Title:
Facial Conformation Modeling via Hierarchical Model Parameterization

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Introduction:
Research on computer face modeling can be dated back to the pioneering work of Parke [6] in 1974. Many studies have been done since then to improve the process of face modeling [1],[2]. The existing face modeling methods can be classified into two approaches: the reconstructive and the creative approaches [8]. The reconstructive approach extracts the face geometry from measurements on a physical face. 3D laser scanners and calibrated or non-calibrated cameras are usually used to implement this approach. The result of the reconstructive approach is accurate. However, this approach involves considerable time and expense and the generated face model is generally quite difficult to animate. On the other hand, the creative approach offers full control over the created face model, including the ability to produce animated expressions and highly efficient facial geometry manipulation. It facilitates manual specification of a face model where *a priori* knowledge can be injected. Two different face modeling methods are widely used in this approach. The first one constructs a face model from scratch employing a general-purpose 3D modeling software tool like Maya and is generally more suited for computer artists. The second one, which is employed in this work, is to generate a new face model by deforming a parameterized, generic face model.

The goal of facial conformation modeling is to reproduce the geometrical shape of a specific face as a 3D model. Some 3D modeling tools such as Maya, Poser, and DazStudio have been widely used to model human faces in movies and computer games. In these tools, the mesh-based face model geometry is specified manually through the deformation of thousands of mesh vertices to achieve the desired shape. Consequently, the face modeling process is usually tedious and lengthy and requires specialized modeling techniques as well as artistic skills. Ordinary users will face a steep learning curve to understand and use such tools. To overcome this issue, this work is aimed at building an easy-to-use face modeling tool, which enables users to construct realistic human face models in an interactive way. In general, generation of a face model involves determining the geometric shape (the 3D coordinates of the face mesh vertices) and the surface color attributes often referred to as the texture. The focus of this work is mesh parameterization for modeling the face geometric shape; hence, face texture generation is not part of this work. A generic face texture is employed and the term face modeling is restricted to facial conformation modeling in this work.

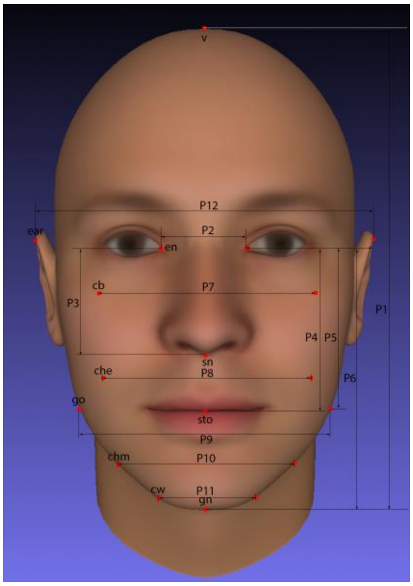
Face Anthropometry:
Although human faces are similar in structure and have the same set of features, there are considerable variations from one individual to another. In particular, human eyes are extremely sensitive to such variations. It is challenging to develop a modeling scheme that supports all these variations successfully. A thorough understanding of facial conformation is thus needed in order to capture the essence of an individual human face. However, unlike facial expressions, which have been extensively studied via muscle and tissue movements, facial conformation has less theoretical basis. In

fact, past research efforts have been spent more on geometrical measurement and statistical analysis. Hence, it is worthwhile to review how human faces are measured first in order to find a reasonable set of parameters to represent facial conformation variations. There are several research subjects related to this, namely, anthropometry, biometrics, and cephalometry. Among these subjects, anthropometry provides applicable information to parameterize facial conformation. A classic book by Farkas [3] on face anthropometry is widely used when studying human faces. It characterizes the human face using linear distance measurements between predefined anthropometric landmark points. The resulting anthropometry-based linear facial conformation parameters provide an intuitive description of the face and constitute the fundamental concept of this work.

<u>Facial Conformation Parameters:</u>

Although face anthropometry has defined and used a set of measurements to describe faces, many of them are not suitable for the parameterization of the face mesh. In addition to the linear parameters, there are circumference and angle parameters within the anthropometric measurement system. For implementation simplicity, a unified definition of the involved parameters is much more preferable. Hence, it has been decided to only use linear distances as the parameters. In fact, most circumference and angle parameters can be approximated by linear distances. Also, some parameters in the anthropometric system are not independent, which can be represented by linear combinations of other parameters. So, this work aims to identify a set of parameters that can be represented by linear measurements only. The parameters should be small in number while they are capable of generating acceptable facial conformation.

After a series of tests, a set of 32 parameters has been selected for the facial conformation modeling system developed in this work. As human faces are in general symmetrical about the center of the face, any two symmetrical face measurements are treated as one parameter. This means that changing a facial conformation parameter will result in the same effect on both sides of the face. Nonetheless, this can be easily extended to support asymmetric facial conformation, if needed. The selected parameters are classified into the facial outline parameters, feature region parameters, and side face parameters. Fig. 1 illustrates the selected 12 facial outline parameters.



Parameter No.	Parameter Name	Definition
P1	Head height	v-gn
P2	Distance between eyes	en-en
P3	Nose position	en-sn
P4	Mouth position	en-sto
P5	Jaw position	en-go
P6	Chin position	en-gn
P7	Cheekbone width	cb-cb
P8	Cheek width	che-che
P9	Jaw width	go-go
P10	Chin middle width	chm-chm
P11	Chin width	cw-cw
P12	Ear protrusion	ear-ear

Fig. 1: Facial outline parameters.

The variation of facial conformation parameters should be bounded in a reasonable range. Otherwise, impractical or improper face models could be generated. In order to determine the proper limits for each parameter, the statistical data in the classic book by Farkas [3] are used. In this book, the mean value and the standard deviation of each facial measurement among the population are given. Accordingly, the initial parameter values in the generic model are to be made the same as the corresponding anthropometric mean values. Assuming all the selected facial conformation parameters follow the normal distribution, 99.74% of the parameter values for the general population would lie within 3 standard deviations of the mean value. To ensure that the current face modeling method has sufficient flexibility to generate extreme facial conformation models, 5 standard deviations have been imposed as the limits for the 32 facial conformation parameters.

Hierarchical Face Model Parameterization:

In the facial conformation modeling process, sometimes we need to change a global parameter like the head height while sometimes we only want to adjust a local parameter like the size of the eyes. It is desirable for improved modeling efficiency that when changing a global parameter, relevant local parameters can be changed with it. For example, if we change to a wider face, the widths of the nose and the mouth should become larger as well. This is supported by the statistical data from face anthropometry showing that this is generally true for the human population. On the other hand, we do not desire a local modification to have any effect on the global parameters. Technically, when an anthropometric landmark point (an end point of any of the 32 linear facial conformation parameters) on the face mesh is moved, the movement of the neighboring vertices needs to be defined. In this work, the geodesic distance based compactly supported radial basis functions (RBFs) are employed to smoothly interpolate the linear displacements of the mesh vertices [4],[7]. It has been demonstrated that the resulting weighted linear combination of the RBFs facilitate localized face deformation and hole handling on the face mesh [5].

To achieve the desirable facial conformation modeling goal stated above, it would be cumbersome to parameterize the face mesh in a single RBF system due to the complexity in handling the large variety of the anthropometric landmark points. If we want a global parameter to have control over some local parameters, it needs to control all of the associated landmark points. To effectively implement this scheme, a hierarchical parameterization system is devised. The basic idea of the hierarchical parameterization is to separate the facial conformation parameters into different levels with each level having an individual set of landmark points and its own RBF system. Landmark points used in a lower level parameter will not be included in a higher level RBF system. Hence, the deformation caused by changing a higher level parameter will not be constrained by the lower level landmark points, thereby achieving a global deformation effect. On the other hand, landmark points used in a higher level parameter will be included in the lower level RBF system in order to retain their constraining effect. In this work, the 32 facial conformation parameters are divided into three hierarchical levels: face profile level, feature position level, and feature details level.

Fig. 2 shows the effect of changing the head height parameter in the highest face profile level. Since no other facial conformation landmark points are constrained in this highest level, when the head height parameter is changed, all vertices in the face mesh model are moved. As can be seen in the figure, a longer (narrower) head/face is on the left and a shorter (wider) head/face is on the right with all the features on the face being changed accordingly, although slightly.

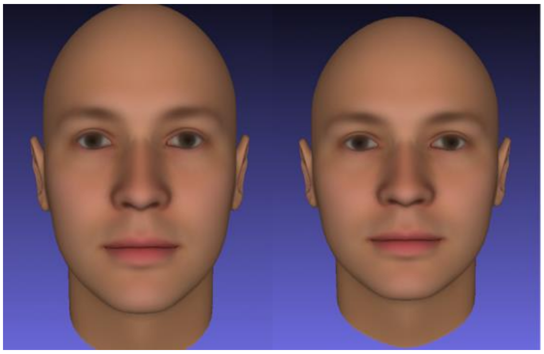
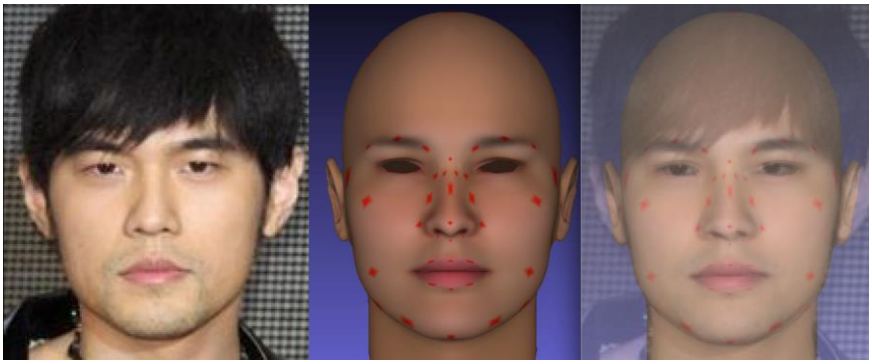


Fig. 2: Effect of changing the head height on the generic face.

Model Validation:
A series of face modeling tests have been performed to validate the facial conformation modeling method presented in this paper. The purpose of the developed face modeling method is to generate a 3D face model that resembles the geometry of a given face. Hence, the objective of the face modeling tests is to verify whether the implemented face modeling tool is able to generate the intended face geometry. It should be noted that texture of the face/head such as that for the eyeballs and hair is not part of this work. In the facial conformation modeling setup, a frontal face image is given as the input. A generic face model and the set of 32 facial conformation parameters with initial values are presented to a human user at the beginning of the modeling process. The user adjusts each parameter through a basic GUI (Graphical User Interface) until he/she reaches a satisfactory geometric model of the face according to his/her observations. Since there is no ground truth 3D face model to serve as the reference, only qualitative analysis results have been made and discussed.

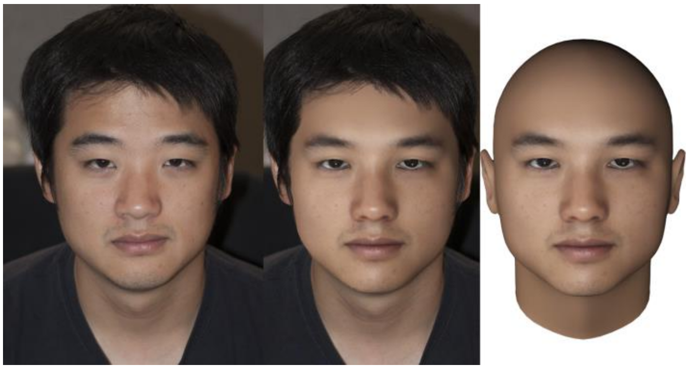
A typical face modeling result is shown in Fig. 3. Fig. 3(a) shows the input frontal image of a face (from http://entertainment.xin.msn.com/en/celebrity/buzz/asia/jay-chou). The corresponding 3D face model was created using the face modeling tool developed in this work by adjusting the 32 facial conformation parameters. The modeling result is shown in Fig. 3(b) with the conformation landmark points marked in red. In Fig. 3(c), the 3D face model image is overlapped on top of the original face image using 50% image transparency. It can be seen clearly that the profiles of the modeled face and the original face are correctly matched, including the head height and width, and chin and jaw contours. The locations and details of the various face features are also well aligned. This indicates that the developed face modeling tool is able to create the geometric shape of the given face correctly.



(a) (b) (c)

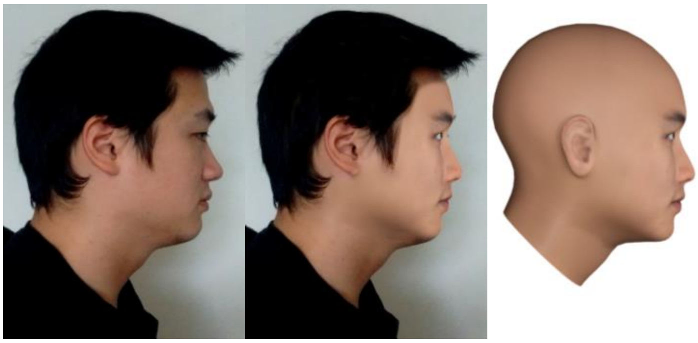
Fig. 3: Typical face modeling result: (a) input (target) face, (b) created model, and (c) overlapped image.

It should be noted, however, that although all the face features in Fig. 3 are well aligned, it is not immediately obvious to the human eyes that the created 3D face model closely resembles the original face in geometry. To further demonstrate that the created face model closely represents the given face, some visual factors that affect the subjective judgment of the likeness of faces need to be added. These visual factors include the facial texture and the material property for the skin. To incorporate these visual factors (both are not part of the technical development in this work), the facial texture map from the input frontal face image is generated and laid on the created 3D face model and the skin material property is simply added through a commercial software tool. These added visual factors yield a more complete feel of a face and reduces the visual distraction in judging the similarity of faces. We can then focus more on comparing the facial conformation, the aim of the development of this paper. In this regard, a face was modeled to the best conformation using the developed tool, mapped with the corresponding facial texture, and rendered with the proper skin material property. With the input image of Fig. 4(a), the resulting 3D face model is shown in Fig. 4(c). Fig. 4(b) shows a synthesized image of the created face model with the original image background and hair. Comparison of the original and modeled face images in the 90° side view is shown in Fig. 5. It can be seen that the synthesized images very closely resemble the original face images, thereby validating the effectiveness of the developed face modeling method.



(a) (b) (c)

Fig. 4: Created face model with corresponding facial texture and proper material property.



(a) (b) (c)

Fig. 5: Comparison in 90° side view: (a) original image, (b) synthesized image, and (c) modeled face.

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