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Research paper

Review on 3D Facial Animation Techniques

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Abstract

Generating facial animation has always been a challenge towards the graphical visualization area. Numerous efforts had been carried out in order to achieve high realism in facial animation. This paper surveys techniques applied in facial animation targeting towards realistic facial animation. We discuss the facial modeling techniques from different viewpoints; related geometric-based manipulation (that can be further categorized into interpolations, parameterization, muscle-based and pseudo–muscle-based model) and facial animation techniques involving speech-driven, image-based and data-captured. The paper will summarize and describe the related theories, strength and weaknesses for each technique.

Keywords: *facial animation; graphical visualization; facial modeling; data acquirement*

1. Introduction

Facial animation is a method of creating virtual character including the facial posture and motion. Graphical visualization is usually used in this approach such as in gaming, filming and human machine communication to guarantee the higher demand in fascinating interaction, advanced facial expression and motion. Since Parke (1972) pioneered his work, facial animation had grown rapidly due to the demand and became research topics for decades. To ensure the performance is improved and being enhanced, lots of recent works with variation of approaches are suggested in every aspect. This paper presents a review of several geometric-based modeling and data driven animation that were used in facial animation research. Due to the scope of discussion, this paper aimed to help the current system of computer facial animation to be improved by the current development using recent technology.

2. Overview of Facial Animation Techniques

Facial animation can be categorized into facial modeling techniques and the data acquirement of facial animation techniques. Figure 1 shows the overview flow of facial animation techniques that starts from input, facial modeling, facial animation and output as end product.

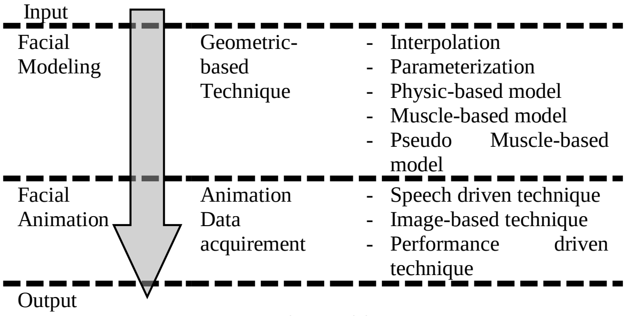

Figure 1 Overview flows of facial animation

2.1 Facial Modeling Techniques

Complexity of facial animation is made up of interaction between varieties of layers of the face and eventually creates the challenge to apply in facial animation; resulting in the introduction of different methods. Geometric-based techniques basically handle the deformation, surface generation and manipulation. Several subcategories covered by the geometric –based include interpolations, parameterizations and muscle-based modeling will be discussed in this section.

2.1.1 Interpolation

Interpolation is a process of generating a value based on its neighbors. Interpolation approach determines the neighboring values that commonly contribute a certain weight to the value that being interpolated; providing user-desired smooth transition between neighbors as the weight is frequently inversely proportional to the distance where the neighbor is located. Interpolation techniques actually help in bringing intuitive approach to computer animation especially in facial animation where this technique offers a function which is specifying a smooth transition between two facial expressions over a normalized time interval. Linear interpolation has been widely used in generating facial animation. Parke had introduced simple geometric interpolation between face model to generate animated sequences of human face expression and being the first one of proposing the 3D model of human face. A method proposed by Arai et al., 1996 which generated facial animation with changes of facial expression and shape simultaneously in real time. Facial expression is superimposed into face shape using 2D parameter space independent of face shape using their model. When more than two key-frame involved, bilinear are able to produce more possibilities of facial expression than linear. Hence, wider range of realistic facial changes created by bilinear interpolation. Shape interpolations were mostly applied because only simple transformation required like scaling and rotating other than being easily computed. However, the drawbacks are the limitation of realistic facial animation generated – manual animations are required in order to produce perfect blendshapes, which is time consuming and require hard work. Besides that, complex face construction also restricts the realism of facial animation (Ping et al., 2013). Acquaah et al. (2015) presented the variation in interpolation process as the techniques evolving through the years. Figure 2 represent the image transition of shape interpolation from neutral to happy expression. Distances measured from movement of each corresponding marker on actor face determine the weight. Hence, blendshape between initial and final frame will be found. However the facial expression is different in density compare to the real expression even though the type and range of expression is similar.

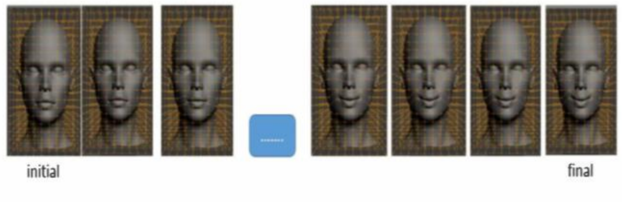

Figure 2 Transition of shape interpolation (blend-shape) from neutral to happy expression (Acquaah et al., 2015)

Interpolation applied commonly in animation that requires simple transformation. Even though the process is fast and good in generating facial animation, it is limited to the small set of animation by key frames. Their ability is insufficient enough to create realistic facial configuration (Li et al., 2012)

2.1.2 Parameterization

Parameterization technique in facial animation (Cohen et al., 1993) help in overcoming the limitation of shape interpolation while maintaining the basis principle of shape interpolation (Ronovan & Pretprious, 2006). A set of parameter are attach properly to each part in facial geometry. Thus, allowing the animator to have facial configuration control (Ping et al., 2013). The parametric model is made up of expression parameter for each different part of face. This expression parameter can influence the set of vertices of each model. The evolvement parametric model by Parke (1974) is based on simple parameterization and image synthesis concept. Parameterization involving selecting the appropriate facial parameter depends on the external observation that leads to certain expression. However as (Water & Frisbie, 1995) further work on reducing parameters to animate facial expression and making direct parameterization, problems do arise due to their method. The set of parameter are limited to certain facial topology only. The parameter needed to be reset as if the face is different and facial expressions look unnatural when parameter has conflict. Hence, parameter only set to certain part of facial area. Parameterization permits the particular facial configuration control. Generally, parameter combination yields wide area of facial expression in low computational cost (Ping et al., 2013). Du et al. (2008) introducing a statistic model that helps to seek for the relation between the facial parameters, emotional status and also the face model whereas Arya et al. (2014**)** proposed the manipulations of facial parameters in order to synthesize the different emotional facial expression which can help in producing some standard set of facial expression. However, the parameter set required a manual tuning to ensure the motion or configuration is high in realism. Hence, this limitation had become a turning point of developing other kind of method such as physic based model, muscle based model, morphing image and so on.

2.1.3 Physic- Based model

Facial animation comes in variety of techniques include physic based techniques. This approach is being developed by Lee et al., (1995) and Choe et al., (2005). Physic based approach are muscle force that able to propagate in spring mesh models skin deformation, deform facial mesh using motion fields in describing the regions of influence and mass spring structure into connected mesh layer to model anatomical facial behavior. This physic based model actually can be categorized in three which is spring mesh muscle, vector muscle and layered spring mesh muscle. Spring mesh muscle present by Platt in 1985 where group of functional block in selected area of facial structure represented facial model with muscle. The blocks in this model are interconnected by the spring network which deform by applied muscle force and hence creating the action units. A muscle model proposed by Waters in 1987 is a huge success. It is a precise deformation model that specializes in action of muscle upon skin. Vector muscle is included in this model. Noh & Neumann (1998) stated that positioning vector muscle into accurate position can be intimidating task since no automatic muscle placing and only involve with trial and error with no guarantee that the placement is efficient enough. Wrong placement can result unnatural animation. Figure 3 displaying the difference of generic face mesh and the transition of faces with different facial muscle layout.

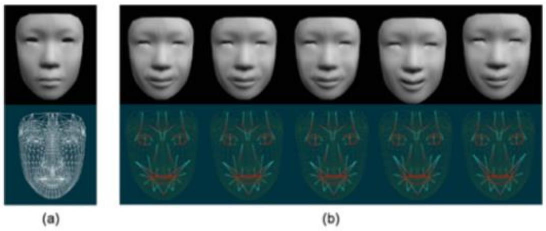

Figure 3 (a)The generic face mesh (top: smooth shading, bottom: wireframe) (b)Example of simulated faces with different facial muscle layouts (Acquaah et al., 2015)

The last category is the layered spring mesh muscles that proposed by Terzopoulos and Waters where a model with human dynamic face is presented. The model with layers that correlate to skin, fatty tissue and muscle that tied to bone is aimed to produce detailed anatomical structure. Despite having high realism, simulating volumetric deformation with 3D lattices for this model demand for ample computation. Maintaining visual realism with less computation time can be done by simplified mesh system (Wu et al., 1994). This approach also can synthesize more realistic facial expression especially particular person facial expression and facial anatomical structure for an individual model. Kubo et al. (2010) also stated that it also able to fix the layout of facial muscle and magnitude of muscle contraction on each facial muscle. However, it is time consuming and limited for few character in one frame only.

2.1.4 Muscle-Based Modeling

In 1981, Platt and Badler draw an outline of constructing the facial expression using muscle-based facial as figure 4 shown the facial muscle. A psychology model, Facial Action Coding System (FACS) used to choose muscle to be activated in underlying model. FACS is a movement of facial muscle from facial anatomy description (Ekman & Friesen, 1978). This system includes 44 basic units (AU) as shown in Table 1 that can be combined to produce facial expression such as tabulated in Table 2. Basically this model shows facial expression using "Action Units"(AU) as the term to represent single muscle or cluster muscle even both can be combined such as combination of AU 1 is "Inner Brow Raiser" , AU4 is "Brow Raiser", AU 15 is "Lip Corner Depressor" and AU 23 is "Lip Tightener" made the sad expression (Li et al., 2012).

Table 1 Sample sign facial action units

AU	FACS Name	AU	FACS Name
1	Inner Brow Raiser	12	Lid Corner Puller
2	Outer Bow Raiser	14	Dimpler
4	Brow Lower	15	Lip Corner Depressor
5	Upper Lid Raiser	16	Lower Lip Depressor
6	Check Raiser	17	Chin Raiser
7	Lid Tightener	20	Lip Stretcher
9	Nose Wrinkler	23	Lip Tightener
10	Upper Lid Raiser	26	Jaw Drop

Table 2 Example set of action units for basic expression

Basic Expressions	Involved Action Units
Surprise	AU1, 2, 5, 15, 16, 20, 26
Fear	AU1, 2, 4, 5, 15, 20, 26
Disgust	AU2, 4, 9, 15, 17
Anger	AU2, 4, 7, 9, 10, 20, 26
Happiness	AU1, 6, 12, 14
Sadness	AU1, 4, 15, 23

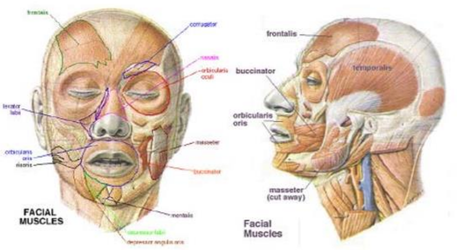

Figure 4 Muscle of the face (Arnstrong, 2011)

Keith Waters in 1987 show how the muscle embedded in facial mesh. Contraction of real muscle are simulated by the muscle, a geometric deformation that being placed by the user on the face. The usage of FACS is also being enlightened to relate the expression to muscle activation. The widely used muscle model is involving compact representation and freedom of facial mesh structure.

2.1.5 Pseudo-Muscle model

Muscle-based models generate realistic result almost similar to the exact model and simulating specific human facial structure only by adjusting the parameters. Pseudo or simulated muscle basically offers the facial mesh deformation in muscle without considering the complex anatomy. It is the act of the muscle that being manipulated thorough abstract idea of muscle, and then the deformation determines what muscle should do (Thalman et al., 1988). The deformation normally only take place at the thin-shell facial mesh and the simulated muscle forces are in the shape of splines **(**Viad &Yahia, 1992; Wang et al., 1994), wires (Singh & Fiume, 1998) or free from deformations (Zhang et al., 2004). Instead of simulating detailed facial anatomy, this approach only focuses on building a model with several parameters for muscle action imitation. Example of simulated muscle is the Free Form Deformation (FFD) (Noh & Neumann, 1998). It can manipulate the control point in 3D cubic lattice (Lewis et al., 2000) and capable of deforming the primitive surface such as polygon, quadric, parametric, implicit surface and solid model. Extended Free Form Deformation(EFFD) permit the control point extension to cylindrical structure to enhance the shape deformation flexibility while Rational Free Form Deformation(RFFD) contribute to specifying deformation by changing weight factor for each control point other than control point positions. RFFD can be FFD if only all weight is equalized. FFD, EFFD and RFFD actually help the transition from depending on its specific surface by extracting the deformation control. However, these approaches unable to model bulges and wrinkles on skin as no particular simulation on actual muscle and skin.

2.2 Animation Data Acquirement

For this section, facial animation that acquired data is included in speech-driven techniques, image-based techniques and performance driven animation.

2.2.1Speech-driven Techniques

Speech-driven is synchronizing the input speech with the facial animation. During speaking, intonation and emotional state used affect the expression. Lip motion synthesis is the basic straightforward speech-driven used in facial animation. Usually input speech is annotated by the standard speech unit; phenome. The annotation of phoneme can be manually done (Parke, 1975) or automatically (Parke & Lewis, 1987).Lewis & Parke (1987) present the system of lip synchronization where recorded speech was then broke into phoneme and parametric model amend the mouth shape. Later in 1990, Cohen and Massaro is using parametric model in terms of speech perception to produce lip sync system. They also enlarged the model for tongue and to model co-articulation effects (Cohen & Massaro, 1990; Massaro & Cohen, 1993). A platt-style system based on speech driven that include blinking, head movement and modified mouth motion being presented by (Pelachaud et al., 1996). Cao et al. (2005) suggested expressive speech-driven facial animation. This proposed approach considered the accuracy of lip sync is acceptable in order to seize the emotions towards existing speech driven model. In conjunction to enhance the performance of real time lip synchronization in facial animation, (Chen et al., 2012) integrate the function of latent dominance and function of intrinsic animeme to fit in the coarticulation by introducing Dominated Animeme Models (DAMS). Only 65% of variance in facial animation can be accounted in static relation between speech acoustic and facial configuration (Yehia et al., 1998). Hence, more improvement can be done to ensure a precise synchronization of lip sync and facial animation.

2.2.2 Image-Based Technique

Pighin et al. stated that few photographs are used to fit in three dimensional template meshes towards certain facial pose and blending the different pose to acquire animation in 1998. Later in 1999, this approach is being used to draw others attention in problems and issue due to modeling and animate high realism of faces from images source (Pighin, 1999). Image-based technique is about creating photorealistic human face model which not only limited by using shape interpolations and muscle deformer. Facial surface and position data encapsulated from the image in variety of view to reconstruct facial model. Image-based facial animation has the chance to reach high level of video-realism when they overcome the video generation problem which is building the generative model of novel video which concurrently with photorealistic, video-realistic and parsimonious. The meaning of photorealism is exact motion, dynamics, and coarticulation effects displayed by the novel generated images. (Cohen & Massaro,1993). Parsimony means few parameters compactly represented the generative model. In 1997, Bregler et al. described this technique as Video Rewrite. Recorded sequences are used to generate novel video that achieve the video-realism with no parsimony. Basically, it only relies on re-sequencing large amount of original video and unable to create novel lip imagery from recorded image due to unavailable space. It only depends on sampling dynamics of mouth since this technique unable to model the movement of mouth. Image-based technique is sorted out by (Noh & Neumann, 1998) few types which consist of images with morphing photographic, texture with manipulation, images bending and vascular expression. Efficiency of system relies on the amount and view of input images and also the scene geometry related. Burshukov et al. (2005) show complex image-based techniques in movies "The Matrix Reloaded". This approach also used as special effects for some other movies. On modeling research purpose, combination of this technique and other geometric-based technique is being proposed to develop better facial model deformation. (Lewis et al.,2005; Deng et al., 2006). The animator keep using image-based technique instead of 3D laser scan facial model as it is low cost and able to produce realistic-looking facial model. However, image-based technique should be improvised to maintain the usage in future (Ping et al., 2013). Morphing is one the technique applied for 2D and 3D in this approach. It deals with the process of generating smooth animated transition from one image to another (Kasat et al., 2014). Precise morphing between acquired and corresponded image can make high realism of facial animation. Beier et al.,(1992), using manually specified corresponding features for 2D morphing between two images where each feature such color balancing, correspondence selection and warp tuning need comprehensive interaction to ensure realistic animation. Pighin et al. (1998) overcome the limit of 2D morphing by combining 2D morphing that perform with corresponding texture map together with 3D transformation of geometric model which used to animate the facial expression. Even so, interpolation between pre-defined key-expression is still the limitation of animation. Table 3 is the table of example different technique applied towards morphing approach.

Table 3 Comparison of different techniques implemented in morphing target animation

Method	Pros	Cons
Image Based Face Replacement in Video (Liang, 2009)	Less time complexity using image-based method; suitable for entertainment purpose	Face expression and pose are similar. Requires similar face expression and pose for shoot target video Manual input in clustering process Limited tolerance to pose variance by robustness of face alignment
3D Morphable Model based Face Replacement in Video (Cheng et al., 2009)	Reducing source to single image Care on facial expression and pose of target face	Time consuming process Limited tolerance to pose variance by robustness of face alignment
Automatic Face Replacement in Video Based on 2D Morphable Model (Min et al., 2010)	Fully automatic without user interference Less time consuming	Face expression being ignored Limited tolerance to pose variance by robustness of ASM Sensitive to sharp lighting and violent movement
Video Face Replacement (Dale et al., 2011)	Plausible result Fully automatic with less interference by user Facial expression is concerned	Optical flow tracking (lighting slowly change over face) Tracking degrades beyond range of poses outside 45° from frontal Similar lighting between source and target
Face Replacement in Video from a Single image (Niswar et al., 2012)	Excellent in non-frontal face Replace target face with full different pose on another face Animating new face based on original speech in video	High complexity
Video Face Replacement System Using a Modified Poisson Blending Technique (Afifi et al., 2014)	Replace the frontal face with another without using morphable model and special equipment Reduce color bleeding and bleeding artifact	Tracking range of face rotation limited to 45° over all axes except y-axis for 30 ° Different illumination used by actor may affect final result

2.2.3 Performance-driven Animation

Performance-driven animation is basically achieved by motion data capture which requires data gloves to be input device and the motion capture cameras to stimulate the synthetic character. Computer animation industry applied in wide range since it makes animator works easier (Parke & Waters, 2008). They can capture the movement directly and transfer the data into digital form. William (1990) introduced performance-driven technique by face scan and markers tracking. The markers are being used on the face while the camera video is for face scanning and marker tracking. Guenter et al., (1998) show that data derivation from video stream can also be done using the technique. Then Kouaudio et al. (1998) build a real-time facial animation from pre-modeled facial expression for animating the synthetic character. Euclidean Distance between corresponding and minimized marker is a point that being associated towards the marker to generate intermediate facial expression. Motion capture (MoCap) data is all about human body joint that being placed with sensors or marker to record the human movement in space over time. It can also be defined as joints parameterized by hierarchical translation and rotation. Figure 5 shows the tree like hierarchical structure to illustrate the normal organizational of joints. (Arif et al., 2017).

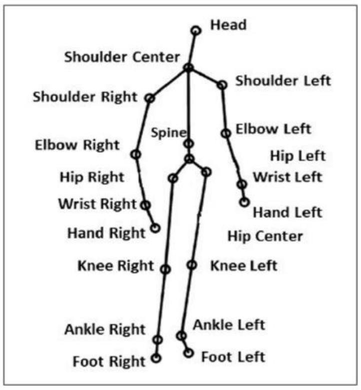

Figure 5 Skeleton and Joints (Arif et al., 2017)

Unuma et al. (1995) who first proposed motion capture approaches to reconstruct new motion in blending motion segments. The results are detailed and realistic as the data captured direct form real world. Usually laser scanner used for other kind of technique to capture surface model of posses in high resolution. In 2003, facial tracking is used to drive animation from motion capture database (Chai et al., 2003). (Wang et al., 2004) tracking the facial motion by using multiresolution deformable mesh and learning the expression style using low dimensional embedding in 2004. As this approach evolving through years, the recorded data of motion capture are in form of series of either 3D trajectories (Wang et al., 2012; Chen & Koskela, 2013) or rotation angles (Sedmidubsky et al., 2013) of body joints. Motion data that obtained are usually being normalized (Poppe et al., 2014) to become invariant towards few aspects that curb fair comparison like variety of human skeleton size or different facing directions. Numerous combinations of modalities can be done (Chen & Koskela, 2013) which eventually helps on focusing simultaneously of multiple motion. Further understanding can be statistically derived such as joint velocities and accelerations (Thanh et al., 2013; Zanfir et al., 2013) where the crucial condition is being able to be fast compared which can be attained through compact feature representations. Currently, the extraction of visualization-based motion feature from motion-image representation had turned out to be widely utilized (Liu et al., 2017; Wang et al., 2016). Arif et al. (2017) proposed an effective modeling method and motion capture (MoCap) data compression by quadratic Bézier curve. Good subjective quality of reconstructed animation produced through this method by parameterizing and independently approximates the motion data of each joint. This method suits modeling and motion data compression well for interactive and real time application since the computational cost low and the less space requirement. Developing real-time performance driven facial animation is challenging. The precise tracking of rigid or not rigid motion of user's face and the way of mapping extracted tracking parameter that drives facial animation are some of the challenges included. Weise et al. (2011) overcome these challenges by using face tracking system made up from geometry and texture registration and remark the system as markerless acquisition system. Performance-driven technique can be integrated to other kind of techniques due to realism factor in generating facial model. Other than that, an improved performance-driven technique facial animation that able to comply the input data motion with current facial animation demand will absolutely bring profit towards the animators and researcher.

3. Discussion

One of the problems in computer graphics is the process of creating and animating the human facial models with high realism. Practically, modeling the facial model had been done manually which is slow and even costly (Chuang & Bregler, 2004) whereas for the facial mesh deformation or muscle action, it is being controlled in animation process (Lee et al., 1995) Since the graphical area had been developing throughout the years, animator currently manage to change facial geometries into digital form by using some sensor or marker scanning and going through variety of facial muscle simulation for facial animation. Modeling facial model require the model to be more detailed and real while facial animation needed to be more realistic and even can perform in real time. The research team had currently focusing on building the facial model using automated facial bone and muscle placement at the correct anatomically position in order to build structured facial model which concerning the potential of animations (Parke & Waters, 2008). Other than that, reconstructing the surface details of model is proposed by Huang et al. (2014) in order to create effective 3D face model which adding higher value of realism. Facial animation currently is in higher demand by the industry. Since then, the research had foster. Mostly animators use interpolation since it is low coast and easy to implement. However, the limitation is the key frame needed to be classified first and skillful animator are required to ensure the facial model have smooth motion. The aim for the research team in this field is to help simplify and automate the control of the animation for facial model (Fratarcangeli, 2013). In 2016, Gunanto et al. concern animation process by using motion data captured based on location and movement of marker as a guidance to generate motion towards the model. Besides that, Arif et al. (2017) had introduced an motion capture data compression using quadratic Be'ezier curve which eventually helps in producing effective high quality of facial model and also better animation performances by parameterizing and approximate independently of each joint's motion data. this method absolutely helps the research team as it well suited for modeling and motion data compression for interactive and real-time since it require less space and consume low cost of computational cost. Basically, the current research trend in this graphical visualization and animation of human facial model are heading towards creating automated method that can create well-structured detailed facial model, realistic facial animation which also concern on performance, production time, usability, details and realism, compatibility, usability, technical limitation and common combination.

4. Conclusion

Throughout this paper, the techniques implemented in facial animation are being described and the issues reviewed are involving the facial modeling techniques and also the facial animation techniques. The facial modeling techniques are categorized into several such as interpolations, parameterization, physic-based model, muscle-based modeling and pseudo-muscle-based model while for techniques of facial animation that acquired data is classified into speech-driven techniques, image-based techniques and performance-driven techniques. While surveying, we are basically discussing the main ideas, the theories related, strength and also the limitation for each category. The research aim is associated to combination of facial animation. However, in order to achieve higher level of realism in facial animation, a lot of improvement will be needed in future.

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