A New Compatible Remeshing Approach for 3D Face Construction and Expression Clone

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Abstract - This paper presents a new compatible remeshing approach, by morphing with Radial Basis Function based on approximate geodesic distance (G-RBF) followed by a mesh optimization to generate compatible meshes efficiently while approximating the input target geometry accurately. To test the proposed approach, a prototype is implemented to clone expressions onto the personalized 3D face model. A PCA based reconstruction algorithm is employed firstly to reconstruct a personalized 3D face model. Then, a personalized cartoon model is obtained by morphing and blending of the existing cartoon model and the 3D face model using the proposed compatible remeshing algorithm. Finally, an efficient expression cloning algorithm based on compatible remeshing is presented to clone the existing facial animation onto the personalized cartoon model. The proposed technique is useful for a wide range of applications, such as computer games, animation films and online avatars.

Index Terms - morphing, shape blending, motion retargeting, 3D face reconstruction

1. Introduction

With the development of 3D virtual environment technology, a large amount of applications that employ 3D avatars have emerged, including games, animations and online chatting. Many of these applications require the techniques of 3D face construction[1], facial animation[2] and animation transfer[3].

The approaches of constructing personalized cartoon 3D faces have been studied extensively in the past few years, which can be classified into two types: creating the cartoon face interactively or automatically[4]. The first kind of methods are time-consuming and professional skills are necessary to create lifelike 3D face models. Therefore, an automatic method of generating 3D cartoon face models would be interesting and meaningful for many researchers.

Transferring animation from one model to another has been challenging researchers for many years[5-6]. Previous works in animation transfer fall into two categories[7-8]: Machine learning based and anatomy based. The machine learning based methods require a large amount of sample data, while the complicated anatomy based methods derive facial animations from physical behaviors. Preserving the style and quality of professional animations as they are transferred to different models plays an important role in the animation production. Our method allows the users without much professional knowledge to directly retarget stylized motion with only little manual work.

Compatible remeshing is studied to modify several meshes to share a common connectivity structure[9]. However, most of the published methods need to construct a base mesh and use Euclidean distance, which is not well suitable for complex surfaces.

Using geodesic distance, we present a new compatible remeshing approach to map one surface model to another one with several correspondences selected manually. Our solution is very easy to implement and it can be applied to surfaces of complex geometry and topology such as human faces. The personalized cartoon face model can be obtained by blending and morphing of the existing cartoon model and the 3D reconstructed model.

2. The Proposed Algorithm

Suppose $\mathcal{M} = (K, V, V^f)$ is a 3D head mesh with feature points, where vertices $V = \{v_1, v_2, \ldots, v_n\}$, $v_i \in \mathrm{R}^3$, feature points $V^f = \{v_1^f, v_2^f, \ldots, v_m^f\}$,$v_i^f \in \mathrm{R}^3$,$V^f \subseteq V$. K is a simplicial complex[10] representing the topological type of the mesh.

Let $v1_k^f \sim v2_k^f$ denotos $v1_k^f$ and $v2_k^f$ are the corresponding feature points of two meshs $\mathcal{M}_1$ and $\mathcal{M}_2$. Given a mesh $M_s(K_s, V_s, V_s^f)$ as source and a mesh $M_t(K_t, V_t, V_t^f)$ as target, the proposed compatible remeshing process $CR()$ amounts to generating a new mesh $M_r(K_r, V_r, V_r^f)$ with the same mesh structure as that of Ms, and similar appearance with that of Mt：

$$CR(M_s, M_t) = M_r \quad (1)$$

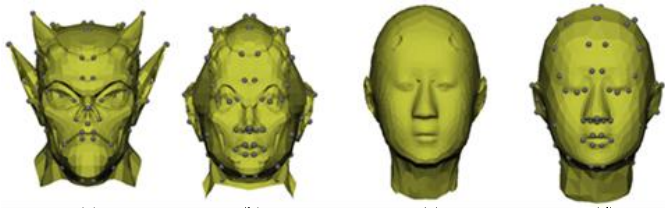
The compatible remeshing process $CR()$ contains two steps: G-RBF (Radial Basis Function based on approximate geodesic distance) followed by OPT (mesh optimization):

$$CR(M_s, M_t) = F_{OPT}(F_{G-RBF}(M_s, M_t), M_t) \quad (2)$$

$$F_{G-RBF}(M_s, M_t) = \widetilde{M_r}, \widetilde{K_r} = K_s \quad (3)$$

$$F_{OPT}\left(\widetilde{M_r}, M_t\right) = M_r, K_r = K_s \quad (4)$$

For example, the cartoon model $\mathrm{M_s}$ in Figure 1(a) is the source mesh. The human face in Figure 1(d) is the target mesh $\mathrm{M_t}$. The gray vertices on the two models are correspondences. To get a new mesh $\mathrm{M_r}$ with the same mesh structure as that of the cartoon face, and with similar appearance as the human face, as shown in Figure 1(c), two steps are processed. First, to be able to deal with complex surfaces such as the cartoon face, Euclidean distance is replaced by Geodesic distance. Morphing with G-RBF roughly aligns features of the two models, the result of $\widetilde{M_r} = F_{G-RBF}(M_s, M_t)$ is shown as in Figure 1(b). Second, Mesh optimization is applied to refine the alignment of Figure 1(b). The final result $M_r = F_{OPT}\left(\widetilde{M_r}, M_t\right)$ is shown in Figure 1(c).



(a) (b) (c) (d)

Fig. 1 Compatible remeshing. (a) The cartoon model M_s (source model); (b) After morphing with G-RBF, $\widetilde{M_r}$; (c) After mesh optimization, M_r; (d) The 3D human face model M_t (target model).

A. G-RBF: Radial Basis Function based on approximate geodesic distance

Radial basis function (RBF) is well known for its powerful capability in interpolation, convergence and smoothness. The Euclidean distance, which is popular in calculating the distance between two vertices on a mesh in previous approaches[8], is not suitable for complex geometry and topology such as human faces. We replaced Euclidean distance with Geodesic distance[11], which is more suitable for complex surfaces. Employing Hardy multi-quadrics for the basis function, the network of G-RBF can be expressed as:

$$F_{G-RBF}(M_s, M_t) = \widetilde{M_r} = (\widetilde{K_r}, \widetilde{V_r}, \widetilde{V_r^f}),$$
$$\widetilde{vr} \in \widetilde{V_r},\ vs \in V_s,\ vs_i^f \sim vt_i^f \qquad (5)$$

$$\widetilde{vr} = f_{G-RBF}(vs) = \sum_{i=1}^{m} w_i \sqrt{\left\|vs - vs_i^f\right\|^2 + s_i^2},$$
$$s_i = \min_{vs \neq vs_i^f} \left\|vs - vs_i^f\right\|, \qquad (6)$$

where m is the number of feature points, vs is the input vector, w_i donates the weights to be trained by the feature points according to Equation (7):

$$vt_k^f = \sum_{i=1}^{m} w_i \sqrt{\left\|vs_k^f - vs_i^f\right\|^2 + s_i^2},$$
$$s_i = \min_{k \neq i} \left\|vs_k^f - vs_i^f\right\|,\ 1 \le k \le m, \qquad (7)$$

where $vs_k^f, vs_i^f \in V_s^f$, $vt_k^f \in V_t^f$, $vs_k^f \sim vt_k^f$.

B. Mesh optimization

To further refine the result, mesh optimization[10] is employed to fit $\widetilde{M_r}$ to M_t (Equation (4)), by minimizing the following Energy. As in [2], only vertex positions are optimized.

$$E(v) = E_{dist}(v,p) + \beta E_{smooth}(v) + \gamma E_{feature}(v), \qquad (8)$$
$$E_{dist}(v,p) = \sum_{i=1}^{n} |p_i - \prod(v,p_i)|^2,$$
$$E_{smooth}(v) = \sum_{i=1}^{n} \left|v_i - \frac{1}{||N(v_i)||} \sum_{v_j \in N(v_i)} v_j\right|^2,$$
$$E_{feature}(v) = \sum_{i=1}^{n_f} \left|T_{v_i} v_i - p_i\right|^2,$$

where $v = (v_1, \dots, v_n)$ denotes the vertices of $\widetilde{M_r}$ (Figure 1(b)), $p = (p_1, \dots, p_n)$ is that of M_t (Figure 1(d)). $\prod(v,p_i)$ is the projection of p_i onto the surface of $\widetilde{M_r}$. $N(v_i)$ is the neighborhood of v_i. T is the transformation applied to the vertexes of $\widetilde{M_r}$. E_{dist} measures the sum-squared distance from the target model to the source surface. E_{smooth} measures the distance from each vertex to the average of its neighboring vertices. $E_{feature}$ is simply the sum-squared distance from source feature points to the corresponding target feature points.

As shown in Figure 1(c), the output mesh M_r is refined greatly.

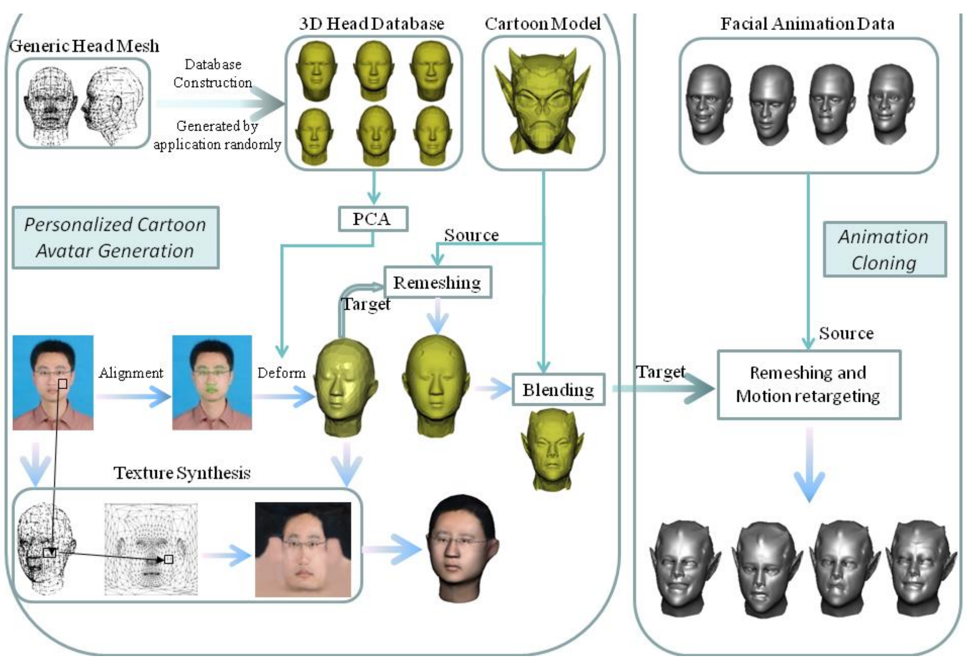


Fig. 2 System framework

3. The Prototype

To demonstrate the effectiveness of our method, a prototype system shown in Figure 2 is developed with two components: personalized cartoon avatar generation and facial animation cloning.

A. *Personalized cartoon avatar construction*

Head models with the same topology, are taken to construct personalized avatar by means of PCA, in which a large amount of data is required, as mentioned in [4]. 500 3D head models are prepared for PCA subspace construction. A 3D head model represented by a vector $H = (X_1, Y_1, Z_1, \ldots, X_n, Y_n, Z_n)^T$, where n is the number of points of each model, can be obtained by applying PCA to the 500 head models:

$$H = \bar{H} + P\alpha, \tag{9}$$

where $\bar{H}$ is the mean head model, α is the coefficient vector, P is the matrix of the top k eigenvectors (in descending order according to the eigenvalues).

68 key facial points, standing for face contour points, eye centers and nose tip etc., are selected from the input image with frontal pose and neutral expression to reconstruct 3D face model by Active Shape Model (ASM)[12]. Let $H_{front} = (x_1, y_1, \ldots, x_t, y_t)$ be the coordinates of the feature vertices on the 2D image. Since each feature point on the 2D image is corresponding to a certain point of the 3D model, $\overline{H_{front}}$ is a sub-vector of $\bar{H}$, and P_{front} is the sub-matrix of P as well.

$$H_{front} = \overline{H_{front}} + P_{front}\alpha \tag{10}$$

For an input image, the coefficient α in Equation (10) is computed by the method of least squares and then applied to Equation (9) to obtain the new 3D face model H. To improve the result, G-RBF is employed to ensure the feature points of the 3D model H align to the corresponding feature points on the 2D image.

(a) (b) $\alpha = 0.85$ (c) $\alpha = 0.70$ (d) $\alpha = 0.30$ (e)

Fig. 3 Blending meshes with varied weights. The frontal snapshots are on the top row, and side ones are on the bottom row. (a) 3D human face model; (b)-(d) Blending results; (e) Cartoon model.

Given a cartoon model $I_{cartoon}$ as source and the reconstructed face model H as target, a remesh model is obtained according to Equation (11):

$$I_{remesh} = CR(I_{cartoon}, H) \tag{11}$$

The personalized cartoon avatar I is generated by blending $I_{cartoon}$ and I_{remesh}:

$$I = \alpha * I_{remesh} + (1 - \alpha) * I_{cartoon}, \tag{12}$$

where $0 \le \alpha \le 1$. Figure 3 shows a set of blending results depending on different α.

B. *Facial animation cloning*

Animation cloning, which means mapping an expression of the existing model onto the target one[8], is based on the facial model parameterization. With the blend shape parameterization, which describes the facial animation as a linear parameterization of the face deformation, animation cloning is reduced to estimate a set of weights for the target face at each frame of the source animation. In the prototype system, the animation data are in the form of vertex motion vectors, which means the face at each frame can be converted into a delta model by subtracting the "neutral" face model.

Firstly, a set of n key expression models, such as angry, talking, smiling, and surprised are represented by

$$\mathcal{M}_i = (K, V_i), i = 0,1,2, \ldots n \tag{13}$$

In particular, $\mathcal{M}_0$ is the base model with neutral expression. Any new expression face can be obtained by:

$$V = V_0 + \sum_{i=1}^{n} \beta_i \Delta V_i \tag{14}$$

Where $0 \le \beta_i \le 1$ is the blendshape weight, $\Delta V_i = V_i - V_0$, $\Delta\mathcal{M}_i = \mathcal{M}_i - \mathcal{M}_0$. For example, giving three key expression models (Figure 4 (b-d)), a new expression face $\mathcal{M}_{syn}$ (Figure 4(e)) can be produced by combining the four basic models:

$$\mathcal{M}_{syn} = \mathcal{M}_0 + 0.5\Delta\mathcal{M}_1 + 0.9\Delta\mathcal{M}_2 + 1.0\Delta\mathcal{M}_3$$

To transfer the animation data to another target model $\mathcal{M}_t$ with neutral expression, the proposed compatible remeshing approach is used to generate a new base model: $\mathcal{M}_0'(K, V_0') = \mathrm{CR}(\mathcal{M}_0, \mathcal{M}_t)$.

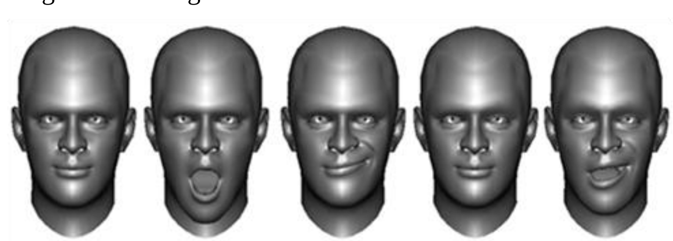
Then the other corresponding key expression models for the target model can be computed by:

$$V_i' = V_0' + f_{G-RBF}(V_i) - f_{G-RBF}(V_0), 1 \le i \le n \tag{15}$$

As the mesh structure of $\mathcal{M}_i'$ is the same as that of $\mathcal{M}_0'$, $\mathcal{M}_i'$ can be represented as

$$\mathcal{M}_i' = (K, V_i'), i = 0,1,2, \ldots n \tag{16}$$

Once the set of key expression models for the target model are built, any expression of the source model can be transferred to the target model by applying the blending weights to the target model at each frame.



(a) $\mathcal{M}_0$ (b) $\mathcal{M}_1$ (c) $\mathcal{M}_2$ (d) $\mathcal{M}_3$ (e) $\mathcal{M}_{syn}$

Fig. 4 Blend shape. (a) Neutral; (b) surprised; (c) smiling; (d) left eyebrow lifting; (e) synthesis of the left four.

4. Experiments and Results

The results of 3D face reconstruction are shown in Figure 5. The experimental results of compatible remeshing and animation cloning are shown in Figure 6.

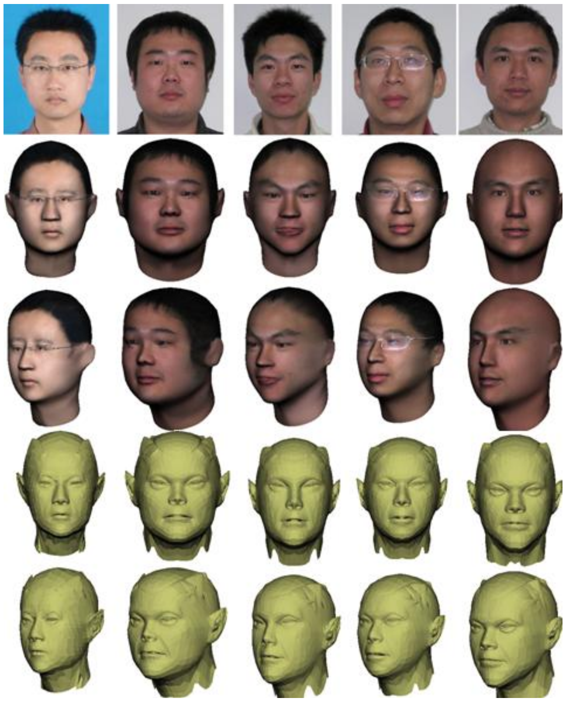


Fig. 5 Some 3D reconstructed faces and personalized cartoon models

5. Conclusions

In this paper, a new compatible remeshing approach is presented to generate compatible meshes efficiently while approximating the input target geometry accurately. The source model is morphed with Radial Basis Function based on Geodesic distance and mesh optimization To test the proposed approach, a prototype is implemented to clone the existing facial animation onto the personalized cartoon models. The experiments show that the cloning results are compelling and successful in practice.

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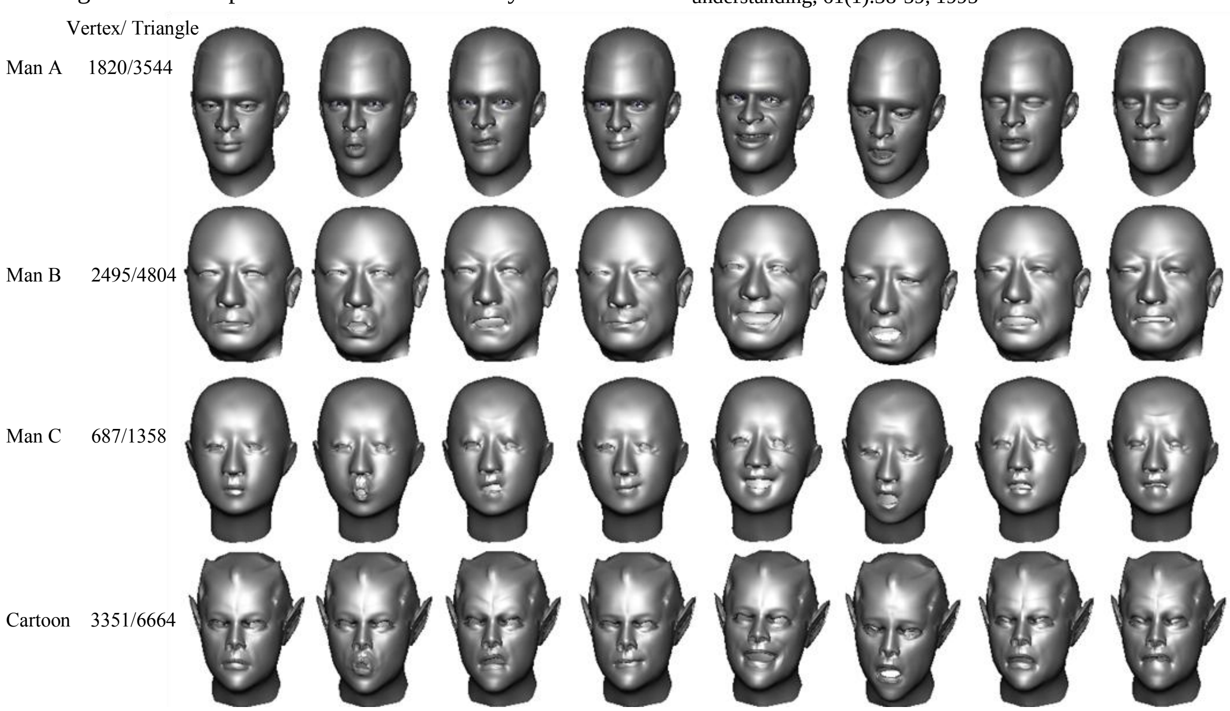

Fig. 6 Facial animation cloning from Man A to the target models