Anatomy-based Human Face Reconstruction Using Multi-layer Deformation

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ABSTRACT

We present a method for reconstructing anatomy-based facial models with minimal manual intervention. The technique is based on deforming a multi-layered prototype model to the acquired surface data in an "outside-in" manner. It enables a variety of applications, including texture transfer, morphing, statistical analysis of the face shape, and face recognition database satisfying large extra- and intra-subject variations.

Keywords

face reconstruction, facial animation, anatomy-based model, deformation.

1. INTRODUCTION

Current dense surface measurement techniques allow us to generate precise 3D shapes of faces by using 3D shape acquisition systems such as a range scanner, a stereo photogrammetry system, or an active light striper. However, using the range data for face reconstruction suffers from several key problems: 1) absence of animation structure; 2) irregular and dense surface data; and 3) incomplete data. We propose a method for efficiently reconstructing animatable 3D faces from range data. It is based on deforming a prototype model to the acquired surface data in an "outside-in" manner: deformation applied to the external skin layer is propagated, with the final effect of deforming the underlying muscles.

2. PREVIOUS WORK

Previous major researches on 3D face reconstruction from range data include studies on conforming a generic face mesh to the located facial features in a 2D depth image [Wat91, Lee95], a study on

deforming a subdivision surface for fitting [Mar00], and a study on morphing a generic model with scattered data interpolation [Kah02]. Our technique differs from these methods in that 1) it uses a dynamic deformable model for the skin layer deformation in 3D space; 2) it automatically adapts the underlying muscle layer that includes three types of muscles; and 3) it is capable of generating animatable models from incomplete scanned data.

3. MULTI-LAYER DEFORMATION

Data Acquisition

The range data acquired by a Minolta VIVID 900 Digitizer is a dense point surface, frequently with holes due to missing data (see Fig. 1a). We have developed an anatomy-based prototype model that incorporates a skin-muscle-skull structure for physically-based facial animation (see Fig. 1b and c).
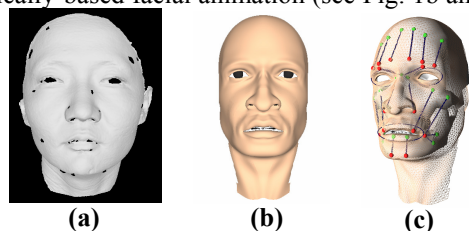

(a)   (b)   (c)
Figure 1. (a) Scanned data. (b), (c) Prototype

Skin Layer Deformation

To accomplish the fitting, a physical model based on the mass-spring-damper (MSD) system is created from the skin mesh of the prototype model: each mesh vertex is characterized by a mass m and each mass point is linked to its neighbors by damped

massless springs. The discrete Lagrangian equations of motion for the MSD mesh can be expressed in 3D vector form as:

$$\mathrm{M}\frac{d^2x}{dt^2}+\mathrm{D}\frac{dx}{dt}+\mathrm{F}_e(x,\mathrm{K})=\mathrm{F}_d(x)+\mathrm{F}_f(x) \qquad (1)$$

Given N vertices, x represents a $3N$ vector of nodal displacement, M, D, and K are $3N \times 3N$ matrices describing the mass, damping, and stiffness between vertices, respectively. F_e, F_d and F_f are $3N$ vectors, representing the elastic force, data force and feature force, respectively.

A vertex x_i receives the data force from the closest scanned data point p_j. Since the scanned data is used to attract the generic mesh and deform it into a consistent shape, we use a type of springs with natural length of zero for this kind of deformation:

$$F_e(x_i)=\alpha\frac{\lVert x_i-p_j\rVert}{H}\overrightarrow{x_ip_j} \qquad (2)$$

where α controls the force strength, and H is a normalizing constant.

We have interactively specified a set of 23 landmarks on both the prototype model and the scanned data to identify facial features (e.g. eye and mouth corners, nose tip etc). For each landmark s_k on the scanned surface, it has a counterpart q_k on the generic mesh. The force generated by s_k is applied to q_k and its neighboring vertices:

$$F_f(x_i)=\begin{cases}\beta\dfrac{\lVert x_i-s_k\rVert}{L}\overrightarrow{x_is_k} & \text{if } d_{ik}<Q_k^{ref}\\ 0 & \text{otherwise}\end{cases} \qquad (3)$$

where β is a scaling parameter, L is a normalizing constant, d_{ik} denotes the topological distance of the vertex x_i from the landmark q_k measured in terms of the smallest number of edges between them, and Q_k^{ref} denotes the reference topological distance of kth landmark point. We integrate Eq. 1 using the explicit Verlet-Leapfrog method.

Muscle Layer Deformation

The muscles incorporated in the prototype model are divided into three types: the *linear muscle*s, *sheet muscle*s, and *sphincter muscles*. The central muscle fiber of the first two types of muscles has one end attached to the skull which is called the *muscle attachment point* and the other end inserted to the skin which is called the *muscle insertion poin*t. For a muscle insertion point, it is located on the surface of an indexed skin mesh triangle. After deformation of the skin layer, its new position is easily found with this transformed triangle. For a muscle attachment point, we first find its counterpart on the skin along the direction of skull surface normal. They are related by a *tissue depth vector*. After deformation of

the skin layer, the new position of the muscle attachment point is obtained by offsetting the transformed skin counterpart along the negated tissue depth vector.

The sphincter muscles consist of fibers that loop around the eyes and mouth and can draw towards a virtual center. They are modeled as a parametric ellipse. To adapt a sphincter muscle, we use one end of its two axes as reference points. By finding their skin counterparts on the undeformed skin surface, we obtain their new positions in the same way as to determine that of the muscle attachment point. The epicenter and half-lengths of two object axes of the elliptic muscle model are then calculated based on the new positions of the reference points.

4. RESULT

Fig. 2 shows the reconstructed facial model with Gouraud shading, its texture-mapped appearance, and adapted underlying muscle layer.

Figure 2. Reconstructed personalized face.

Our method creates a consistent surface parameterization of range scans, which gives immediate point correspondences between all the models via a single, prototype layout. This in turn enables a series of applications that involve multiple models simultaneously, including texture transfer, morphing, statistical analysis of the face shape space, and face recognition database satisfying a large extra-and intra-subject variations.

5. REFERENCES

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