3D Face Deformation Using Control Points and Vector Muscles

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Summary
The creation and animation of 3D facial models has depended on animators' manual work frame by frame. Thus, it needs many efforts and time as well as various hardware and software. This paper is aimed at developing a facial expression modeling system based on vector muscle which can produce diverse and realistic facial expressions. 8 standard facial models fitting the characteristics of Korean faces was introduced. Thereupon, this paper suggests a way to model 3D human faces easily and quickly just with the front and profile images. In addition, in order to produce more precise 3D facial models, a delicate adjustment method using the Radial Basis Function is introduced. Facial models produced by these methods may be synthesized or varied. Moreover, this paper suggests a method of synthesizing various 3D facial expressions in consideration of the anatomical vector muscles. Besides, This paper suggests a way to apply such methods to produce caricatures by adjusting the control points of the RBF and the vectors of the facial muscles.

Key words:
3D Face Model, Facial Animation, Control Points, Muscle Vector, Caricatures .

1. Introduction

There is a long history of study on human face through human psychology or other fields, and there are many studies in process recently for recognizing human face and facial expression, generating face model and facial expression, and on-line avatar using technologies such as image processing, computer vision or computer graphics. Since people are having conversation and exchange their thoughts by facing each other, face animation using computer needs natural face modeling not to have artificial feeling in it, and interface between human and computer should be able to process a face model and facial expression naturally similar to real human. 3D face animation has been applied widely through virtual reality, MPEG-4 compression, teleconference, advertisement, and game. Especially, it has developed to a point where it can express 3D face in real time thanks to a development of hardware and software. General 3D face modeling generates 3D face model and matches face model by using vertex points on 3D mesh as control points or generating random control points to match the image corresponding to each individual's face form.

However, since this type of work uses control point coordinates on a whole mesh, it takes a lot of time and effort to distort mesh form or to match the image corresponding to user's face form.
A general method of face modeling is to generate a face model and match a face model using a vertex on mesh as a control point or generate a random control point to match according to an individual's face. However, this is a complicated work since it uses control point coordinate on a whole mesh resulting in changing or distorting of mesh, or it takes a lot of time and effort to adjust according to each user's face form.
Therefore, this paper suggests a method of synthesizing various 3D facial expressions in consideration of the anatomical vector muscles.
In addition, this study provided a face control point generating and matching method using FFPs(Facial Feature Points) information extracting method using RBF(Radial Basis Function) from 3D face mesh. And this paper suggests a way to apply such methods to produce caricatures by adjusting the control points of the RBF and the vectors of the facial muscles.

2. Related Study

Techniques for animating human beings and human faces in particular have been an active area of research since the early 1970's. The very first facial animation can be traced back to Frederic I. Parke's in the early 1970[2]. Parke created the system of animation by means of interpolation, which was enable to open and shut 3D model's eyes and mouth. Parke, Lippman and Balder in the early 1980s in America who began to, for the first time in history, get access to the facial synthesis and the facial animation systematically on the basis of the arithmetically well-controlled model[3][4][5]. However, they synthesized the animated face relying on only the simple graphic technique, so they achieved the unnatural animations.
Ekman suggested FACS(Facial Action Coding System) methodology expressed by the combination which was deduced from classifying the emotion and expression of the face by each fundamental AU(Action Units), and in 1987 Walters tried to explain the motion of the skin tissue by the motion of facial expression muscle affecting the change of the facial expression as he had interpreted the

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change of facial expression was the result of the facial muscular motion[7][8][9].
3D face model generating methods can be divided into a method that uses 3D input data and a method that uses 2D input method. The methods that use 3D information are 3D scan digitizer using method, CT or motion capture equipment using method. These methods are relatively faster in generating 3D face model, but they need very expensive equipments. The methods that use 2D input data in generating face model are a method that finds out face depth information using stereo image and a method that uses generic face model.
The shortfalls in using stereo image are that it needs well-arrayed expensive cameras to make accurate 3D model and a calculated value is too big. A method that uses generic face model extract FFPs from 2D input image and adopts it into a general model to make 3D face model. FFPs that express each individual's characteristics are widely used in face recognition, face model generation and face animation. There are FFPs extracting methods such as a method that uses deformable templates, snake method, a method that uses fixed facial symmetry, and a method that uses wavelet filter. Study of 3D face model creation that use implicit function primitive recently is proceed. Implicit function primitive 3D modeling for objects that is consisted of complex curved surface such as 3D character or fluid etc. curved surface of easy and various to data of the use amount form express can. However, because face model creation that use implicit function primitive is lacking that is technological yet to create natural face model, a lot of studies are necessary part. Next Fig. 1 is 3D face that creates using implicit function primitive.

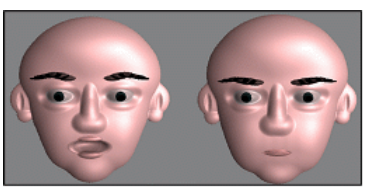

Fig. 1 3D face using implicit primitive

3. The Structure of Facial Animation System

When creating a 3D facial model using a single frontal image of a face, the accurate depth information is not available. Therefore, the general 3D model is used for image compensation and 1:1 mapping is performed with a 2D image to complete the 3D facial model. In order to compose a general model with a facial image, the general model is first projected on to an axis perpendicular to the original axis of the face from which the image is to be acquired. The mapping relation between the facial image and the projected general model is then defined, and the general model is composed and transformed in 2D.
The 3D face deformation system is a standalone 3D facial expression and caricature generation system.
First, we produced the standard facial model which fit for the Korean facial characteristics. After we get the images of the frontal faces photographed by a camera, we synthesize these images with the standard model, so that we were able to create the 3D facial model rapidly and easily.
And then, we precisely adjust can the 3D facial model to the specific individual's face using the control points of the RBF. So by the 3D facial model, we succeeded in realizing the caricature creating system through which, by the muscle vector based on anatomical. As shown in Fig. 2 the system consists of two parts: Face Modeling system and 3D caricature system.

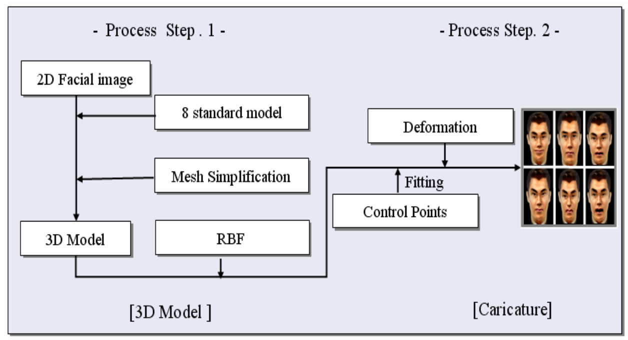

Fig. 2 Overall system diagram

4. 3D Face Modeling and Control Points

4.1 3D Generic Model for Face Modeling

Considering face image as a reflection of 3D face on a 2D screen, analyzing and synthesizing of face image should be done on 3D. To analyze and synthesize 2D face image as 3D, it needs a complete 3D face model for an image. General way of making 3D face using 2D image is to use generic model that has characteristics of a general people, not a specific model.
In addition to that, full face and side face images are used in most of the systems for 2D face input image since those are parts that have the most information of a face. However, this study uses 3D generic model and one image of 2D full face for an easy and fast process.

4.2 The Eight Types of General Standard Models

There is a limitation to express all sorts of human facial expressions by a single general model, and it is unsuitable

to express the Korean characteristic face or facial expression accurately or properly because the human being's facial appearance is different form by race, gender and age.
In this research, so as to make up for these defects, we classified eight types of general standard models of Korean face and produced each of the them on the basis of the result of the research on the Korean standard face, the Korean standard physical size, and the related various reports. After choosing the facial model per each type of it which is consistent with the input facial image, we can create the proper 3D facial model easily and rapidly.
Also each facial model consists of innumerable meshes which consist of fixed points, angles and sides. Each face consists of 3D structure, so that each fixed point has such 3D co-ordinates system as x, y and z. It means that we need to vary at least three variables in order to control the 3D co-ordinates system.

4.3 Simplifying Face Mesh

Most of the developed face modeling systems now use 3D face model that has hundreds or thousands of meshes. Corresponding vertex points existing on a face model image need manipulating process to make it agree with 2D image inputted when it was matched and modified. These methods need complicated work, lots of processing, matching and rendering time since a user should control in detail for a specific face form[6]. Likewise, complicated face mesh needs lots of storage space, and speed is too slow makes it impossible to materialize in real time.
Therefore, this study removed vertex points on a minimum distance and a curvature standard and minimized mesh that have the same figure on a screen to simplify and optimize 3D face mesh data through removing and combining vertex points.
The standard of generic model mesh simplification this study used is as follows:
First, visual substantiality should be considered. Therefore, it should control levels of simplification for each face consisting factor.
Second, it should reduce a size of generic model to reduce after-treatment time, to be effective in data structure and memory management, to optimize mesh, and to make it easy to edit.
Third, matching and rendering time should be reduced to make 3D face model easily and fast. Fig. 3 displays the forehead of 3D facial model created using simplification model.

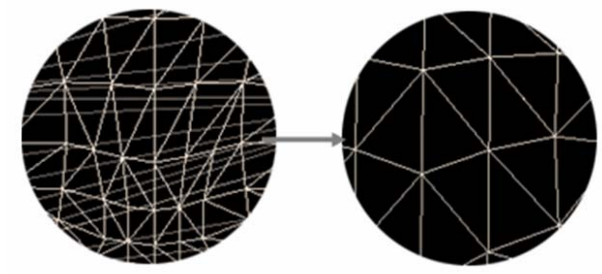

Fig. 3 Simplification of mesh (forehead)

4.4 Dividing Facial Characteristics

Generic face model is used by extracting FFPs from inputted face images and generating 3D face model adopting FFPs to a generic model.
When there is a complicated background and full face in 2D color image, it can extract face part by using skin color of face and also can extract facial characteristics by using color information of face area as well as boundary line information. However, these methods have complicated algorithm, and they take lots of time processing it.
This study suggested a method that can generate face control points using RBF. Since a face form is complicated and detailed, it divided control points into each group on 3D mesh to be appropriate for each face form. Therefore, each components of face that make characteristic of face are divided into a different group based on a general form, size, location and direction of a face. These components of a face were located on a whole face and boundaries of each component.
There are distinguishable characteristics on a human face as you can see in a Fig. 4 Such as figure of a head, size and location of a forehead, eyes, nose, lips, eye brows, cheek and facial line. This characteristic area dividing is used as a standard area when generating control points using RBF on a mesh.

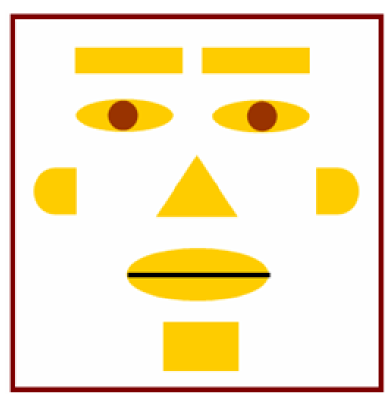

Fig. 4 Facial characteristic area

4.5 Nerve Net Structure

A human brain has a superior ability in recognizing complicated patterns based on huge amount of inputted information, and neural network of human body consists of 1 billion nerve cells function connected to each other in a row. Each nerve cell receives electrical chemical signals from 200 thousands other nerve cells.

These connection structures can be changed according to surrounding environmental stimulus. If a nerve cell receives correct signal at an input area, the nerve cell is activated and sends constraint or stimulus signals to another nerve cell.

A nerve net that modeled the information handling method that nerve cells use has a high level parallel handling characteristic compared to the series information handling method of general computers. A nerve net is made of neurons with layers that form net, and each neuron is recognized as a process factor that operates as a part of the whole.

A nerve net is distinguished from general statistic model by a factor called hidden unit. The following Table. 1 shows consisting factors and functions of a nerve net.

Table 1: Factors that consists a nerve net

Factor	Function
Hidden Unit	Receives combination of input variables and sends them to a corresponding variable
Input Layer	Consists of units that correspond to each input variable.
Hidden Layer	Consists of many units. Each hidden unit sends variables received from input layer to an output layer or another hidden layer.
Output Layer	Consists of units that correspond to target variable

The following Fig. 5 is a structure of a nerve net. Followings are nerve net techniques that construct a forecasting model using a nerve net.

- Multi Layer Perceptron: MLP
- Radial Basis Function: RBF

RBF is a kind of nerve nets and is well adopted to surface approximation problems. A basic form of RBF can be expressed as following equation. 1.

$$s(x)=p(x)+\sum_{i=1}^{N}\lambda_i\phi(|x-x_i|) \qquad x\in\Re^d \qquad (1)$$

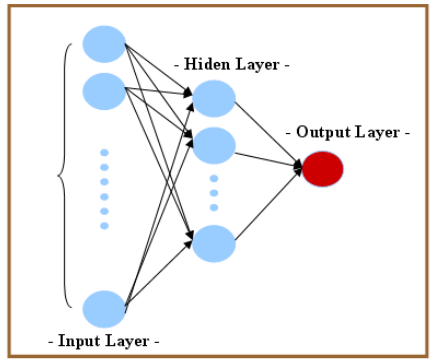

Fig. 5 Nerve net structure

RBF nerve structure has one hidden layer and it uses radical basis function Equation. 2 as a hidden layer connection function.

$$H_i = \exp\left(-\frac{(x_1-c_{1i})^2+(x_2-c_{2i})^2+\cdots+(x_k-c_{ki})^2}{r_i^2}\right) \qquad (2)$$

4.6 The Control Points Generation

To match 2D full face image with 3D generic model, control points are needed to match them according to face characteristic factors. Likewise, face characteristic factors should be actualized through control points. Face control points are the points that are located on a base when matching face model. They are located on a shape of a face, eyes, nose, and lips. When corresponding control points on a generic model are shifted using located 3D position of control points, other vertexes move naturally according to control points.

Corresponding vertexes on a face mesh are used directly as control points as it is shown in Fig. 6 very often in general system. However, this process uses control point position that needs a lot of effort and time since a mesh form can be distorted when generating or changing face model and it is hard to adjust control points according to an individual user's face form.

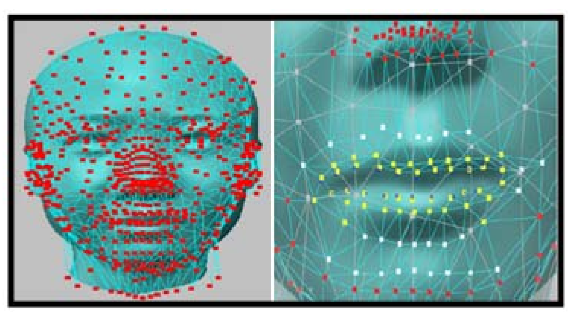

Fig. 6 Control points of generic face model

This study used expanded and changed RBF for control point generating and matching. Since a face form is complicated, symmetric and detailed, control points are divided into different groups on a 3D figure model based on face characteristic factors to be compatible to a face. Likewise, to reflect a basic form of a face maximally, basic form of control points is organized based on characteristic factors of each part of a face.

Table 2: Characteristic factors of each part of a face

Division	Characteristic Factors
Outline	Form of outlines
Eyes	General location, width and length
Eye Brows	General location, width
Face Shape	Face form, width and length, size of a chin
Nose	Width and length of a nose, size and height of ridge of a nose
Lips	Width and length, location of lips, upper lip, thickness of lips
Ears	Width and length
Chin Line	General location
Neck	Form of neck line

Therefore, users can shorten face model matching time and also can match and synthesize directly according to an individual's face form by seeing inputted full face image. The following Fig. 7 shows control point generation process.

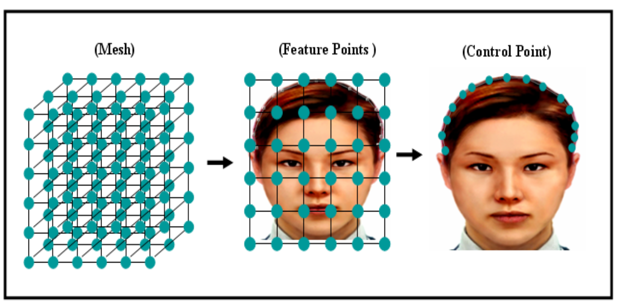

Fig. 7 Control point generation process

Table.3 shows the counted number of the final control points generated for each part of a face.

Table 3: The number of control points on each part of a face

Location	The number of control points
Forehead	15
Eyes	6 each on the left and right side
Eye Brows	3 each on the left and right side
Face Shape	10
Nose	7
Lips	7 each on the upper and lower lip
Ears	5 each on the left and right side
Neck	3 each on the left and right side

The following Fig. 8 display position of control points for face.

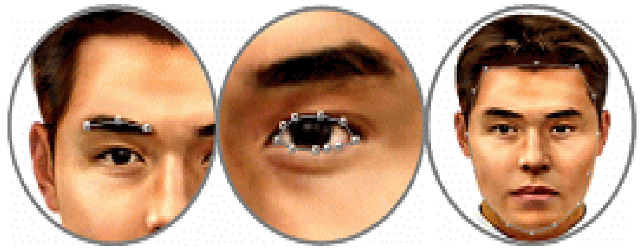

Fig. 8 Control points on eye brows, eye and face shape

In this paper, use technique that composes vector muscle editor, and controls vector muscle editor and control point and creates face model and changes using angle and direction etc. that do control point in face characteristic area range in produced 3D face model and achieves with muscle vector quantity, elastic force by muscle, elasticity direction, face muscle. Fig. 9 takes change of face skin mesh by size of muscle, angle and elastic force.

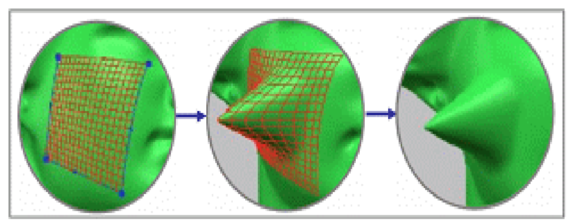

Fig. 9 The change of face skin mesh

Also, offer each 3D face model of two form of general-type and caricature type to express change of face skin mesh. The etymological and historical meanings of the word, caricature are various and vary with the character of each work. Originally it was derived from the Italian word, Caricature, and it means the picture which was drawn by exaggerating and comically a certain person's characteristic factor or a part of the specific person's body when drawing a certain person.

After distributing the 3D facial model changed on the specific part of the face by adjusting control points, we created the caricature with the various facial shapes according to each user's preference with control lines and control points, muscular model and muscle vector amount. And finally we succeeded in providing the 3D facial model which consists of such two types as the general type and the caricature type.

In the case of the general type, it is used for creating the 3D facial model and facial expression. In the caricature type, it is the facial model which can be adapted for the creation of caricature by varying more 3D.

Fig. 10 displays caricature generation step utilizing face image, standard model, control point and vector muscle editor.

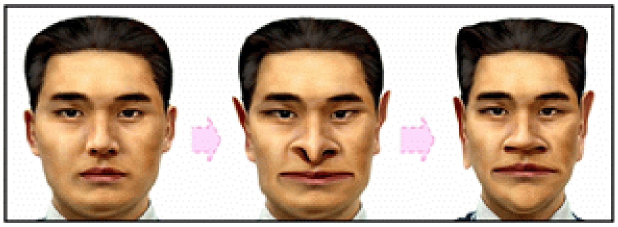

Fig. 10 Caricature generation steps

5. Realization and Consideration

This study used Pentium 4(1.8 GHz) and 512 MB memory and Visual C++, and OpenGL was used for rendering, and MFC was used for GUI. 2D full face image was captured from actual objects, movies, videos, snapshots, and images. Fig. 11 shows matching process of control points on lips and a figure of lips.

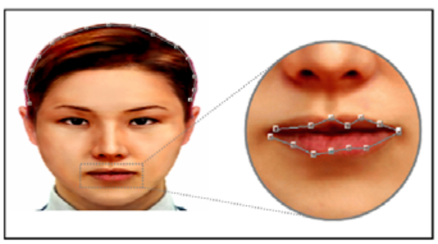

Fig. 11 matching process of control points

Fig. 12 is deformed face model of front side face image and caricature

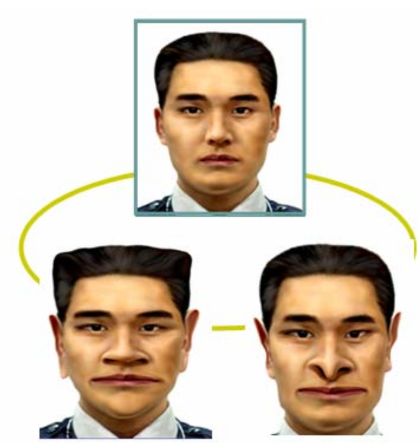

Fig. 12 2D facial image and 3D caricature model

The following Fig. 13 indicate the number of control points for eyes, nose, lips, and a whole face of a generic model, and simplified result model. Although there were partial differences between the face model matching using simplified face model, total matching time was 50% faster.

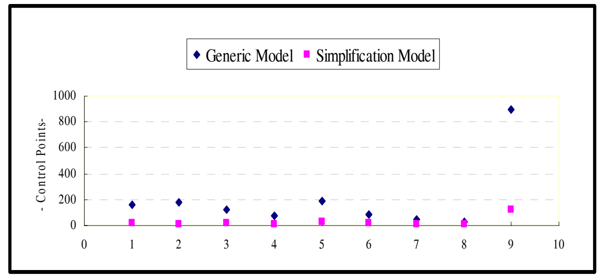

Fig. 13 Control points

Fig .14 is that represent guided process of face expression using kind /length of AU, muscle vector editor.

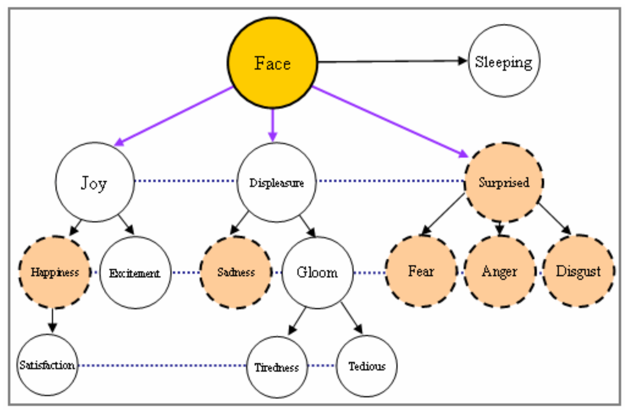

Fig. 14 Control points

6. Conclusion

This study made a special study on effective method that generates 3D individual face model and caricature automatically using 2D full face image. Using FFPs extracting method that uses RBF from 3D face mesh, face control point generating and matching method were suggested. Likewise, this study suggested 3D face model generating method activated by inputting one full face image and control point generating and matching method using RBF allowing users to express exact face model according to an each individual's face form easily and intuitively.

The direction of future study worked be desirable to focus on generating natural, realistic face form model and facial expression using emotion based facial expression synthesizing method based on anatomical structure. At the same time, by actualizing skin formation and face wrinkles that are close to real ones and changing lip figures when it talks accomplishing emotion based face animation that can interact to use them for a home network and as a user interface on Ubiquitous computing environment.

Reference

[1] D. Terzopoulos, L. Waters, "Analysis and Synthesis of Facial Image Sequences Using Physical and Anatomical Model", IEEE Transactions on Pattern Analysis and Machine Intelligence 15(6), pp. 569-579, 1993.

[2] F. I. Parke, "A Parameric Model for Human Faces", University of Utah. Salt Lake City, Utah, 1974.

[3] Frederic I. Parke, "Computer Generated Animation of Faces", MS thesis, Univ, Of Utah, Salt Lake City, December 1974.

[4] Frederic I. Parke, Keiths Waters, "Computer Facial Animation, A. K. Peters Wellesley, 1996.

[5] F. I. Parke, "Parameterized Models for Facial Animation," IEEE Computer Graphics, Vol. 2, No. 9, pp. 61-68, 1982.

[6] Hoppe. H., "Progressive Mesh", in SIG GRAPH'96 Proceedings, 1996.

[7] K. Waters, "A Muscle Model for Animating Three-Dimension Facial Expression," In Proceeding of SIGGRAPH 87, Vol. 21, No. 4, pp. 117-24, July 1987.

[8] K. Waters, D. Terzopoulos, "Analysis of Facial Images Using Physical and Anatomical Models," In IEEE Proceeding of ICCV conference, 1990.

[9] P. Ekman, W.V. Friesen, "Facial Action Coding System", Consulting Psychologists Press Inc, 577 College Avenue, 1978.

[10] Sobottka, K. Pitas, I, "Segmentation and tracking of faces in color images", Automatic Face and Gesture Recognition, 1996,

[11] T. Akimoto, Y. Suenaga, "3D Facial Model Creation Using Generic Model and Front and Side Views of Face", In IEICE TRANS, Vol. E75-D, No. 2, March 1992.

[12] Yuencheng Lee, Demetri Terzopoulos, Keith Waters, "Realistic Modeling for Facial Animation", SIGGRAPH 95, pp 55-62, 1995.

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