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Facial conformation modeling via interactive adjustment of hierarchical linear anthropometry-based parameters

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ABSTRACT
This paper presents a new and easy-to-use interactive facial conformation modeling method. The modeling of a specific face is performed on a generic, triangle mesh based face model by adjusting a set of hierarchically organized facial confirmation parameters, which are derived from the anthropometric data on human faces. The method transforms complex facial conformation mesh manipulations into simple linear parameter adjustments between the specified anthropometric landmark points on the face mesh. The parameter adjustments are made interactively via a three-level hierarchical framework. Geodesic distance based compactly supported radial basis functions are employed to smoothly interpolate the displacements of the face mesh vertices and facilitate localized deformation and hole handling on the face mesh. The involved linear anthropometry-based parameters are classified into three different levels with each level governed by its own radial basis functions. Simple and interactive mesh manipulations are thus achieved for effective facial conformation modeling. A series of practical face modeling case studies have been carried out to validate the presented interactive facial conformation modeling method.

KEYWORDS
Facial conformation; interactive modeling; face anthropometry

1. Introduction

Research on face modeling using computers can be dated back to the pioneering work of Parke [14] in 1974. Many studies have been done since then to improve the process of face modeling [4],[7],[13]. The existing face modeling methods can be classified into two approaches: the reconstructive and the creative approaches. 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 [1],[2],[3],[6]. The result of the reconstructive approach is accurate. However, it usually involves considerable time and expense to generate the complete face model from the measurement data. More importantly, the generated face model is often not readily available for animation due to the face model being parameterless. To generate parameterized face models from 3D scans, Weissenfeld et al. [18] proposed to deform a generic face model according to a 3D scan via a global adaptation procedure followed by a local adaption procedure for superior modeling accuracy. Zhang and Badler [19] introduced a novel method to generate realistic controllable face models from 3D scans based on statistical facial feature control models. The feature shapes on the generic face model were parameterized according to a principal component analysis of the scanned feature data.

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 modifications on a face model where *a priori* knowledge can be easily injected. There are two distinct methods under the creative approach. The first one constructs a face model from scratch by employing a general-purpose 3D modeling software tool like Maya and is generally more suited for computer artists. The second one is to generate a new face model by deforming a parameterized, generic face model [5]. To implement such a method, Patel and Zaveri [15] proposed to automatically extract face features from a given frontal face image. The extracted face features were then used to deform a generic face model via the scaling and translation geometric transformations. It should be noted that human eyes are known to be sensitive to variations in human faces. As a result, to facilitate user-level control over the visually sensitive face modeling task, building an easy-to-use interactive face modeling tool, which enables ordinary users to quickly construct realistic human face models, is the primary objective of

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this work. Such a face modeling tool is motivated by the increasing appearance of customizable 3D face models in computer games and web applications. In these applications, user-level control that facilitates quick creation of satisfactory customized face models is the attribute in most demand. Conversely, existing methods on face modeling predominantly focus on modeling accuracy and automation, but not on easy-to-use interactive face modeling.

The goal of facial conformation modeling is to produce the geometrical shape of a specific face as a 3D computerized 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 always face a steep learning curve to understand and use such tools. In general, generation of a visually acceptable 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 [16]. The focus of this work is to develop a set of facial confirmation parameters for interactive modeling of 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 paper.

2. 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.

Generally speaking, anthropometry is the study of human body measurements. It plays an important role in today's industrial design, clothing design, ergonomics and architecture where statistical data about the distribution of body dimensions in the population are used to optimize the design of products. As for face anthropometry, a classic book by Farkas [8] is widely used when studying human faces. It characterizes the human face using linear distance measurements between predefined anthropometric landmark points. The associated anthropometric parameters provide an intuitive description of the face. In this work, the basic anthropometry notions, facial landmark points, and linear measurements are adopted and implemented.

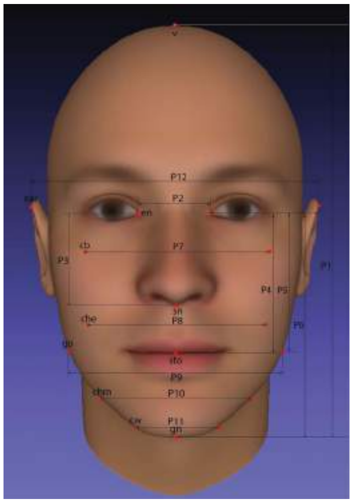
3. Facial conformation parameters

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 on the basis of the face anthropometric measurement system 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 and described in the following subsections.

3.1. Facial outline parameters

Head, chin, jaw, cheek, and ear parameters are conceptually classified as facial outline parameters in this work because they form the general shape of a face. These



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

Figure 1. Facial outline parameters.

parameters are mostly referenced from the eyes position. As a 3D mesh model can be easily scaled, the model size is not of practical significance. To parameterize the head size, we are only interested in the head height-width ratio. Hence, we fixed the head width and left only the head height to be adjustable. As shown in Fig. 1, the head height (v-gn) is defined as the distance between the top of the head (v) and the bottom of the chin (gn). Three parameters are used to specify the distance between eyes and the nose and mouth positions with respect to the position of the eyes. The chin, jaw, and cheek occupy a large area of the face but their geometry is relatively simple. Seven parameters are chosen to define their shapes. Ears have very complex geometry and their detailed geometry is not of interest in the current parameter system. However, the protrusion of ears appears to be sensitive to the human eyes. So, an ear protrusion parameter is added to the system, resulting in the set of 12 facial outline parameters.

3.2. *Feature region parameters*

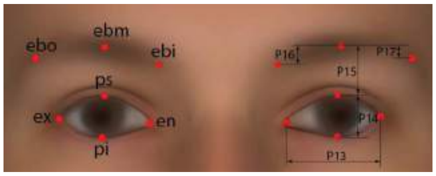
Eyes are one of the most recognizable and important features on a human face for facial confirmation. For modeling simplicity, five parameters are employed, which include parameters for specifying the symmetric eye profiles and the eyebrows, as depicted and listed in Fig. 2.

The geometry of a human nose is very complex. It is difficult to use explicit quantitative metrics to parameterize the nose shape precisely. With the nose position already specified as a facial outline parameter, eleven parameters are employed in this work to attain acceptable nose modeling versatility. Four of the eleven parameters are side face parameters to be presented in the next subsection. The other seven parameters to model the nose in the frontal view are shown and listed in Fig. 3.

The last feature to be modeled on the face is the mouth. The involved mouth region parameters include the mouth width and the lip thickness, as depicted and listed in Fig. 4. It should be noted that, for minimizing the number of parameters used, the upper and lower lip thicknesses are not specified individually. A standard thickness proportion for the upper and lower lips has been employed. Hence, only a combined upper and lower lip thickness is required.

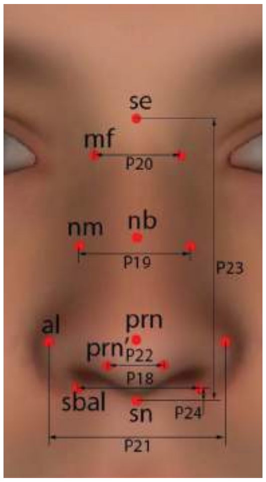
3.3. *Side face parameters*

Side face parameters are measured in the 90° side view plane of the face. The involved parameters essentially



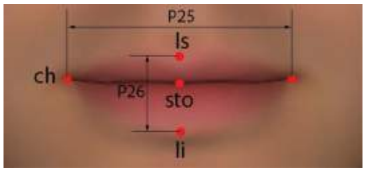
Parameter No.	Parameter Name	Definition
P13	Eye width	en-ex
P14	Eye size	ps-pi
P15	Eyebrow position	ebm-ps
P16	Inner eyebrow height	ebi-ebm
P17	Outer eyebrow height	ebo-ebm

Figure 2. Eye region parameters.



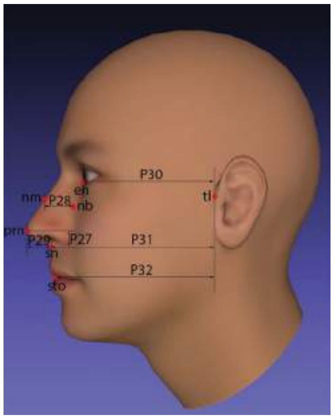
Parameter No.	Parameter Name	Definition
P18	Nose width	sbal-sbal
P19	Nose middle width	nm-nm
P20	Nose base width	mf-mf
P21	Nostril width	al-al
P22	Nose tip thickness	prn'-prn'
P23	Nose height	sn-se
P24	Nostril tilt	sbal-sn

Figure 3. Nose region parameters (frontal).



Parameter No.	Parameter Name	Definition
P25	Mouth width	ch-ch
P26	Lip thickness	ls-li

Figure 4. Mouth region parameters.



Parameter No.	Parameter Name	Definition
P27	Nose tilt	prn-sn
P28	Nose bridge height	nm-nb
P29	Nose tip height	prn-sn
P30	Eye protrusion	en-tl
P31	Nose protrusion	sn-tl
P32	Mouth protrusion	sto-tl

Figure 5. Side face parameters.

represent the protrusion of the eyes, nose and mouth, as shown and listed in Fig. 5.

3.4. *Parameter limits*

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 [8] 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.

4. 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 [9],[11],[12],[17]. More specifically, an interpolation function has been formulated as:

$$f(X) = \sum_{i=1}^{n} w_i \phi(||X - X_i||) \tag{4.1}$$

where X denotes the 3D coordinate position of a face mesh vertex, X_i the position of the ith landmark point (out of n such points), and w_i the weighting factor for the ith landmark point. It should be noted that in Eqn. (4.1), $\|X - X_i\|$ represents the geodesic distance between X and X_i (the shortest distance following the face mesh edges) rather than the Euclidean distance. The employed RBFs with compact support are taken as [9]:

$$\phi(r) = \begin{cases} (1-r)^4(4r+1) & 0 \le r \le 1 \\ 0 & r > 1 \end{cases}$$
$$r = ||X - X_i||/R \tag{4.2}$$

in order to maintain C^2 continuity between support regions of the specified radius R. It has been demonstrated that the resulting weighted linear combination of the RBFs facilitate localized face deformation and hole handling on the face mesh [10].

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. As stated previously, a parameter is essentially a linear distance between two landmark points and each parameter is to control over a particular domain. More specifically, if we want a global parameter to have control over some local parameters, it needs to control all of the associated landmark points. Otherwise, changing the global parameter will not have any effect on the associated local parameters. 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. The coarse-to-detail multi-level face modeling approach is to be presented and discussed in the following subsections.

4.1. Face profile level

There is in fact only one parameter being placed in this level, which is the head height. It has the highest global effect in the developed facial conformation modeling system. When the head height parameter is changed, all vertices in the face mesh model are moved. No other constraints are present in this level. Hence, only two landmark points are used for the RBF system in this level, which are the head height landmark points v and gn (Fig. 1). The effect of changing the head height parameter is demonstrated in Fig. 6, showing a longer (narrower) head/face on the left and a shorter (wider) head/face on the right. It should be noted that all the features on the face are changed accordingly with the head height parameter adjustment, although slightly.

4.2. Feature position level

Facial conformation parameters in this level control the positions of the various feature regions on the face as well as most facial outline parameters. Landmark points from the (upper) face profile level are included in the RBF system of this level. These upper level landmark points will remain unchanged because no parameter in this level

Figure 6. Effect of changing the head height on the generic face.

is associated with them. The head height parameter has been placed in the face profile level. Out of the remaining 31 facial conformation parameters, 10 parameters are employed and a total of 22 landmark points for the whole face are placed in this level. These parameters specify the positions of chin, jaw, mouth, nose, and eyes. For example, Fig. 7 shows a face with wider apart eyes, higher position nose, and lower position mouth on the left, and a face with closer eyes, lower position nose, and higher position mouth on the right. It should be noted that the face profile remain the same and although the feature details remain close to those in the generic model, some small distortions can be seen in order to blend with the whole face.

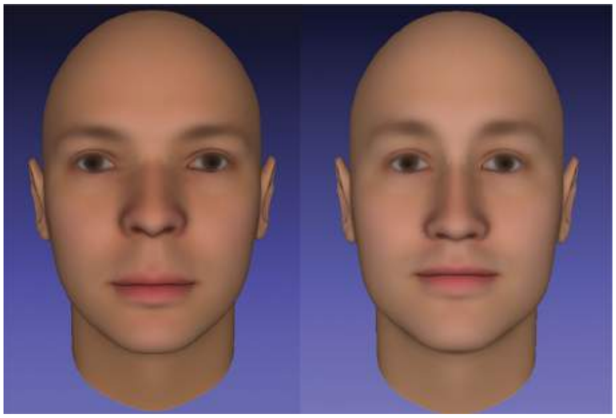


Figure 7. Effect of changing the feature positions on the generic face.

4.3. *Feature details level*

One facial confirmation parameter has been allocated to the face profile level and 10 parameters allocated to the feature position level. The third or feature details level include all the remaining 21 parameters, which relate to the local detailed modifications of the face features. The deformation effects of the parameters in this level are largely constrained within their specific feature regions. Fig. 8 shows an example of the typical changes made to the face features (on the right) from the generic face (on the left). It should be noted that both the face profile and the feature positions remain the same and changes to the various features are localized.

Figure 8. Effect of changing the feature details on the generic face.

5. Modeling validation

A series of practical face modeling case studies have been performed to validate the interactive facial conformation modeling method presented in this paper. It should be noted that quantitative evaluations of the face modeling results were not done and only qualitative analysis results were made (and to be discussed here). This is because the primary objective of this work is to develop an easy-to-use interactive face modeling tool to enable ordinary users to quickly construct realistic human face models so as to facilitate user-level control over the visually sensitive face modeling task. Accurate face modeling is important but is not the primary objective. After all, accuracy can always be improved by increasing the number of the derived set of 32 facial conformation parameters. In other words, the developed face modeling tool is not designed to model highly accurate face models but to function as an easy-to-use interactive tool for quickly producing visually acceptable face models. The case studies to be shown below attempt to confirm the face modeling capability of the 32 facial conformation parameters and the modeling simplicity facilitated by the interactive linear parameter adjustments and grouping of the parameters into three hierarchical coarse-to-detail levels. The face modeling capability is to be confirmed by generating 3D face models that resemble the intended face geometry. As stated previously, 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. Then, 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. The entire interactive modeling process has been found to be simple and smooth, thereby confirming the modeling simplicity qualitatively in the absence of scientifically designed user participation and quantitative surveys.

A typical face modeling result is shown in Fig. 9. The 3D face model was created using the face modeling tool developed in this work through adjusting the 32 facial conformation parameters from an input frontal image of a face. The conformation landmark points are marked as red in the figure. It was observed that the profile of the modeled face could be adjusted easily to match the original face profile correctly, including the head height and width, and chin and jaw contour. The locations and shapes of the various face features could also be matched well. This indicates that the developed face modeling tool has the ability to construct the geometric shape of a given face closely. Nonetheless, although all the face features were well positioned and shaped, it was not immediately obvious to human eyes that the created 3D face model resembled the original face well in geometry. To further demonstrate that the constructed face model closely represents the given face, some visual factors that affect the subjective judgment of the likeness of faces need to be added.

One of the most important visual factors besides geometric conformation is the facial texture. The facial texture reflects the skin color, surface property, and feel of a face. It is vital to the perception of faces to human eyes. In order to include this visual factor that much affects our judgment on face resemblance, the facial texture map from an input frontal face image was generated and laid on the 3D face model created using the face modeling tool developed in this work. A typical result is shown in Fig. 10. It can be seen that with the added facial texture, the created 3D face model gives a much more realistic feel of a human face.

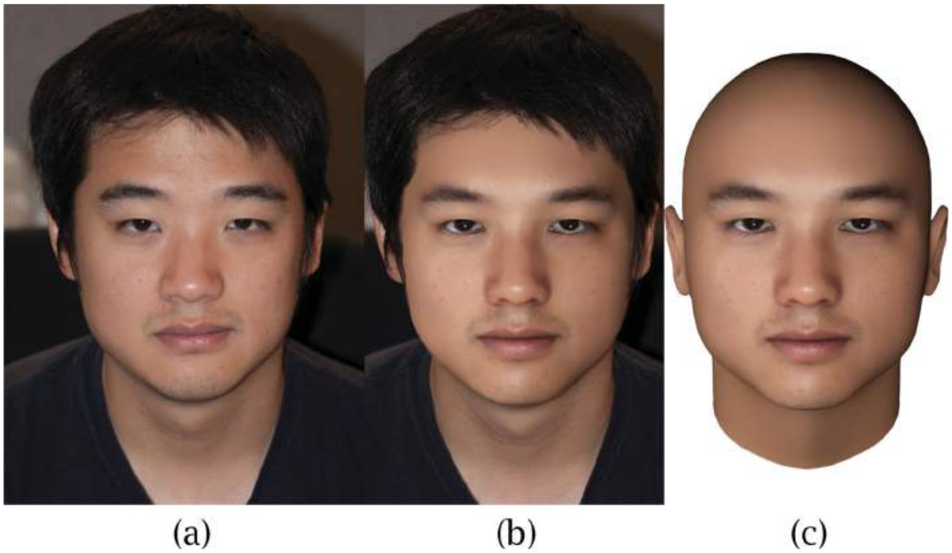
Having the facial texture from a frontal face image mapped onto the created 3D face model clearly enhances the subjective judgement of the similarity of the modeled face to the actual face. However, it is not clear how much the added facial texture effectively contributes to the perceived similarity in the created 3D face model. More specifically, if mapping the facial texture onto a face model with arbitrary conformation (geometry) can make the face model look similar to the actual face, then we cannot confirm the effectiveness of the developed facial conformation modeling method. Hence, in order to demonstrate the importance of geometric conformation, another test case was carried out to show two face models (of different geometry) mapped with the same facial texture map: the generic face model and the geometrically conformed face model to a given frontal face image. The comparison is shown in Fig. 11. It can be seen in the figure that as the same facial texture is mapped onto two different 3D face models, the resulting face models look quite different because of the geometric conformation deviation. The created face model with proper conformation (right) gives a very different look than the generic face model (left). This justifiably confirms the significance of facial conformation.

Material property is another visual factor that influences the human perception of a face. Basic material properties include reflectivity, scattering and transmittance. They all contribute to the visual feel of a

Figure 9. Typical face modeling result with conformation landmark points marked as red.

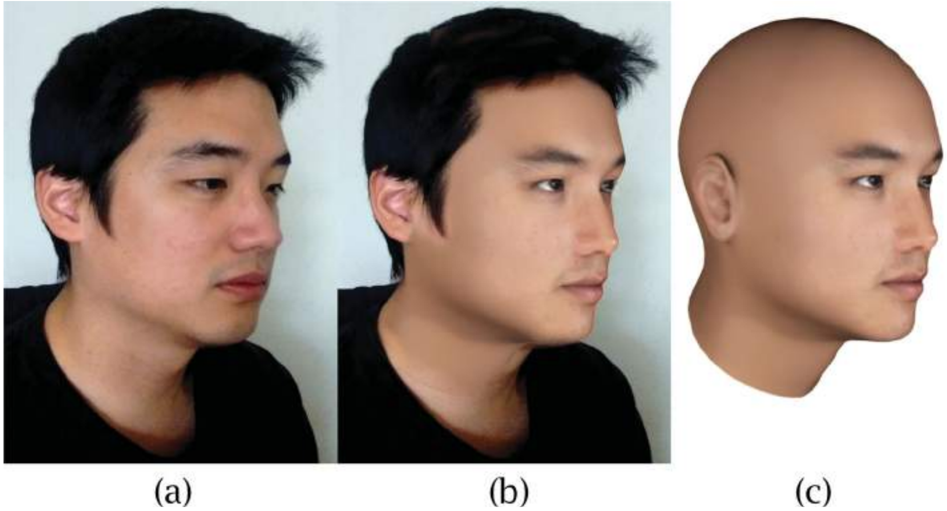
Figure 10. Created face model with an added facial texture.

Figure 11. Same facial texture mapped onto two different face models.



(a) (b) (c)

Figure 12. Created face model with corresponding facial texture and proper material property.



(a) (b) (c)

Figure 13. Comparison in 45° side view: (a) original image, (b) synthesized image, and (c) modeled face.

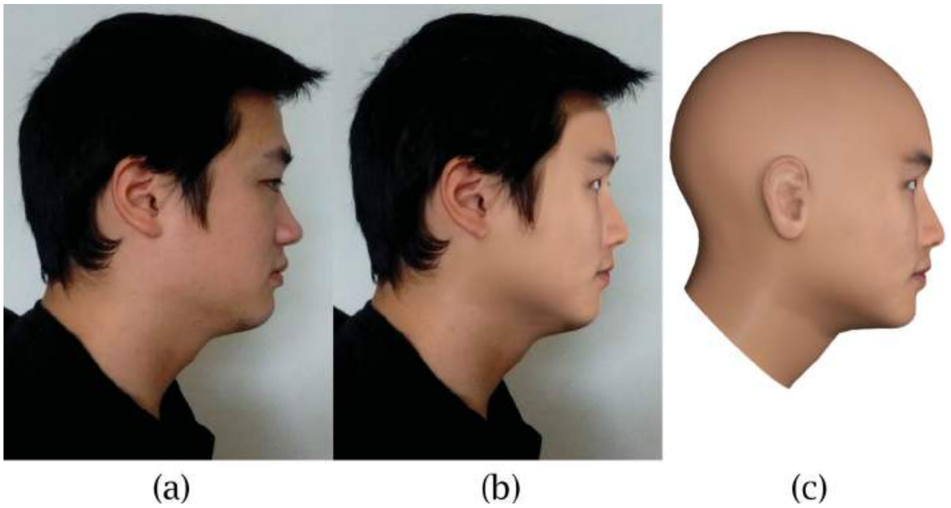


Figure 14. Comparison in 90° side view: (a) original image, (b) synthesized image, and (c) modeled face.

face. Including the material property of the face skin gives a more complete feel of a face and reduces the visual distraction when judging the similarity between faces. We can then focus more on comparing the facial conformation. In this regard, a face was modeled to the best conformation using the developed interactive tool, mapped with the corresponding facial texture, and rendered with the proper material property using a commercial software package. With the input image of Fig. 12(a), the resulting 3D face model is shown in Fig. 12(c). Fig. 12(b) shows a synthesized image of the created face model with the original image background and hair (along with ears). It can be seen that the synthesized image very closely resembles the original face image. To illustrate how the modeled 3D face looks in different view angles, comparisons of the original and modeled face images in 45° and 90° side views are shown in Fig. 13 and Fig. 14, respectively. The close resemblance of the synthesized face images to the original images clearly demonstrates the effectiveness of the developed face modeling method.

6. Conclusions

An easy-to-use facial conformation modeling tool for ordinary users has been developed and presented in this paper. This tool specifically targets the modeling of human faces and is not immediately applicable to the modeling of other human/biological forms. The main feature of this work is that modeling of the varying geometric features among human faces has been simplified as direct linear parameter adjustments via moving the corresponding conformation landmark points on a generic 3D face model. A set of 32 facial conformation parameters have been carefully selected to balance between the face modeling capability and simplicity for the developed tool. In addition, these parameters have been grouped into three hierarchical coarse-to-detail levels to facilitate the logical progression of modeling various features on a face, which aims to reduce the face modeling efforts by the users. To further improve the face modeling efficiency, a semi-automatic procedure can be developed. The prospective semi-automatic procedure models a given face from an automatically generated, individualized 3D face model instead of the generic 3D face model. The individualized face model is expected to be generated automatically from the frontal image of the face to be modeled and only rough conformation to the given face is sufficient. The benefit is that the individualized face model provides a much closer representation of the given face than the generic face model; hence, the remaining modeling efforts can be significantly reduced.

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