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Blend Shape Interpolation and FACS for Realistic Avatar

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Abstract The quest of developing realistic facial animation is ever-growing. The emergence of sophisticated algorithms, new graphical user interfaces, laser scans and advanced 3D tools imparted further impetus towards the rapid advancement of complex virtual human facial model. Face-to-face communication being the most natural way of human interaction, the facial animation systems became more attractive in the information technology era for sundry applications. The production of computer-animated movies using synthetic actors are still challenging issues. Proposed facial expression carries the signature of happiness, sadness, angry or cheerful, etc. The mood of a particular person in the midst of a large group can immediately be identified via very subtle changes in facial expressions. Facial expressions being very complex as well as important nonverbal communication channel are tricky to synthesize realistically using computer graphics. Computer synthesis of practical facial expressions must deal with the geometric representation of the human face and the control of the facial animation. We developed a new approach by integrating blend shape interpolation (BSI) and facial action coding system (FACS) to create a realistic and expressive computer facial animation design. The BSI is used to generate the natural face while the FACS is employed to reflect the exact facial muscle movements for four basic natural emotional expressions such as angry, happy, sad and fear with high fidelity. The results in perceiving the realistic facial expression for virtual human emotions based on facial skin color and texture may contribute towards the development of virtual reality and game environment of computer aided graphics animation systems.

Graphical Abstract Realistic facial expressions of avatar.

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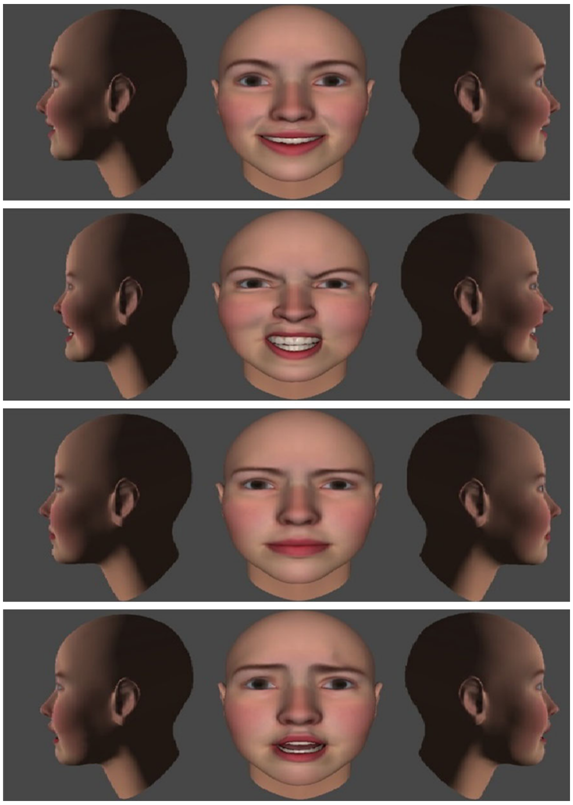

Keywords Facial expression · Facial animation · 3D modelling · Texturing · Blend shape · Facial action coding

1 Introduction

Face of human is undoubtedly the most important art object and central aspect of phenotype that plays a momentous role in the interaction process. The proportions and the expressions of the face are important to identify the origin, emotional tendencies, health qualities and often fundamental to human social interaction. Many different types of important information are visible in faces [1, 2].

The facial recognition is one of many innate reflexive cognitive competencies. Therefore, facial animation is an important alternative for enabling natural human computer interaction. Computer aided facial animations render diversified applications including realistic virtual humans in the entertainment industry, medical, forensic and diagnostics.

The interactive talking faces in communication applications make the users and machines interaction much better by providing a friendly interface to attract users. Regarding the realism of synthesized facial animation, the creation of humanlike expression is one of the critical issues [3, 4]. The complexity associated with the deformation of a moving face and the inherent sensitivity of human to the subtleties of facial motion makes facial animation a challenging topic to the computer graphics community. Furthermore, interpretation of human emotion remains an extremely difficult interdisciplinary research topic in computer graphics, artificial intelligence, communication, psychology etc., to cite a few [5, 6].

The human faces are intensively studied to determine their impact on the health perceptions, attractiveness, emotions, species, age and shapes. Majority of the studies on the skin color and texture contribute towards the apparent facial health and attractiveness without establishing any correlation effects [7, 8]. Despite many efforts, the mechanism behind the appearance of facial colors and their influences on emotional expressions are far from being understood. Generating a realistic facial expression is an intricate task due to multifaceted face cuts [9, 10]. To achieve realistic results of computer facial expressions it is necessary to produce a consistent representation of the face and obtain an accurate model for animation [11–13]. Truly, feasible facial animation is accomplished using at least five fundamental approaches including direct parameterization, muscle-based method, performance-driven process, facial action coding system and interpolation.

Direct parameterization represents the face as a polygonal mesh and allows it to move through a set of parameters that modifies the characteristic points of the face. Thus, this approach attempts to build a model to generate a wide range of faces and facial expressions based on a set of delicately varying tiny control parameters. Some drawbacks of this method is the facial topology dependent variation in parameters which must be rewritten for using in other models. This limitation is overcome by introducing the MPEG-4 standard which intends to be an international standard for the parametric face animation [14–21]. Recently, both approaches are widely explored [22–28].

FACS accurately measures and describes the facial behaviors via the perception of every facial muscle. It studies the actions caused by the muscles instead of considering the muscle directly [29]. In fact, facial expressions are not only complicated but no expression is made by only one muscle. The same muscle is responsible for creating various expressions in which the configuration is very complex. Therefore, facilitating a clear comprehension on facial expression is difficult by studying each muscle individually. This hitch is overcome by facial Action Units (AUs) used in FACS. FACS is capable of accurately mimicking all the facial muscle movements related to basic expressions by sorting various AUs on the face [30–32]. Linear interpolation is exhaustively applied in several studies [12, 15, 16, 33–37]. We develop a new computer animation system by combining BSI and FACS to create a realistic facial expression of virtual human corresponding to five basic natural emotional expressions. Our method mimics reasonably accurate human facial emotional expression based on facial skin color and texture. The new scheme may constitute a basis for the generation of human facial skin colors on 3D avatar including facial action coding system, emotion theory, color theory, animation via blending and image based color analysis useful for assorted applications using computer aided graphics animation systems.

2 Facial Modeling

Lately, the facial modeling for humans became predominantly significant by imposing many challenges in the fields of medicine, engineering, animation and computer graphics [38]. Indeed, the process of generating realistic synthetic faces with three-dimensional characteristics and trying to make it desirable has attracted much attention. With the advent of a variety of algorithms and techniques on facial animation, it is possible to create the geometry of the human face in detail using 3D photometric tools and scanners. The progress in precise articulation of the human faces made us less tolerant to ignore the imperfections in the animation and modeling that happened in the past [39]. The fabrication of computer facial animation with appropriate and intricate expressions is still difficult.

The interaction with characters is very important to create effective connection with the user. Therefore, virtual characters use various types of emotions such as facial expression or diverse body motions to build this connection effectively. However, these emotions seem to be affected by the interaction of the user in some games. Facial modeling and animation expression are categorized into two main groups. The first one depends on the manipulation of images and the second one depends on the geometric manipulations. Geometric manipulations include key-framing and interpolations [40], parameterizations [41], finite element methods [42], muscle based modeling [12], visual simulation using pseudo muscles [43], spline models [44] and free-form deformations [43].

Pighin et al. [45] presented the technique for creating 3D facial models from photographs of a human subject. Zhang et al. [46] introduced a geometry-driven facial expression system by using an example based approach. The bump mapping approach of Blinn [47] attempted to modify the surface normal prior to the lighting calculations to achieve a visual impression of wrinkles without deforming the geometry. This idea has extensively been used especially for facial wrinkles [48]. Bando [49] used an interface to specify wrinkles one by one on the 2D projection of the 3D mesh by drawing a Bezier curve as the wrinkle furrow. Computation of a specific mesh turned out to be expensive in terms of energy minimization. The bump map can also be obtained using complex physical-based simulations [48, 50]. Viaud [51] employed a mesh to align the locations of potentially existing wrinkles with olines of a spline surface by directly deforming their geometry. Oat [52] introduced a technique involving compositing multiple wrinkle maps and artist animated weights to create a final wrinkled normal map. The manual tuning of the wrinkle map coefficients for each region is required [22, 53]. Wu et al. [54] proposed approaches suffer from complex parameter tuning and expensive computations and thereby unable to provide enough realistic facial expressions.

3 Methodology

Figure 1 illustrates our method in achieving the realism and generating five facial expressions (natural, anger, happiness, sad and fear) for the avatar. This newly developed computer animation system combines BSI and FACS to create the expression of virtual human.

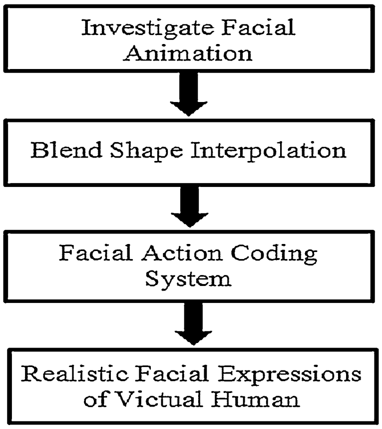

Fig. 1 Flow-chart of the proposed method

3.1 Facial Animation Scheme

Achieving animation of superior quality poses several challenges connected to the elements of the face such as facial muscles, facial bones and synchronization of the lips formation. Accurate and efficient identification of these elements need outstanding efforts and adequate time for skilled animators. However, the knowledge of facial animation is essential because most of the information contained in human face are their signature of emotions and mental states. Magnenat et al. [55] asserted that face being the fundamental art object in understanding human emotion the creation of believable facial animation is very significant.

Non-existence of any specific boundaries between two facial animation methods makes the classification often tricky. To realize realistic effects, animators must take special care around the edges of different facial regions. Natural representation of the details and creases of face are extremely hard due to their exotic features.

3.2 Blend Shape Interpolation

Blend shape being a simple shape interpolation animation is widely used in commercial animation software packages such as MAYA and 3D Studio max for generating realistic facial expressions. It is performed by shaping distortion while fading it into another through marking corresponding points and vectors on "before" and "after" shapes which are used in the morph [37]. In one-dimensional case, given two values one needs to determine an intermediate value which is specified by a fractional interpolation coefficient α expressed in Eq. 1,

$$value = \alpha(value1) + (1.0 - \alpha)(value2) 0.0 < \alpha < 1.0 \quad (1)$$

The central concept of this method relies on the creation of several key poses of a subject where the animation system automatically interpolates the frames in-between. Technically, blend shape animation is a point set interpolation, where an interpolation function (typically linear) specifies smooth motion between two sets of key points. Generally, it is from models of the same topology. This type of animation process includes modeling of polygonal meshes of a human face to approximate expressions. Besides, it also includes visemes for synchronizing the position of lips with its speed [56, 57], which is then continued with the automatic blending of different sub meshes [15, 16, 33–35, 37, 58–60]. It is known as morphs targets or blend shapes (shapes contain expression). Since the blend shape method generally uses a linear algorithm of topology of the face meshes, animators can easily control the weights applied on the vertices of polygonal models. Thus, controls the degree to which it is blended. Blend shape interpolation is used here for two purposes. Firstly, for creating the base shape (natural face) and secondly for combining the base shape with the FACS generated target shapes (four facial expressions) as described below.

3.3 Facial Action Coding System

FACS was introduced by Ekman and Friesen in 1976 for gauging and depicting facial actions by examining every facial muscle and the manual was published in 1978. Currently, it is considered as a standard for displaying the facial appearance stimulated by the changes in each facial muscle. It is derived from a facial anatomy analysis by describing the performance of human face muscles including the movements of the tongue and jaws. The exploration of facial anatomy confirms that the changes in expressions are caused by facial actions. The working principle of FACS in understanding the facial behaviors are based on facial actions. Unlike other muscle-based techniques, FACS studies the muscle actions not the muscle directly. No facial expression is the manifestation of one muscle it is rather cooperative effects with complicacy. A single muscle may be responsible for various expressions in which the relationship is very complex.

A clear understanding of facial expressions emerges through the introduction of facial action units (AUs) [30, 31]. AUs are constructed in accordance to these actions where every AU can involve numerous facial muscles. When an expression is made, the involved muscles cannot be recognized easily. Conversely, each muscle is divided by two or more AUs to explain quite self-governing actions of various muscle parts. FACS divides the human face into 46 action units. Every unit embodies an individual muscle action or a group of muscles that characterize a single facial position.

The principle is that every AU is the smallest unit that cannot be reduced into minor action units. By accurately sorting various AUs on the face, FACS is able to mimic all the facial muscle movements [30, 61]. Representation of different AUs and the corresponding FACS name are listed in Table 1. Different action units can be combined to create an altered facial expression. For example, combination of AU4 (Brow Raiser), AU15 (Lip Corner Depressor), AU1 (Inner Brow Raiser) and AU23 (Lip Tightener) generates a sad expression. Originally, FACS was not introduced to generate facial animations it was rather aimed to describe the score of facial movements. Truly, the widespread usage and acknowledgement of this method for facial actions popularize it in facial animation domain. FACS assists animators to exemplify and build realistic facial expressions via all possible details of human facial animation units with the descriptions for measuring the positions of head and eye [30]. The manifested expressions generated by us via the combinations of different AUs are summarized in Table 2. Four realistic facial expressions such as angry, sad, happy and fear are generated using FACS.

Figure 2 shows an illustration of these action units used for human FACS.

3.4 Realistic Facial Expressions of Virtual Human

In the past, most of the studies on facial animation are focused towards the development of models for the recognition and tracking of expressions. Commonly, these models are centered on the short-term dynamic (basic facial expressions) or the static state of the face (natural expression). For instance, the action of a smile or a frown requires the face to undergo few changes from neutral to the final state. FACS is commonly used for studying the basic facial expressions which encodes the face movements into 46 small units called AUs. It is the qualitative measure in producing facial expressions such as anger, happy, sad, and fear. Furthermore, BSI being an efficient method for producing the natural human expression is used in commercial animation software packages. As mentioned before, the BSI generates the natural face and the FACS reflect the exact facial muscle movements reliably. We propose a new technique by combining them to achieve more precise and efficient human facial expressions. It is hoped that our hybrid model may serve better performance in the computer graphics animation system.

4 Implementation

A pilot study is administered to assess the applicability of facial animation that provides an opportunity to bring human facts and emotional expressions into the realism which is suitable for computer game environment. Now we turn our attention to describe the procedure of generating realistic facial expressions of virtual human based on the integrated approach of BSI and FACS. We use develop the code using C# for XNA Game as programing language in computer graphics.

4.1 Implementation of Blend Shape

We achieve the BSI by shaping distortion and fading via marking points and vectors on the "before" and "after" shapes used in the morph. First a base shape

Table 1 Representation of action and their units [31]

AU	FACS name	AU	FACS name	AU	FACS name
6	Check raiser	23	Lip tightener	15	Lip corner depressor
1	Inner brow raiser	26	Jaw drop	5	Upper lid raiser
17	Raiser chin	20	Lip stretcher	9	Nose wrinkle
4	Brow lower	14	Dimpler	16	Lower lip depressor
10	Upper lip raiser	2	Outer brow raiser	12	Lid corner puller

Table 2 The generated basic expression based on the combination of various AUs

Expressions	Involved action units
Anger	AU (26 + 4 + 17 + 10 + 9 + 20 + 2)
Fear	AU (2 + 4 + 5 + 26 + 15 + 20 + 1)
Happiness	AU (14 + 12 + 6 + 1)
Sad	AU (23 + 1 + 15 + 4)

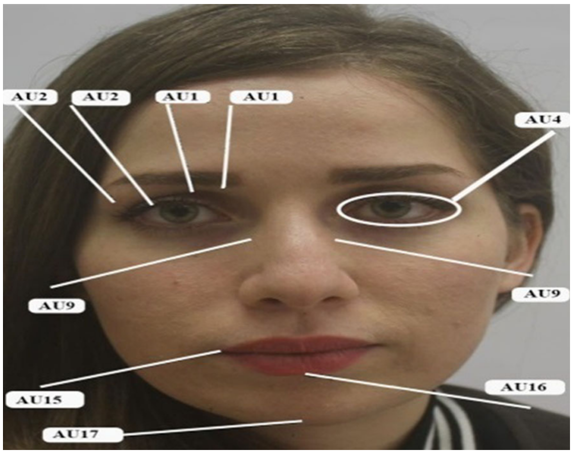

Fig. 2 Re-illustration of action units (AUs) in human facial action coding systems.

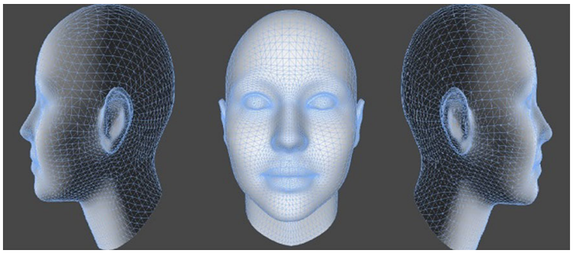

Fig. 3 3D model of natural face using shape interpolation

(natural face) is created and then it is combined with the target shapes (four facial expressions). Figure 3 displays the three dimensional model for natural face using our shape interpolation scheme.

4.2 Implementation of FACS

Based on FACS we generate four realistic facial expressions (angry, happy, sad and fear). Figure 4 shows the three dimensional model for the four facial expressions using FACS.

4.3 Realistic Facial Expressions of Avatar

The area of computer facial animation combines different techniques and methods to generate animation models or images for characters such as animal, humanoid, fantasy creature and human. The animated character have many implications in the field of artistic, scientific, traditional and psychological due to its theme, subject and output type. The advancement in computer graphics software and hardware in addition to the importance of human faces in verbal and non-verbal communications have initiated significant technological, artistic and scientific interests in field of computer facial animation. Facial expressions carry the information associated to internal emotions or the response to social communications. A number of studies are conducted to create realistic facial expressions. However, the sensitivity related to subtle facial

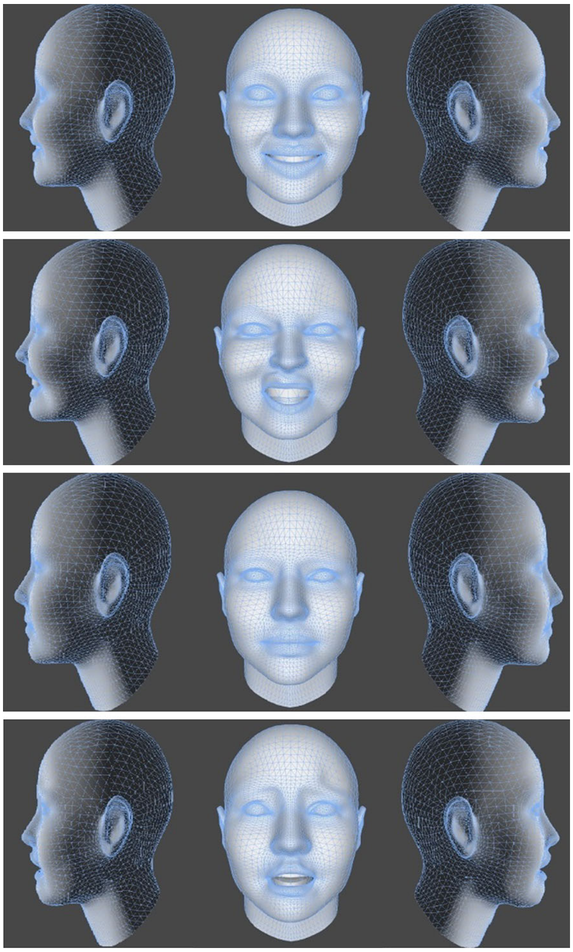

Fig. 4 3D models of four facial expressions using FACS

movements makes the creation of realistic expressions a formidable task. Algorithm 1 describe the process of creating realistic facial appearances for four emotional expressions.

Algorithm 1: Realistic facial expressions of avatar

1: Add four expressions values, E ={Happy, Anger, Sad, Fear} based on FACS
2: Create an domain control map with four poles and middle point (0,0)

3: Draw the neutral Model N and place its values in the middle of the domain control map based on Blend shape interpolation
4: Set Absolute Expressions Values E_i in each pole to the domain control map

5: User controls the cursor position (C_x , C_y) to the desired expression
6: Set the weight w of each expression according to the position of the cursor:

```
if Cx ≥ 0 then
wE3 = x
wE4 = 0
end if

if Cx ≤ 0 then
wE3 = 0
wE4 = |x|
end if

if Cy ≥ 0 then
wE1 = y
wE2 = 0
end if

if Cy ≤ 0 then
wE1 = 0
wE2 = |y|
end if
```

7: Calculate the interpolation values I are by translating the neutral values towards the expressions weight position α

8: I = α (value1) + (1.0 − α) (value2) 0.0 < α < 1.0 where value1 and value2 are the expressions which have positive weights according to the position of the cursor,

9: Draw the new expression model as in the values of I

The program reads the face model in the neutral state based on the blend shape interpolation algorithm then calculates the maximum expression values for four major expressions described in FACS. This allows the user to navigate through the domain control map displaying the change on the expression of the model smoothly. The domain control map is a visual navigation model that helps the user to determine the exact desired expression. It consists of five points, four poles and a main point in the middle. Each of the four points represents the maximum end of the expression while the middle point signifies the average neutral expression. Figure 5 shows the achieved results for the realistic facial expressions of natural, happy, angry, sad, fear of virtual human (avatar).

Fig. 5 Realistic facial expressions of avatar

5 Conclusions

A new method is established by combining BSI and FACS to create a realistic and expressive computer facial animation design for 3D avatar. Five basic reliable emotional expressions such as natural angry, happy, sad and fear are used. Our method of computer synthesis for practical facial expressions dealt with the geometric representation of the human face and precise control of the facial animation. The natural face is generated by BSI and FACS is used to reflect the exact facial muscle movements for all expressions. The need of computational tools to analyze the architecture of prototype by creating human-like expression comprising of artificial muscles, elastomeric skin and mechanical components are emphasized. The facial animation methods that can successfully be used to produce more useful avatar representations of human facial expression and communication are asserted. Our systematic study on realistic facial expression for 3D avatar based on facial muscle movements, skin color and texture may be useful for the advancement of computer aided graphics animation systems.

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