Items / Judge	Ease of operation	Texture mapping quality	Speed	Improvement
1	5	4	5	5
2	4	5	5	5
3	4	5	5	4
4	5	5	5	4
5	3	5	5	4
6	5	4	5	5
7	5	4	5	4
8	4.5	5	5	4
9	5	4	5	5
10	5	4	5	4
Average	4.55	4.5	5	4.4

Table 1: Evaluation marks

6. Conclusion and Future Research

In this paper, we proposed an approach for reconstructing the human face model, especially for features on a face, such as, mouth and eyes. A deformable

3D curve template is developed for modification of the 3D model. Given a set of specific parameterized curves, the mouth and eyes can be represented by the template and interactively modified. Detailed modeling of nose and ears are currently ongoing. In future work we plan to develop tools to assist in reconstructive surgery by extending the current work.

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