3D Facial Expression Synthesis: A Survey

Samuel Agianpuye and Jacey-Lynn Minoi
Faculty of Computer Science and Information Technology
Universiti Malaysia Sarawak
Kuching, Malaysia

***Abstract*—Facial expression synthesis is a process of generating new face shapes from a given face and still retain the distinct facial characteristics of the initial face. The generated facial expressions can be used to improve the performance of existing face identification systems, or to enhance human recognition. Earlier work on synthesizing face shapes used 2D face images. Only recently, the work moved to using 3D face shapes given the availability and improvement in 3D scanner technologies. The advantage of 3D faces over 2D image data is that 3D face holds more geometric shape data and is invariant to poses and illumination. This paper aims to give an overview of the methods used for 3D facial expression synthesis. We present an overview of 3D face expression synthesis, its applications and benefits and then we review some of the most resent 3D face expression synthesis approaches.**

Keywords— Facial expression, 3D faces, synthesis

I. INTRODUCTION

Facial expression synthesizing is a growing field of research in computer vision and biometrics. This is because of several advantages it holds, especially in the areas of face recognition and face reconstruction. Facial expression can be described as the movement or position of facial muscles on the skin that could convey the emotional state of an individual. People have a unique ability to understand facial expressions of other individuals. Computers on the other hand do not have this ability. As people become heavily dependent on computers, it will be useful if computers can recognize human facial expressions in order to improve human-computer interaction. This has led to several research interests springing up in the area of computer vision. One of which is synthesizing facial expressions. Synthesizing facial expression simply means artificially creating or replicating human facial expression on an image or 3D face data and in this paper we shall be discussing several approaches to synthesizing realistic human facial expressions, specifically on 3D faces.

Facial expression synthesis has several benefits when applied to certain systems as an add-on module. For example, it can improve the performance of face recognition systems, because a slight expression change can greatly distort recognition accuracy [8][4][7]. Facial recognition is a process of identifying a face by matching it against a library of known faces. An experiment by Chang et al. [7] revealed 90% recognition rate without any facial expression, but when facial expression was added, the recognition rate dropped significantly to between 25% to 50%. Synthesizing neutral face expression can be used to solve this problem when implemented in a face recognition environment.

Facial expression synthesis can also be of benefits as an add-on to gender classification algorithms. Existing gender classification methods only deals with neutral faces [14][16]. Neutral facial expression can be synthesized from other kinds of facial expression before gender classification is carried out.

Cartoons or anime production studios can also use facial expression synthesis methods to reduce the amount of frames required to animate a facial expression onto a character's face. Video game developers can also synthesize realistic facial expressions on 3D models and avatars.

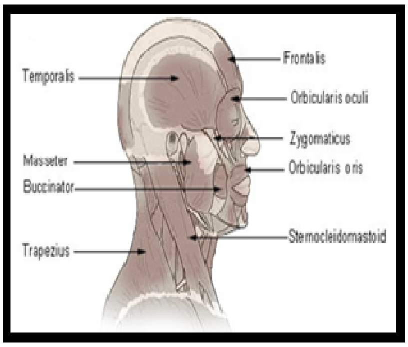
Facial expression synthesis can also improve Human-Computer Interaction. For example, in future, front camera sensors on a mobile device can be used to track the facial expression of the user in order to guess his or her emotional state. This information can help the device carry out certain task like telling a joke if it senses the device owner is in a sad mood. It can also be used to improve access control on the mobile device. The mobile user is not required to have a neutral facial expression to log in. The device can grant access no matter the expression on the user's face. Lastly, facial expression synthesis can serve as add-on to existing aging systems by synthesizing facial expressions used for comparing young and old face data of the individual. These are just a few of the many benefits of facial expression synthesis.

II. BACKGROUND AND LITERATURE REVIEW

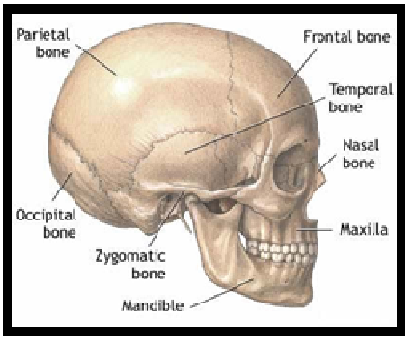
In order to synthesize facial expression, we need to understand the human facial anatomy and how facial expressions are created. Facial muscle contractions and relaxation in conjunction with the movement of the mandible creates different forms of facial articulations and expressions. As seen in Fig. 1, specific face muscles in conjunction with skull bones, specifically the mandible Fig. 1 (b), are responsible for the generation of various facial expressions on the human face. These sets of muscles deform in specific patterns to create various facial expressions or facial appearance as a whole, like during speech, yawning etc.

Psychologists Paul Ekman and Wallace V. Friesen in 1978 [1] studied the human facial anatomy and created Facial Action Coding System (FACS) framework to explain how facial muscle contractions alter appearance in relation to the creation of expressions. They used Action Unit (AU) to describe each facial muscle contraction or relaxation. All facial expressions can be represented by AUs and can be further described by intensity, asymmetry and duration. Nearly any anatomically possible facial expression can be manually coded by human using FACS.

978-1-4799-1092-2/13/$31.00 ©2013 IEEE



(a)



(b)

Fig. 1. Facial Muscles (a) Facial Muscles (b) The Human Skull.

Image source [4]

This is done by constructing it into components of AUs and temporal muscle segments to produce the facial expression. Ekman and his colleagues also created EMFACS (Emotion Facial Action Coding System) [21], which consider only emotion-related facial actions. Several synthesizing of facial expression methods used FACS as a reference for facial muscle manipulation [2] [19] [13]. For example, Ekman and his colleague's work on FACS inspired researchers to synthesis facial expressions using muscle-based facial model [13], which we shall discuss in a later section of this paper along with other facial expression synthesis methods.

For over two decades there have been many approaches towards implementing facial expression synthesis. Facial expression synthesis methods could be categorized into two major categories, Geometric or Three- dimensional (3D) manipulations and Image manipulation [23][24][20]. In this paper, we shall focus on 3D geometric manipulation approaches that have been used for synthesizing realistic facial expressions on 3D face, such as interpolation, physics-based muscles which comprises of mass-spring mesh muscle, vector muscle and layer spring mesh muscles. Others are pseudo muscle models, free form deformation, Spline pseudo muscle, Statistical-based methods, leaning-based method, morphing and finally MPEG-4 facial animation parameters.

A. Interpolation

Interpolation function is used to specify smooth motions between two key frames over a normalized time interval [24] [9]. One of the advantages of using interpolation is that it creates a primitive facial expression easily at a fast pace. The disadvantage of the method is the output of the synthesized facial expressions, whereby it is limited in range of realistic facial configuration. Interpolation can be combined with simultaneous image morphing to create a wide range of facial expression changes [25]. Geometric interpolation directly updates the 3D positions of the face mesh vertices, while parameter interpolation controls functions that indirectly move the vertices. Sera et al. [26] achieved mouth shape change by carrying out linear interpolation of spring muscle force parameters, rather than the positions of the vertices. Fig 2 shows linear interpolation on blend shapes.

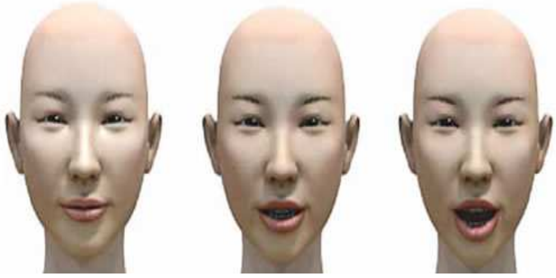


Fig. 2. Left: Neutral pose, Right: "A" mouth shape, Middle: Interpolated shape.

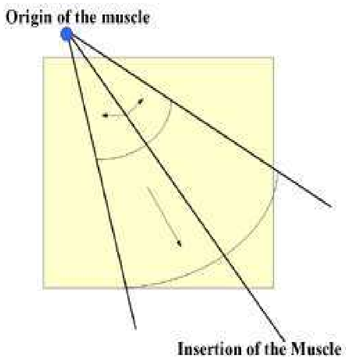
Image source [24]

B. Physics-based approach

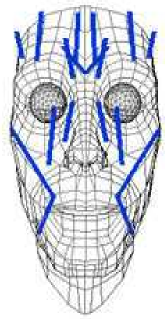
Physics-based muscle approach can be categorized into mass-spring method, vector muscle method and layered spring mesh muscles. These methods are carried out on blend shapes data. Blend shape data is the linear weighted sum of a number of topologically conforming shape primitives [18].

Mass-spring mesh muscle method distributes muscle forces in an elastic spring mesh that models skin deformation [27]. Realistic facial expressions are generated when forces are applied to the elastic meshes via muscle arcs. Early work on facial expression synthesis using mass-spring was by Platt and Badler [27]. Their research focused on muscle modeling relating to the structure of the human face. Later work by [28] proposed a facial model with muscles represented as collections of fictional blocks in defined regions of the facial structure. The model is made up of 38 regional muscle blocks interconnected in a spring-network. Only recently, Kahler et al. [29] presented a convenient editing tool that provides an interactive way to specify mass-spring muscles into 3D geometry. Three-dimensional face data used here are blend shapes.

Vector muscle approach is a physics-based approach that deforms a facial mesh using motion fields in delineated regions of influence. It models the action of muscles upon skin, exploiting the delineated deformation field. FACS framework was applied in Vector Muscle (VM) approach to facial expression synthesis by [2]. The disadvantage of using this approach is that the positioning of vector muscles into anatomically correct positions was a daunting task. Manual trial and error had to be done with no guarantee of efficient or optimal placement. Placing the VM into incorrect positions only resulted in anomalous or undesirable animation of the meshes that make up the face model [30].Vector muscles are widely used on blend shapes because of their compact representation of independence of the facial mesh structure. Fig 3 illustrates a muscle definition that includes the vector field direction, an origin, and an insertion point.



(a)



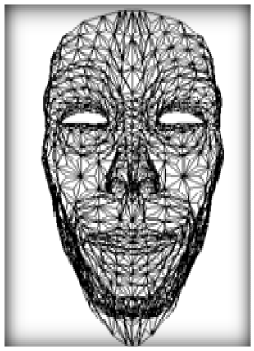
(b)

Fig. 3. Vector Muscle (a) Deformation decreases towards the direction of the arrow (b) Water's linear muscle[12][9]. Image source [9]

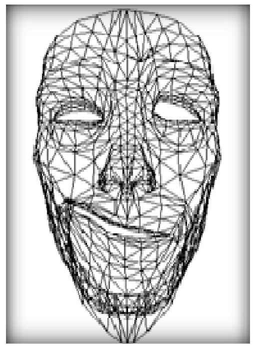
Another physics based approach is the layered spring mesh muscles method. The method models detailed anatomical structure and dynamics of a human face [31]. It consists of three-layers of deformable mesh corresponding to facial skin, fatty tissue and muscle tied to bone. The method could achieve high facial expressions and anatomy realism. The down side is that it requires extensive computation when simulating volumetric deformations with 3D lattices. To reduce computation time and also maintain similar quality, a simplified mesh system can be employed [32]. Fig. 4 shows the topology of the skin after lattice construction. 960 polygons are used to model the tissue, resulting to approximately 6,500 spring units. Fig. 4(b) illustrates the tissue distortion when the corner of the lip is raised due to the influence of the zygomaticus muscle (FACS action unit 12). The inner frontalis muscle (FACS action unit 1) raises the inner portion of the brow.

C. Pseudo muscle models

Pseudo muscle model approach achieves realistic facial expression synthesis results by approximating human facial anatomy. Facial muscle forces are simulated in the form of free form deformations and Splines [27][33][24]. The examples of this method are Free Form Deformation (FFD) and Spline pseudo muscles. These methods are carried out on blend shapes data. FFD deforms volumetric objects by manipulating control points in a 3D lattice [34]. Different types of surface primitives can be deformed using FFDs, such as polygonal meshes; quadratic, parametric, and implicit surfaces; and solid models. A variation is the EFFD (Extended Free Form Deformation) [35], which allows the extension of the control point lattice into a cylindrical structure.



(a)



(b)

Fig. 4. Layered Spring (a) Undeformed geometry of the skin layer. (b) Deformed geometry (only epidermis is displayed for clarity). Image source [31]

Another free form variation is the Rational Free Form Deformation (RFFD) [36], which incorporates weight factors for each control point. Spline pseudo muscles supports even, flexible deformations, allowing for localized deformation on a face surface and reduces the computational complexity involved. The number of unnecessary control points can be reduced by the use of a hierarchical Spline model [39]. Bicubic or B-splines offers both smoothness and flexibility, which are difficult to achieve with conventional polygonal models. The disadvantage of using native B-splines for complex surfaces becomes more apparent when a deformation is required to be finer than the patch resolution [24]. Hierarchical B-splines are an economical and more compact method to represent a Spline surface in order to achieve high rendering speed. Muscles coupled with hierarchical Spline surfaces are capable of creating a variety of facial expressions.

D. Statistical-based methods

Statistical-based methods synthesize expressions based on a collection of face data samples [22][33][6]. Here, realistic facial expressions can be synthesized in real-time with low computational cost. Active Shape Models and Statistical Discriminant Model are examples of statistical approach used to synthesis facial expressions.

Using Active Shape Models (ASM) [40], new facial expressions can be generated as surface points are moved along the most discriminant and expressive vector direction in the training set space. Developed by T. Cootes and C. Taylor [11], ASMs is a statistical model shape of objects that iteratively deform to fit to an example of the object in a new image. Point Distribution Model (PDM) [11] is used to constrain the shapes so that they will only vary in ways seen in a training set of labeled examples. A set of points is used to represent the shape of an object, which is controlled by the shape model. ASM is widely used in the analysis of 2D and 3D faces [3][4] and medical images[2].

Minoi et al. [6] synthesized realistic facial expressions on 3D face data using Statistical Discriminant Model (SDM). SDM is based on an idea of using a two-stage separating hyper-plane to interpret and reconstruct face data [17]. SDM requires a pre-alignment of the captured images to a common template in order to minimize variations that are not necessarily related to differences between the faces. Principal Component Analysis (PCA) [3][42][15][5] is first used to reduce the dimensionality of the original face data. Secondly, Maximum uncertainty Linear Discriminant Analysis (mLDA) [41] is used to characterize the face data groupings. Reconstruct of face data can be done based on the most discriminant change vectors. This method was tested on Binghamton University 3D Facial Expression Database (BU-3DFE) [6].

E. Learning-base method

One of the recent works in expression synthesis was by Gang et al. [20]. They focused on the task of recovering neutral 3D face of a person, given a 3D face model with facial expression. They used a learning-based approach to remove facial expression residue from samples, and then use the inferred expression residue from the input expressional face model to recover the neutral one. The result of their experiment carried out on BU-3DFE dataset [38] showed some significant effectiveness in their approach. They used a generic face model with 11 landmarks to align and unify the test samples so that they can focus on the problem of synthesizing neutral facial expression on the test face.

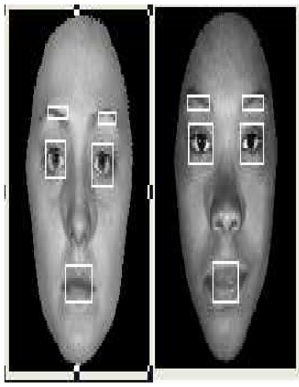
F. Morphing

Yang et al. [45] proposed a 3D morphing target method using Graphic Processing Unit (GPU) for real time facial expression synthesis. They used the following seven steps algorithm; create morph target expressions, evaluate difference vector, initializing morph data structure, loading data into vertex buffer object, linking attributes to shader and rendering facial expressions. An advantage of their approach is the quick and efficient computation resulting from the fast morphing process that is integrated in the GPU pipeline. This is valuable because it achieves a high Frames per Seconds (FPS) when applied in the development of 3D games to enhance immersion and realistic appearance of avatars.

Another work by Blanz et al. [44] generated new facial expressions and attributes on morphable 3D faces. Beginning from an example set of 3D face models, they derive a morphable face model by transforming the shape and texture of the examples into a vector space representation. New faces and expressions were modeled by adding or subtracting shape and texture vectors specific to the attribute. Applying performance based technique [43], facial expressions are synthesized by recording two scans of the same subject with different expressions, and adding the expression residue differences onto a different subject in a neutral expression.

G. MPEG-4 facial animation parameters (FAPS)

Patel et al. [10] generated six facial expressions with the help of MPEG-4 Facial Animation Parameters (FAPS) on 3D face model generated from a 2D face data. They have also tested and evaluated their results using BU-3DFE datasets. Their system was made up of three components. The first is responsible for identifying the distinct features of the face like mouth, contour of the face, eyes and eyebrows. The second component is responsible for automatically adapting the generic 3D model into face specific 3D models via geometric transformations. Finally, facial expression synthesis is carried out on the generated face model. Fig. 6 illustrates how feature extraction was done and expression is synthesized on the face models.



(a)

(b)

Fig. 6. (a) Features detection (b) Face models with synthesized expressions. Image source [10].

III. DISCUSSION

To the best of our knowledge, we have looked at several approaches to synthesizing facial expression on 3D face data, and can see some trends in this interesting area of research. One of which is the type of 3D face data used in evaluating the algorithms. Some 3D data are computer generated blend shape faces. Some other 3D data are from converting 2D picture images of real human faces into 3D face data [10]. Also due to the advancement in 3D image capturing technology, we also have 3D faces that are captured from human subjects. These face data are then preprocessed and used for different purposes like for instance in evaluating face recognition algorithms. The few examples of 3D face data sets captured using 3D capturing devices are the Imperial College London, United Kingdom [4] [3] and Binghamton University 3D Facial Expression Dataset (BU-3DFED) [38]. Another thing to note is that the different 3D face expression synthesizing methods are most suitable for specific purposes. For example, a statistical based method is mostly applied in face recognition while physic-based approach is applied in computer animation and gaming. Table I shows a summary of the discussed methods for synthesizing facial expressions on 3D face data.

IV. CONCLUSION

In this paper, we have looked at different approaches to synthesize facial expressions and they are summarized as follows; Physics, Pseudo muscle models, Statistical, Learning based, morphing and facial animation parameters. As an add-on, 3D facial expression synthesis can improve the performance of face recognition systems and gender classification algorithms. It is also used in animation studio productions and video games and can improve human-computer interaction when applied to mobile applications.

TABLE I. TABLE SHOWS THE SUMMARY OF METHODS USED IN SYNTHESIZING FACIAL EXPRESSIONS ON 3D FACES, 3D DATA TYPES USED TO EVALUATE THE DIFFERENT METHODS, POSSIBLE APPLICATION, ADVANTAGE AND DISADVANTAGE OF THE METHOD

Method	3D face data	Possible Application	Advantages	Disadvantages
Interpolation [9] [24]	Blend shapes / Generic 3D data**	3D character facial expression animation, adverts or gaming.	Easily creates a primitive facial expression at a fast pace.	Output of the synthesized facial expressions is limited in range of realistic facial configuration.
Mass-spring Mesh [27]	Blend shapes / Generic 3D data	3D character facial expression animation, adverts or gaming.	Realistic facial expressions are generated when forces are applied to the elastic meshes via muscle arcs.	Synthesizing facial expressions cannot be automated. An editing tool [29] can be used to provide an interactive way to specify mass-spring muscles into 3D geometry.
Vector Muscle [2]	Blend shapes / Generic 3D data	3D character facial expression animation, adverts or gaming.	Models the action of muscles upon skin, exploiting the delineated deformation field.	Positioning of vector muscles into anatomically correct positions was a daunting task. Manual trial and error had to be done with no guarantee of efficient or optimal placement.
Layered Spring Mesh [31]	Blend shapes / Generic 3D data	3D facial expression construction, animation of facial skin, fatty tissue and muscle.	Achieves high facial expressions and anatomy realism by modeling detailed anatomical structure and dynamics of a human face.	Requires extensive computation when simulating volumetric deformations with 3D lattices.
Free form deformation (FFD)[35] [36]	Blend shapes / Generic 3D data	3D facial expression construction and animation.	Different types of surface primitives that combine to make up the face model can be deformed by manipulating control points in a 3D lattice.	Very difficult to synthesis realistic facial expressions because of unsmooth deformation of the face model while manipulating control points.
Spline pseudo muscles [24] [39]	Blend shapes / Generic 3D data	3D facial expression construction and animation of facial muscle to create facial expressions.	Reduces the computational complexity involved by supporting even and flexible deformations, allowing for localized deformation on a face surface.	Complex surfaces become more difficult to deformation when it is required to be finer than the patch resolution.
ASM [40]	Imperial College London 3D Face database / BU-3DFED	As an add-on to improve face recognition or Human computer Interaction.	Lower computational cost due to faster personal / mobile computing.	Requires significant differences in facial expression in the face database for training in order to achieve discriminant values that represent different facial expressions to be synthesized.
SDM [6][17]	Imperial College London 3D Face database / BU-3DFED	As an-add on to improve face recognition or Human computer Interaction.	Lower computational cost due to faster personal / mobile computing.	Requires significant differences in facial expression in the face database for training in order to achieve discriminant values that represent different facial expressions to be synthesized.
Two-step Non-rigid Alignment / Poisson-based framework [20]	BU-3DFED	As an add-on to improve face recognition or Human computer Interaction.	Fast processing. Each expression removal test completes in less than one minute.	Generic face model with 11 landmarks was used to align and unify the test samples. More Land marks will help to capture more facial features and therefore more facial expression characteristics.
Morphing [44][45]	Blend shapes / Generic 3D data	3D face animation and morphing between different facial expressions for 3D games characters. This enhances immersion and realistic appearance of avatars.	Quick and efficient computation resulting from the fast morphing process that is integrated in the GPU pipeline.	Highly dependent on GPU. If the GPU is of low specification the processing speed is reduced.
MPEG-4 [10]	3D face reconstruction from one single image / BU-3DFED	As an add-on to improve face recognition or Human computer Interaction	Automatic, robust, fast and accurate.	Generated facial expressions were not very realistic.

*** Generic 3D data mentioned in this table refers to 3D faces that were modeled using any 3D modeling software like Maya.*

ACKNOWLEDGMENT

This research is funded by FRGS grant number: FRGS/02(29)/837/2012(77). The authors would like to thank the referees for their constructive comments, which helped improve this paper and UNIMAS.

REFERENCES

[1] P. Ekman and W. Friesen. Facial Action Coding System: A Technique for the Measurement of Facial Movement. Palo Alto: Consulting Psychologists Press, 1978.

[2] T.F. Cootes, A. Hill, C.J. Taylor, and J. Haslam, "Use of active shape models for locating structures in medical images," Image and Vision Computing, vol.12 (Issue 6), pp. 355–365, July–August 1994.

[3] M. McDowell, 3D facial animation using warping and morphing. MSc Project Report, Imperial College London, March 2007.

[4] J.L. Minoi, Geometric expression invariant 3D face recognition using statistical discriminant models. PhD Thesis, Imperial College London, March 2009.

[5] I.T. Jollife, Principle Component Analysis. New York: Springer-Verlag, 1986.

[6] J.L. Minoi, S.H. Amin, C.E. Thomaz, and D.F. Gillies, "Synthesizing Realistic Expressions in 3D Face Data Sets," 2nd IEEE International Conference on Biometrics: Theory, Applications and Systems (BTAS) 2008, pp.1-6, Sept. 29-Oct. 1, 2008.

[7] K. Chang, K. Bowyer, and P. Flynn. "Face recognition using 2D and 3D facial data," Workshop on Multimodal User Authentication, pp. 25–32, 2003.

[8] G. Givens, R. Beveridge, B. Draper, and D. Bolme. "A statistical assessment of subject factors in the pca recognition of human faces," Workshop on Statistical Analysis in Computer Vision, 2003.

[9] L.H. Li, Y.K. Liu and H.B. Zhang, "A Survey of Computer Facial Animation Techniques," 2012 International Conference on Computer Science and Electronics Engineering (ICCSEE), vol.3, pp.434-438, March 23-25, 2012.

[10] N. Patel, and M. Zaveri, "3D Facial model construction and expressions synthesis from a single frontal face image," 2010 International Conference on Computer and Communication Technology (ICCCT), pp.652-657, Sept. 17-19, 2010.

[11] T.F. Cootes, C.J. Taylor, D.H. Cooper and J. Graham, "Active shape models - Their training and application," Computer Vision and Image Understanding, vol. 61, pp. 38–59, 1995.

[12] K. Waters, "A muscle model for animating three-dimensional facial expressions," Comput. Graph., vol. 21, no. 4, pp. 17–24, 1987.

[13] S.M. Platt and N.I. Badler, "Animating facial expressions," Comput. Graph., vol. 15, no. 3, pp. 245–252, 1981.

[14] Y. Liu and J. Palmer. "A quantified study of facial asymmetry in 3D faces," In AMFG'03.

[15] M. Kirby and L. Sirovich. "Application of the karhunen-loeve procedure for the characterisation of human faces," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 12, no. 1, pp. 103–108, 1990.

[16] X. Lu, H. Chen, and A. Jain. "Multimodal facial gender and ethnicity identification," Advances in Biometrics, 2006.

[17] E.C. Kitani, C.E. Thomaz, and D.F. Gillies, "A statistical discriminant model for face interpretation and reconstruction," 19th Brazilian Symposium on Computer Graphics and Image Processing, SIBGRAPI '06, pp. 247-254, Oct. 2006.

[18] B. Gong, Y. Wang, J. Liu, and X. Tang, "Automatic Expression Recognition on a Single 3D Face by Exploring Shape Deformation," In ACM Multimedia, 2009.

[19] T. Goto, M. Escher, C. Zanardi, and N. Magnenat-Thalmann, "MPEG-4 based Animation with Face Feature Tracking," In Proc. Eurographics Workshop on Computer Animation and Simulation'99, pp. 89–98, 1999.

[20] P. Gang, S. Han, Z. Wu, and Y. Zhang, "Removal of 3D facial expressions: A learning-based approach," 2010 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 2614-2621, Aug. 2010.

[21] EMFACS - Using Facial Action Coding System to Score Emotion Expressions. http://face-and-emotion.com/dataface/facs/emfacs.jsp. [Accessed April 3, 2013].

[22] H. Pyun, Y. Kim, W. Chae, H. Kang, and S. Shin, "An Example-Based Approach for Facial Expression Cloning," ACM SIGGRAPH, In Eurographics Symposium on Computer Animation, pp. 167–176, 2003.

[23] Q. Zhang, Z. Liu, B. Guo, D. Terzopoulos, and H. Shum, "Geometry-driven photorealistic facial expression synthesis," IEEE T-VCG, vol. 12, no.1, pp.48–60, 2006.

[24] S. Krinidis, I. Buciu, and I. Pitas, "Facial expression analysis and synthesis: A survey," In HCI'03, pp.1432–1433.

[25] K. Arai, T. Kurihara, and K. Anjyo, "Bilinear interpolation for facial expression and metamorphosis in real-time animation," The Visual Computer, vol. 12, pp. 105–116, 1996.

[26] H. Sera, S. Morishma, and D. Terzopoulos, "Physics-based muscle model for moth shape control," In IEEE International Workshop on Robot and Human Communication, pp. 207–212, 1996.

[27] S. Platt and N. Badler, "Animating facial expression. computer graphics," Computer Graphics, vol. 15, no. 3, pp.245–252, 1981.

[28] S.M. Platt, A structural model of the human face. PhD Thesis, University of Pennsylvania, 1985.

[29] K.K¨ahler, J. Haber, and H.P. Seidel, "Geometry-based muscle modeling for facial animation," In Proc. of Graphics Interface'2001, 2001.

[30] K. Waters, "A muscle model for animating three-dimensional facial expression," In SIGGRAPH Proceedings, vol. 21, pp. 17–24, 1987.

[31] D. Terzopoulos and K. Waters, "Physically-based facial modeling, analysis, and animation," Journal of Visualization and Computer Animation, vol. 1, no. 4, pp. 73–80, 1990.

[32] Y. Wu, N.M. Thalmann, and D. Thalmann, "A plastic-visco-elastic model for wrinkles in facial animation and skin aging," In Proc. 2nd Pacific Conference on Computer Graphics and Applications, Pacific Graphics, 1994.

[33] C. Kouadio, P. Poulin, and P. Lachapelle, "Real-time facial animation based upon a bank of 3D facial expressions," In Proc. of the Computer Animation, pp. 128, 1998.

[34] T.W. Sederberg and S.R. Parry, "Free-form deformation of solid geometry models," In Computer Graphics, SIGGRAPH, vol. 20, pp. 151–160, 1996.

[35] S. Coquillart, "Extended free-form deformation: A sculpturing tool for 3D geometric modeling," Computer Graphics, vol. 24, pp. 187–193, 1990.

[36] P. Karla, A. Mangili, N.M. Thalmann, and D. Thalmann, "Simulation of facial muscle actions based on rational free form deformations," In Computer Graphics Forum, pp. 59-69, 1992.

[37] W.S. Lee, P. Karla, and N. Magnenat-Thalmann, "Model based face reconstruction for animation," In Proceedings of Multimedia Modeling, pp. 323-338, 1997.

[38] L.J. Yin, X.Z. Wei, Y. Sun, J. Wang, and M.J. Rosato, "A 3D Facial Expression Database For Facial Behavior Research," 7th International Conference on Automatic Face and Gesture Recognition (FGR06), pp.211–216, April 10-12, 2006.

[39] C.L.Y Wang and D.R. Forsey, "Langwidere: A new facial animation system," In Proceedings of Computer Animation, pp. 59–68, 1994.

[40] T.F. Cootes, C.J. Taylor, D.H. Cooper and J. Graham, "Active shape models - Their training and application," Computer Vision and Image Understanding, vol. 61, pp. 38–59, 1995.

[41] C.E. Thomaz, "Maximum entropy covariance estimate for statistical pattern recognition," PhD Thesis, Imperial College London, 2004.

[42] M. Turk and A. Pentland, "Eigenfaces for Recognition", Journal of Cognitive Neuroscience, vol. 3, pp. 71-86, 1991.

[43] F.I. Parke, "Computer generated animation of faces," In ACM National Conference, ACM, November 1972.

[44] V. Blanz and T. Vetter, "A morphable model for the synthesis of 3D faces", In Proceedings of the 26th annual conference on Computer

graphics and interactive techniques (SIGGRAPH '99). New York, USA: ACM Press/Addison-Wesley Publishing Co., pp. 187-194.

[45] M. Yang, K. Wang, and L. Zhang, “Realistic Real-time Facial Expressions Animation via 3D Morphing Target,” Journal of Software, North America, 8 Feb. 2013.