

A PLASTIC-VISCO-ELASTIC MODEL FOR WRINKLES IN FACIAL ANIMATION AND SKIN AGING

YIN WU, NADIA MAGNENAT THALMANN

MIRALab, CUI , University of Geneva

DANIEL THALMAN

Computer Graphics Lab (EPFL)

ABSTRACT

A model is described to simulate expressive wrinkles in 3D facial animation and skin aging. A plastic-visco-elastic skin surface is defined that can slide over an underlying layer. This layer constrains the skin surface by the spring force that simulates the connective fat tissue between skin and muscles. Muscle masks are constructed to characterize the muscular contractions that offer the tension to the skin and provide the facial movement. By choosing proper parameters for this physically based model, wrinkles in facial animation and skin aging are simulated through the elastic process assembled with visco and plastic units.

Keywords:

Physically Based Model, Elasticity, Plastic Unit, Visco Unit, Expressive Wrinkles, Facial Animation, Skin Aging.

1. Introduction

Human face modeling and animation is a very complex task because of the complex physical structure and also the dynamics that involves psychological and behavioral aspects. Natural and realistic facial animation is rather difficult. However, there have been many successful research effects in this area. One of the earliest approaches is the use of interpolation of a few expressive poses of a face. But the immense possible space of human face makes this approach extremely difficult in 3D facial animation. The limitation and restriction of the interpolation technique prompted Parke^{8,9} and others to develop parametric models for facial animation in order to obtain a fairly large range of facial actions by specifying a small set of appropriate parameters. However, the design of the parameter set depends on the personal facial topology and therefore a complete set of such parameters is difficult to obtain. Furthermore, the parametric model easily produces incorrect shape, unrealistic motion and other undesirable effects. The drawback of these earlier models makes researchers work on models whose parameters are based on the anatomy of the human face. Most simulations have used Facial Action Coding System(FACS)

developed by Ekman and Friesen³. In FACS, facial expression is specified in terms of Action Units (AU) which are the actions of a single muscle or a cluster of muscles. Platt and Badler¹⁰ developed a model based on underlying facial structure. Facial expressions are manipulated by applying forces to the interconnected elastic skin meshes through the muscle arcs. Waters¹⁵ designed a muscle model as geometric deformation operators which have vector properties and are independent of the underlying structure. Magnenat-Thalmann et al.⁷ have provided an alternative approach to simulate muscle action by using a procedure called an Abstract Muscle Action (AMA). An AMA is a specialized routine which simulates the specific action of a face muscle.

The purely geometric facial models ignore many complexities of human facial tissue. It is difficult to mimic many of the subtleties of facial tissue deformation such as wrinkles during animation. This suggests using a physically based approach. Terzopoulos and Waters¹¹ proposed a physically based model using three layered deformable lattice structure for facial tissues. The three layers correspond to the skin, the subcutaneous fatty tissue, and the muscle. This model offers realistic results using point to point physically based method to compute deformation. Simulating deformation using three dimensional lattices can result in a large number of discrete nodes and is very time consuming. However, elastic surface simulated as two dimensional lattices requires fewer discrete nodes and also produces useful results while taking not so much CPU time.

Wrinkles are important for understanding and interpreting facial expression and also one major sign for recognizing age. There are two types of wrinkles: expressive wrinkles and micro wrinkles. Expressive wrinkles appear during facial expression at all age but become permanently visible over time. An older face has more wrinkles and the wrinkles are more pronounced. The change of skin is mainly attributed to the change of the elastic and collagen fiber. The elastic fibers of skin are stretched and make the skin less elastic, the collagen fibers gather in sheaves and make the skin less homogenous, especially at those points affected by much stress. The present system does not provide the facilities or means to generate expressive wrinkles which gradually become permanently visible. Viaud and Yohio¹⁴ have presented a hybrid model for the formation of wrinkles, where bulges are modeled as spline segments. In our model, expressive wrinkles will be considered with a physically based method.

In this paper, we will present a plastic-visco-elastic model for wrinkle generation. Viscosity and plasticity are two of the canonical inelastic properties. Viscosity manifests itself as a fluid like flow and a time dependent deformation. Plasticity causes the irreversible atom dislocation and permanent deformation above certain force limit. Combining them together simulates the inelasticity that produces atom dislocation of skin surface depending on the whole history of facial animation. The skin surface is represented as two dimensional lattices of three dimensional points. Muscle masks are constructed according to the anatomy that characterize the facial movement. Connective fat tissue between the skin and muscle is simulated as hookian spring force constraints acting between points. With the elastic process, the simulated skin surface is deformed with the muscle contraction and produces expressive wrinkles. During the elastic process, a visco-plastic-elastic process is applied to update the rest metric measure, the rest curvature measures of the skin surface and the rest length of connective tissue spring.

In section 2, we will describe the histology of facial tissues and their simulations in our model. Section 3 gives the details of the plastic-visco-elastic process which physically simulates skin

behavior in facial animation and aging process. Section 4 discusses our implementation and demonstrates some examples, and Section 5 presents our conclusion.

2. Simplified Facial Model

The major components in anatomy that are responsible for the appearance and movement of the face are bones, muscles, skin and connective fat tissue. Until now, there does not exist a model which is based on the complete description of a head's anatomy because of its complexity as well as the compromise between interactive speed and realism. In this paper, we attempt to create a face model based on the simplified structure of the head's anatomy, which can also produce some subtleties of facial deformation such as wrinkles. Bones are ignored in our model; instead, the skin surface defines the geometry of the face. The muscle and fat layers are also located according to the skin surface. Fig 1. shows the structure of our simplified facial model.

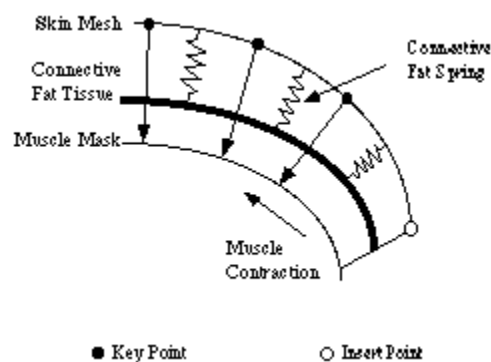


Fig 1. Simplified Facial Structure

2.1. Skin Mesh

Human skin has a layered structure consisting of the dermis and epidermis. The dermis is primarily responsible for the mechanical properties of the skin and makes skin have a plastic-visco-elastic behavior. Skin is almost incompressible except for a very limited amount offered by existing micro furrow. Under low strain, dermal tissue offers very low resistance to elongation but under great stress the resistance to stretch is much more marked⁴. This yields a simulated multi-phasic stress-strain curve (Fig 2.). The elasticity of skin changes with age, the skin can not recover to its initial shape over time because of its viscosity and plasticity and thus forms permanent wrinkles.

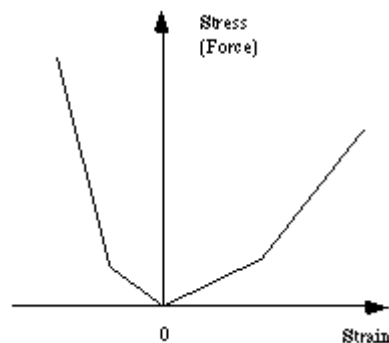


Fig 2. Simulated Stress-Strain Curve of Skin

The skin surface is the only facial tissue that is purely physically based in our model. The facial surface is discretized using the finite difference technique and is represented as an MxN rectangle meshes of 3D points at regular intervals in material coordinates (Plate 1). The skin layer takes the external shape of the face, and is described as a plastic-visco-elastic deformable surface. The detailed description of its deformation will be presented in Section 3.

2.2. Muscle Mask

Muscles are responsible in determining and providing the facial movements that create facial expressions. Muscles are defined for each region of interest in a face. All facial muscles except orbicularis oris are attached to underlying bone with the other end embedded into the soft tissue of the skin. Though muscles have a large variety of sizes, shapes and complexity, they are essentially bundles of fibers operating in unison⁵.

Muscles are inside the skin layer and do not directly reflect the facial appearance. In this case, the exact shapes of muscles may be ignored in our model for simplification. Revolution surfaces, such as cylinders, cones, or ellipsoids are employed to represent the muscle surfaces with parametric description. Sets of key points are defined on the skin surface and their inward offsets are specified. Each set briefly describes the shape of a muscle and its inward offset indicates the distance between the skin and this muscle. With these data, the revolution surface of the muscle can be created. In this situation, the muscle contraction can be simulated by adjusting the geometry parameters of the revolution surface regularly. The different types of muscle contraction are defined by tuning different parameters.

The facial skin is animated by the tension caused by muscle actions through insert points (where muscle is embedded into skin). The insert points are specified on skin for each muscle according to the anatomic knowledge. They are projected to the muscle surface to get their corresponding muscle connection position (See Fig 1.). The insert point pairs in the muscle and skin are therefore constructed. We call this simplified muscle structure as a muscle mask because it is not a precise description of muscle but offers enough information to characterize the muscle action. In fact, a muscle mask includes a set of geometry parameters, a set of insert point pairs and the muscle contraction type. During the muscle action, tension to the skin from muscle is simulated by spring force between each insert point pair. The force applied to the skin insert point by contraction is to be:

$$\vec{f}_{muscle} = -k_{muscle}(\|\vec{r} - \vec{r}_{st}\| - \|\vec{r}^0 - \vec{r}_{st}^0\|)(\vec{r} - \vec{r}_{st}) \quad (1)$$

where $\vec{r}^0$, $\vec{r}$ are respectively the initial and current position of skin insert point and $\vec{r}_{st}^0$, $\vec{r}_{st}$ are those of corresponding muscle point, k_{muscle} is the spring constant. The insert points of skin are closely connected to the corresponding muscle points. The spring constant should be big enough to let skin insert point "stick" to the muscle during muscle contraction and therefore pull the whole skin surface.

Facial expression is defined as a set of muscle mask actions. A complete facial expression procedure includes different phases such as attack, decay, sustain and release². These phases

differ in their motion characteristic. This suggests us to separate the muscle movement corresponding to different phases. Fig 3. shows the velocity pattern during muscle action. The muscle contraction period takes a bit longer time than the release period and there is a short sustain period between them. After the action, the muscle returns to its original position. In our method, the muscle contraction is implemented using kinematics.

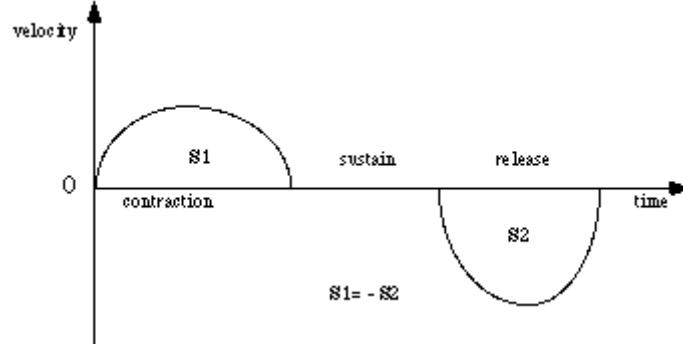


Fig 3. Muscle Action Velocity

2.3. Connective Fat Tissues

Underneath the skin and above the muscle there is a layer of subcutaneous fat tissue which allows the skin to slide over the underling layer with some constraints. In our model, this layer is simply specified as a thickness between the skin and muscles. Every skin point takes a step inward to the facial surface and achieves its connective points in fat layer (See Fig 1.). The inward step length is the thickness of fat tissue at that region. The fat point keeps still, the constraint between skin and fat tissue points is implemented using hookian spring force:

$$\vec{f}_o = -k_o \left(\left\| \vec{r} - \vec{r}_o^b \right\| - \left\| \vec{r}^b - \vec{r}_o^b \right\| \right) \frac{\vec{r} - \vec{r}_o^b}{\left\| \vec{r} - \vec{r}_o^b \right\|} \quad (2)$$

where $\vec{r}^b$, $\vec{r}$ is respectively the initial and current position of skin point, $\vec{r}_o^b$ is position of connective fat point, and k_o is the spring constant. The spring force between skin and connective tissue is much weaker than that for insert points, thus these points can more freely slide.

The connective fat tissue also changes due to age, it becomes thicker in some places and thinner in other places. The spring force also becomes weaker. To simulate these aging effects, the plastic-visco-elastic process will be applied to the length of constraint spring L , $L(t) = \left\| \vec{r} - \vec{r}_o^b \right\|$. We will describe this process in the following section.

3. Plastic-Visco-Elastic Model

We first describe here an elastic process which simulates facial animation without permanent deformation. In addition, visco and plastic units are used to simulate a more realistic facial animation and skin aging. An ideal elastic model stores potential energy during deformation and releases energy entirely as it recovers original shape completely. Unfortunately, facial skin is not in such an ideal case. A human face really tells the flowing time of life with wrinkles caused by inelastic deformation. An inelastic deformation occurs to real material when forces exceed some

limit and produces unrecoverable deformation. We also present here a model assembling the elasticity, viscosity and plasticity to simulate skin's inelasticity.

3.1. Elastic Process

The deformable surface such as skin can be described by elastic model in an ideal condition. One of the equations governing the motion of a deformable surface is based on the variational principle of mechanics in Lagrange's form as follows:

$$\mu \frac{\partial^2 \vec{r}}{\partial t^2} + \gamma \frac{\partial \vec{r}}{\partial t} + \frac{\delta \varepsilon(\vec{r})}{\delta \vec{r}} = \vec{f} \quad (3)$$

where t is time, $\vec{r}(u_1, u_2, t)$ is the surface position, $\vec{f}(u_1, u_2, t)$ is the external applied force, μ is the surface mass density and γ is the surface damping density. $\varepsilon(r)$ is the total elastic energy, a scalar valued functional, and its variational derivative $\delta \varepsilon(\vec{r}) / \delta \vec{r}$ represents the elastic force at each point on the surface.

One reasonable choice of strain energy for an elastic deformable surface in space^{1,13} is to be:

$$\varepsilon(\vec{r}) = \int_{\Omega} \sum_{i=1}^2 (\eta_u (G_u - G_u^0)^2 + \xi_u (B_u - B_u^0)^2 + \varphi_u \cdot E_u^2) du_1 du_2 \quad (4)$$

where G_u , G_u^0 is 2×2 symmetric current metric tensor and rest metric tensor respectively, B_u and B_u^0 are the current curvature and the rest curvature, E_u is the function to measure the change of metric tensor. η_u , ξ_u and φ_u are weighting functions. η_u controls the shrinking or growing deformation of the surface, ξ_u controls the flattening or curving deformation of the surface and φ_u controls the speed of deformation of the surface.

The variational derivative of this expression can be approximated by the equation

$$\frac{\partial \varepsilon(\vec{r})}{\partial \vec{r}} = \sum_{i=1}^2 - \frac{\partial}{\partial u_i} ((\eta_u (G_u - G_u^0) + \varphi_u \cdot E_u) \frac{\partial \vec{r}}{\partial u_i}) + \frac{\partial^2}{\partial u_i \partial u_i} (\xi_u (B_u - B_u^0) \frac{\partial^2 \vec{r}}{\partial u_i \partial u_i}) \quad (5)$$

In our skin model, external force $\vec{f}$ in equation (3) is set as $\vec{f}_{mask}$ for the active insert points. (The insert points that their muscle mask is currently in action), and $\vec{f}$ is set as $\vec{f}_0$ for all other points that include in the affected region of current muscle actions. Points outside the muscle action region are not considered in the equation.

Skin is a very soft surface and exhibits low resistance to bending; therefore, the weighting factors for the curvature tensor are relatively small. On the other side, the weighting factors for the metric tensor are much bigger. To satisfy the multi-phasic stress and strain characteristic of skin described in Fig 2., the weighting function η_u is defined in multi phase according to the simulated stress-strain curve.

3.2. Visco and Plastic Units

A purely elastic model has only the memory of its initial shape, and whenever the applied force is released, the elastic surface returns to its original shape. This is the case of young facial skin: expressive wrinkles appear during facial action and disappear after. But facial skin is not always in such an ideal case, inelastic deformation will happen and expressive wrinkles will become permanently visible. Terzopoulos¹² proposed an approach to simulate inelastic deformation of visco-elasticity, plasticity and fracture with a model based on the reference component which describes the natural shape.

Facial skin is not only visco-elastic but also plastic. It records all the passed time for a person and gradually produces an aged face with wrinkles. In our method, the natural shape is described by rest geometric measures used in elastic model. A plastic-visco-elastic process, which assembles elasticity, viscosity and plasticity together, is applied to the geometric measures of the surface and changes the rest measure values. The obtained changes from this inelastic process is dynamically fed back to the elastic model described above. Therefore, the current deformation is calculated by the elastic process but generates inelastic deformation.

Suppose a geometric shape measure M , $M(t)$ is the current shape measure at time t , $M^0(t)$ is the rest shape measure at time t (Rest shape is the restored shape when internal deformation force is zero if external forces are released at moment t). Suppose $e(t)$ is the strain of a measure which is set as $e(t) = M(t) - M^0(t)$. For an ideal elastic model, the strain stress relation is to be: $f = k \cdot e(t)$ and there is no change for the rest shape and therefore satisfies $M^0(t) = M^0(0)$

For an ideal visco unit, rate of increase in strain of the spring is proportional to applied force: $f = k \cdot de/dt$. It stores no deformation energy and has no resilience. Visco-elasticity is a generalization of elasticity and viscosity. The instantaneous restoring force is a function of the entire history of the deformation. A simple case of visco-elastic model is the Maxwell model which is used also by Terzopoulos¹² to simulate inelasticity. Applying the Maxwell model to measure M , the rest measure can be obtained from equation:

$$\frac{dM^0(t)}{dt} = k \cdot e(t) \quad (6)$$

An ideal plastic unit is capable of arbitrary elongation or contraction as soon as the applied force exceeds a yield force. There is no definite relationship between displacement and applied force. The rest shape just takes the currently shape : $M^0(t) = M(t)$.

Plastic-visco-elasticity is a generalization of elasticity, viscosity and plasticity. It is characterized by time dependent deformation under certain force and the arbitrary deformations beyond some force limit. The instantaneous restoring force is related to the entire history of the deformations and decreases after exceeding the force limit of plasticity. Here we simply connect visco-elastic unit and plastic unit with weighting factors to form a general formula to calculate the rest shape measures. A time discrete representation of this formula can be :

$$M^0(t + \Delta t) = \kappa_{vis} M^0(t) + \kappa_{vis} (M(t) - M^0(t)) \Delta t + \kappa_{pl} M(t) \quad (7)$$

where $\kappa_{elastic}$, κ_{visco} and $\kappa_{plastic}$ are weighting factors for elasticity, viscosity and plasticity, Δt is the time interval. The weighting factors are small and positive (no more than 1.0) in order to guarantee convergence. Choosing proper values for this factor, the model can simulate various inelastic behaviors.

To simulate inelastic skin deformation, the above process is applied to the metric and curvature tensor measures of the skin surface. This process is also applied to the connective fat tissue spring to simulate the changing of fat tissue. The formula are represented as:

$$G_u^0(t + \Delta t) = \kappa_{elastic} \cdot G_u^0(t) + \kappa_{visco} \cdot (G_u(t) - G_u^0(t)) \Delta t + \kappa_{plastic} \cdot G_u(t) \quad (8)$$

$$B_u^0(t + \Delta t) = \kappa_{elastic} \cdot B_u^0(t) + \kappa_{visco} \cdot (B_u(t) - B_u^0(t)) \Delta t + \kappa_{plastic} \cdot B_u(t) \quad (9)$$

$$L_u^0(t + \Delta t) = \kappa_{elastic} \cdot L_u^0(t) + \kappa_{visco} \cdot (L_u(t) - L_u^0(t)) \Delta t + \kappa_{plastic} \cdot L_u(t) \quad (10)$$

where L_u^0 , L_u is the rest and current spring length of the connective tissue.

We use this plastic-visco-elastic model to simulate desired facial animation by tuning appropriate parameters. For the skin case, the plasticity does not exist within a range of deformation, it happens only when the deformation is beyond some threshold. The plasticity does not occur to all points at same time, it occurs first at those points which are much affected. The plasticity weighting factor $\kappa_{plastic}$ is defined to be:

$$\kappa_{plastic} = \begin{cases} 1 & |M(t) - M^0(0)| > T \\ 0 & |M(t) - M^0(0)| \leq T \end{cases} \quad (11)$$

where M represents any of the three measure at a point, T is the threshold above which plasticity happens. The permanent expressive wrinkles become more and more apparent by repeating this inelastic facial animation.

4. Implementation and results

Our model for wrinkle generation in facial animation and aging is implemented in three steps. The first step is to obtain the skin surface and define anatomic information. The second step is to construct the other facial components and the connections between them. The plastic-visco-elastic process is implemented at the last step.

First, the facial skin mesh is obtained using finite discrete method. The key points and their inward offsets, which describe the muscle shapes briefly, are set interactively. The regions for muscle actions, the insert points of each muscle mask are also set interactively according to anatomic knowledge⁶.

In the second step, muscle mask surfaces are constructed according to the key points and their inward offsets. The insert points in skin are projected to the muscle mask surface to get their

connecting points in the muscle. The connective fat tissue points are simply obtained by an offset inward from the skin points.

The last step is the most important part of our model: animating the skin surface by the plastic-visco-elastic process. A facial expression is defined as one or more muscle mask actions and applied to the affected region. A muscle action is defined as intensity of contraction or elongation to muscle mask within a duration. Muscle movement is implemented by kinematics obeying the velocity description in Fig 3. It offers tension to skin through insert points. For a young face, only elastic process happens, $k_{elastic}$, $k_{viscous}$ are set to zero and $k_{plastic}$ is set to 1.0. During the facial action, wrinkles appear and the skin surface returns to initial shape after action. To simulate the aging process, proper values of $k_{elastic}$, $k_{viscous}$ should be chosen as well as the threshold for plasticity. With the inelastic process, wrinkles can no more disappear after action, it becomes permanent. Age's effect on wrinkles can be considered in two way factors: the weighting factor $k_{plastic}$ and the repetition of inelastic process. With bigger $k_{plastic}$, the deformation is apparent after one facial animation. But it is more natural to repeat the inelastic process with smaller $k_{plastic}$ and forms the permanent expressive wrinkles gradually.

By now, our tests to the model are only limited to the frontal region. Plate 2 (a) shows a neutral face, Plate 2 (b), (c), (d) show three action units in forehead, "raise inner eyebrow," "raise outer eyebrow," "squeeze eyebrow." Combined with these action units, facial expressions such as surprise, sadness can be produced on the upper face. Plate 3 (a) shows emotion surprise in different muscle action phases: contraction, sustain and release. The surprise emotion is composed of two action units, "raise up inner eyebrow" and "raise up outer eyebrow". Plate 3 (b) shows sequence of faces with sadness. This emotion is composed of three action units, "raise up inner eyebrow", "raise down outer eyebrow" and "squeeze eyebrow". In Plate 4, wrinkles in the forehead resulted from aging process are presented. With some positive value to $k_{plastic}$, the plasticity occurs when the deformation goes beyond the threshold. The parts of surface with larger deformation, such as the parts of wrinkles, are first affected by the plasticity. Thus the skin surface deforms permanently with some wrinkles after the facial action. Plate 4 (a), (b) show expressive wrinkles resulted from raising and squeezing eyebrows respectively.

5. Conclusion

In this paper, we present a physically based model to simulate the generation of wrinkles in facial animation and aging process. Skin deformation is represented by the plastic-visco-elastic model. Muscle masks and connective fat tissues are specified as simplified tissue structure. The system produces expressive wrinkles with the physically based model. Expressive wrinkles, micro wrinkles, texture and color and even the geometry of face change over time and are signs of age. Great efforts should be made to simulate a realistic aging process.

6. Acknowledgment

The authors would like to thank Prem Kalra, Ying Yang and Laurent Moccozet for useful suggestions and valuable discussion. This research was supported by the Swiss National Research Foundation.

7. Reference

1. Carignan M, Yang Y, Magnenat-Thalmann N, Thalmann D (1992) "Dressing Animated Synthetic Actors with Complex Deformable Clothes," *Proc. of SIGGRAPH' 92*, pp. 99-104.
 2. Ekman P, Friesen WV (1978), *Facial Action Coding System, Investigator's Guide Part2*, Consulting Psychologists Press Inc.
 3. Ekman P, Friesen WV (1969), *The Repertoire of Nonverbal Behavior: Categories, Origins, Usage, and Coding, Semiotical*.
 4. Elden H.R (1977), *Biophysical Properties of Skin*, Ed. Wiley-Interscience, New York.
 5. Kalra P, Mangili A , Magnenat-Thalmann N, Thalmann D (1992), "Simulation of Facial Muscle Based on Free Form Deformation," *Proc Eurographics' 92, Computer Graphics Form*, **Vol. 2**, No. 3, pp. 59-69.
 6. Kalra P, Mangili A, Magnenat-Thalmann N, Thalmann D (1991) "SMILE: A Multilayered Facial Animation System," *Proc IFIP WG 5.10*, Tokyo, Japan (Ed Kunni Tosiyasu L) pp. 189-198.
 7. Magnenat-Thalmann N, Primeau E, Thalmann D (1988), "Abstract Muscle Action Procedures for Human Face Animation," *The Visual Computer*, **Vol. 3**, No. 5, pp. 290-297.
 8. Parke FI(1974), "A Parametric Model for Human Faces," *Ph. D Dissertation*, University of Utah.
 9. Parke FI(1982), "Parametric Model for Facial Animation," *IEEE Computer Graphics and Applications*, **Vol. 2**, No. 9, pp. 61-68.
 10. Platt S, Badler N(1981), "Animating Facial Expressions," *Proc SIGGRAPH'81 Computer Graphics*, **Vol. 15**, No. 3, pp. 245-252.
 11. Terzopoulos D, Waters K(1990), "Physically-Based Facial Modeling and Animation", *Journal of Visualization and Computer Animation*, **Vol. 1**, pp. 73-80,1990.
 12. Terzopoulos D, Fleisher K (1988), "Modeling Inelastic Deformation: Viscoelasticity, Plasticity, Fracture," *Computer Graphics, Proc. SIGGRAPH'88*, Vol. 22, No. 4. pp. 269-278.
 13. Terzopoulos D, Platt S(1987), "Elastically Deformable Models," *Computer Graphics, Proc. SIGGRAPH'87*, **Vol. 21**, No. 4, pp.205-214.
 14. Viaud M, Yahia H(1992), "Facial Animation with Wrinkles," *3rd Workshop on Animation, Eurographics'92*, Cambrige.
 15. Waters K(1987), "A Muscle Model for Animating Three Dimensional Facial Expression," *Proc SIGGRAPH'87, Computer Graphics*, **Vol.21**, No. 4, pp. 123-128.
-

