Simulation of Static and Dynamic Wrinkles of Skin

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Abstract

Wrinkles are an extremely important contribution for enhancing the realism of human figure models. In this paper, we present an approach to generate static and dynamic wrinkles on human skin. For the static model, we consider micro and macro structures of the skin surface geometry. For the wrinkle dynamics, an approach using a biomechanical skin model is employed. The tile texture patterns in the micro structure of skin surface are created using planar Delaunay triangulation. Functions of barycentric coordinates are applied to simulate the curved ridges. The visible (macro) flexure lines which may form wrinkles are predefined edges on the micro structure. These lines act as constraints for the hierarchical triangulation process. Furtheremore, the dynamics of expressive wrinkles --controlling their depth and fold-- is modeled according to the principal strain of the deformed skin surface. Bump texture mapping is used for skin rendering.

Keywords: Wrinkle, Skin, Texture, Animation.

1. Introduction

The modeling and rendering of skin is very important for human figure modeling because it greatly enhances the realism of the model's animation. The skin is a continuous, protective sheet that envelops the entire body and is attached to the deeper structures by way of connecting tissues [1]. This is the outer most visible layer of the body. At a number of places, skin adheres closely to its underlying tissue, elsewhere it glides rather freely, and at some places it becomes checked and puckered into wrinkles. Skin changes with age, more lines and wrinkles emerge and become pronounced with time. A close look at the skin surface shows a well defined geometric structure which influences the general appearance and texture of the skin. The lines, creases and wrinkles of different shapes and configurations present all over the skin constitute major elements affecting its visual appearance.

In addition to their visual effects, wrinkles indicate the age of a person, and expressive wrinkles act as an important factor for understanding and interpreting facial expressions. Also, the unique patterns of palm lines are used for psychophysical analysis and interpretation.

Many research efforts have been undertaken for generating textures for animal as well as human skin. Miller [2] generated realistic snake skin using bump mapping and color mapping techniques. Kaufman et al. [3] simulate reptile skin pattern by using the texture synthesis language, which provides tools for defining and generating regular and random texture patterns. Nahas et al. [4] proposed a method for obtaining the skin texture by recording the data of human face. Ishii et al. [5] proposed a geometric model of micro wrinkles which uses a curved surface on a based polygon for expressing folds and ridges. The method employs a hierarchical Voronoi division process for creating skin texture patterns.

There have been a few efforts for the dynamic model of wrinkles. Viaud et al. [6] have presented a geometric hybrid model for the formation of expressive wrinkles, where bulges are modeled as spline segments. Terzopoulos and Waters [7] proposed a physically based model using a three layered deformable lattice structure for facial tissues which produce some of the expressive wrinkles during the skin deformation. A simplified facial model with a two dimensional lattices skin surface is proposed to simulate expressive wrinkles in facial animation and the aging process [8]. However, the present models do not provide a system to generate different kind of wrinkles with animation. Texture mapping offers a good simulation of static wrinkles, but it is difficult to mimic the wrinkle deformation during animation by a purely geometric model with texture mapping. A physically based approach can offer a better simulation of wrinkle formation, but if it requires geometrical modeling of all the wrinkles it may be expensive. Therefore, in our model, the deformation of skin is decided by a biomechanical model while the rendering nuance is reflected by a bump texture. The influence of the skin deformation to wrinkle formation is affected by controlling their bulge depth according to the principal strain at the skin surface corresponding to the wrinkle points.

The paper is organized as follows. In Section 2, we briefly give the physiology of wrinkles which yields the foundation for the model and simulation. Section 3 describes the static model of wrinkles. In Section 4, the dynamic model of wrinkles is presented based on a biomechanical skin model for deformation of the skin. Finally, we give some concluding remarks in Section 5.

2. Physiology of Wrinkles

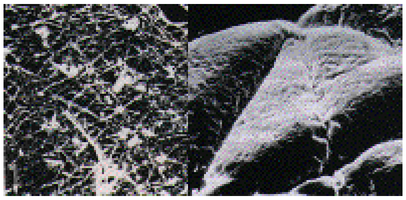
Though we do not intend to model and simulate the true biological forms and functions of human skin, we consider it is important to study and analyse the physiology to determine the characteristics and attributes which are necessary for realistic modeling and simulation. Skin consists of three layers: the epidermis, dermis and hypodermis. Various kinds of lines or wrinkles on the skin come from the different combined effects of these layers.

2.1 Skin Surface

The outer skin surface consists of a geometrical structure which manifests the form of visible skin. This may look different for different parts of the body depending on its characteristics and how it is attached to the body. However, skin when observed from a close-up depicts a micro structure which is common for most parts on the body. This micro structure has a rather well defined geometrical shape and form. The visible lines, patterns, creases and folds constitute a distinct structure which may be specific to one part; this structure we refer to as a macro structure. In the following sub-sections we present the characteristic features of the micro and macro structures of the skin surface which have been considered for the models.

2.1.1 Micro Structure

The micro structure of the skin surface, determined by the epidermis resembles a pattern with a net-like structure. This structure consists of polygonal forms, most often triangles [9]. The edges of the triangular forms define the location of furrows or micro lines, and the curved surface surrounded by furrows define the ridges. The micro lines can become the location for the macro lines or wrinkles. They have a fine layered structure and are modified locally according to the direction and frequency of movements. Though micro lines have various patterns and different orientation preferences at different body sites, they still appear to be a simple basic pattern in most skin regions. The vertical direction of the micro lines is inward (toward the dermis), and the principal plane of triangular form is exteriorly curved. Figure 1 shows the real skin's geometrical structure [10, 11]. The global configuration of furrows and ridges determines the general appearance of the skin. Figure 1 (a) shows the net-like structure of the skin surface and (b) shows the magnified view with triangular structures.



(a) (b)

Figure 1: Real Skin.

2.1.2 Macro Structure

The macro structure defines the characteristic features of skin associated to a region of the body. For example, the macro structure defines the location and pattern of the lines on the palm and the sole, the visible deep flexure lines on other parts, and the potential wrinkle lines which may appear due to age or movement (expressions on the face). Thus, the macro structure gives information at the macro level to characterize skin for a region of the body. The macro lines form deeper and wider furrows and creases as compared to the micro lines.

2.2 Wrinkles

There are two major factors to describe the characteristics of wrinkles: the furrow (macro) and the bulge. The furrow defines the location of the curved line of a wrinkle, and the bulge gives the shape of its curved surface. The location and formation of the wrinkle lines are reflected at the macro structure of the skin.

Two types of wrinkles can be considered: expressive wrinkles (particularly for the face), and wrinkles due to age. Expressive wrinkles appear on the face during expressions at all ages and may become permanently visible over time. These wrinkles are formed due to the deformations of the dermis and the hypodermis layers of skin as a result of muscle contraction. The position of the wrinkle is vertical to the muscle movement direction, and the height of its bulge depends on the amplitude of the muscle contraction. As skin changes with age, wrinkles appear and become permanent and more pronounced. The skin cells regenerate themselves at slower rate with age, and tend to favor a specific orientation, thus creating wrinkles. In this paper we have considered primarily the expressive wrinkles. Figure 2 presents an example of expressive wrinkles on a real face [12].

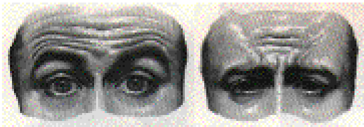


Figure 2: Skin with Expressive Wrinkles.

3. Wrinkle Model

According to the skin characterisitics described in the previous sections, we classify two types of wrinkle models: static and dynamic. For the static model we define the shape and form of the wrinkles or other macro lines as geometrical structures on the planar skin surface which do not change with time. The dynamic model accounts for the changes in the form and shape over time. The following sections present the static and dynamic models.

3.1 Static Model

The physiology of wrinkles demonstrates that one needs to consider the micro and macro structure of the skin surface for modeling the geometrical features of the skin texture. For the static model the location and the form of the wrinkles or other lines are established on the structure of the skin surface. In the following section we describe our method of modeling the geometrical features in the micro and macro structure of the skin.

3.1.1. Micro Structure

The micro structure appears to be a layered net-structure. A close look at this structure in Figure 1 shows a triangular mesh pattern with several layers of furrows. This suggests applying a hierarchical triangulation to a skin region to obtain geometrical patterns for the micro structure. A ridge surface is defined as a function on the triangle base.

Furrow Pattern

The furrow pattern is generated by a Delaunay triangulation [13] for each skin region. Given the texture image boundary corresponding to the 3D object, the Delaunay triangulation divides the 2D texture image plane into a triangle mesh where the edges represent the furrows. By imposing some conditions such as edge size or angle constraints, different kinds of triangle mesh can be produced.

Ridge Shape

The ridge shape is defined on the triangle base. The height of the ridge increases while going from the egde to the centre of the triangle. Figure 3 shows a ridge shape model: *C* is the centre of the triangle, *P* is any point inside the triangle, *H(C)* and *H(P)* are their corresponding ridge surface heights.

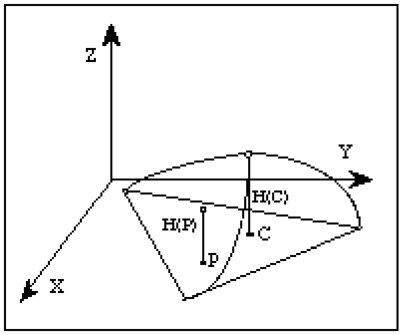


Figure 3: Ridge Shape Model

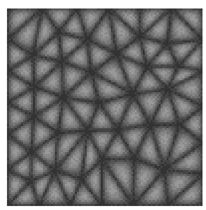
The basic shape function of micro wrinkles can be represented in the general form as

$$H(P) = H(C) \cdot f(P) \quad (1)$$

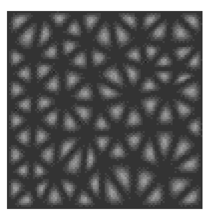
f(P) is a shape function whose value is zero at the edge, and reaches unity at the centre. One simple example of such a function is

$$f(P(u,v,w)) = K(u.v.w)^{n} \quad (2)$$

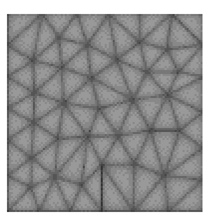
where *u*, *v*, *w* are the barycentric coordinates of the point *P* inside the ridge base triangle, and *n* is a positive exponent. By adjusting the exponent value, sharper or flater bulges can be obtained. Figure 4 shows several examples with different parameters.



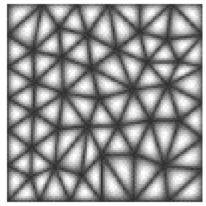
(a): H(C)=0.4, n=1



(b): H(C)=0.4, n=3



(c): H(C)=0.4, n=0.25



(d): H(C)=0.8, n=1

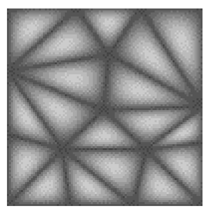
Figure 4: Examples of Ridge Function Parameters.

Hierarchical Structure

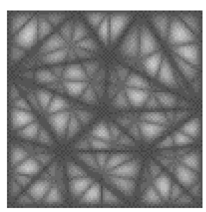
Micro furrows present a hierarchical structure: there are samller ridges inside a small ridge. Thus, the Delaunay triangulation is repeated until the desired layer is achieved. Figure 5 shows triangle patterns with different levels. The shape function of the hierarchical structure can be recursively defined as,

$$H(0,P) = H(C).\, f(P)$$
$$H(r,P) = H(r-1,P) - a \cdot H(r-1,P)(1 - f(P,r)) \quad (3)$$

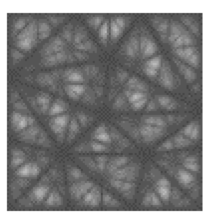
where *H(r,P)* is height of point *P* with level *r* and *f(P,r)* is the corresponding shape function.



(a): level (r) = 1



(b): level (r) = 2



(c): level (r) = 3

Figure 5: Different Levels

Figure 6 shows examples of micro structure rendering using bump texture mapping. The effect of bump mapping is slightly exagerated to illustrate the underlying structure.

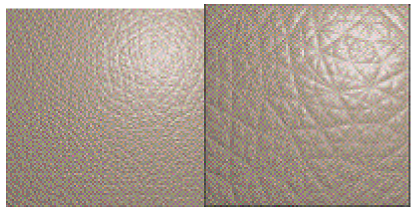


Figure 6: Examples of Micro Structure Rendering

3.1.2. Macro Structure

Furrows Pattern

In addition to micro furrows all over the body, macro furrows such as palms lines and potential flexure lines of wrinkles exist in some skin region. These are modeled as the macro structure. An array of points on the skin model surface is defined interactively to locate the position of the macro furrows. A B-spline curve is then obtained by interpolation or approximation through the defined points. This 3D curve is mapped to a poly line on the 2D texure image using cylinderical or planar projection. As the macro lines are always along the furrows of micro lines, a constraint Delaunay triangulation is employed to generate the skin pattern such that the edges on the micro structure are retained. For more natural visual effects, a random deviation is added to the furrow. Figure 7 shows examples of triangulation patterns with macro lines.

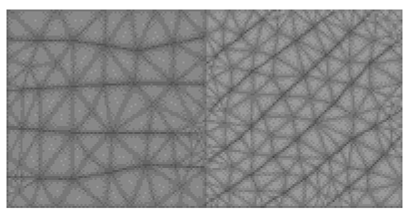


Figure 7: Constraint Triangulation Patterns for Macro Lines

Bulge Shape

Macro lines bulge between the furrow lines. The bulge region can be defined in the 2D texture image space (S,T) as a quadrilateral mesh along the polyline (see Figure 8). The bandsize -- defined as an offset-- of the wrinkle gives its neighboring points along the bulge direction. We use bilinear interpolation parameters (u,v) in each quadrilateral to define the bulge function.

With B_{00}, B_{01}, $B_{10}$and B_{11}as the four vertices of a quadrilateral, for any point P inside the quadrilateral, we have [13]

$$P(u,v) = (1-u)(1-v)B_{00} + (1-u)vB_{01} + u(1-v)B_{10} + uvB_{11} \quad (4)$$

For obtaining the (u,v) values, two straight lines are defined (e.g., in S and T direction respectively) from the point P, and their intersection points with the edges of the quadrilateral are computed (P_{s1}, P_{s2}, P_{t1}, P_{t2} in Figure 8). The (u,v) values of these four points are easily computed using the linear relationship along the edges in the texture image space (S, T). Then (u,v) values of the point P are determined as the intersection of the two lines ($P_{s1}P_{s2}$ and $P_{t1}P_{t2}$) in uv space.

The (u,v) values of P are used as parameters to obtain the height value (h) for the bulge shape function. The band width (b) for the height function h, is computed as the linear distance ratio of P along the isoparametric line for a given u. Different kind of shape functions can be used for simulating the bulge shape. Examples of some shape functions are given in Figure 9.

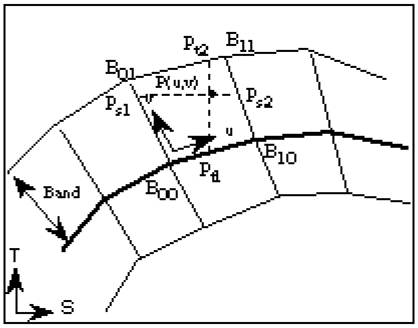


Figure 8: Macro Wrinkle Band

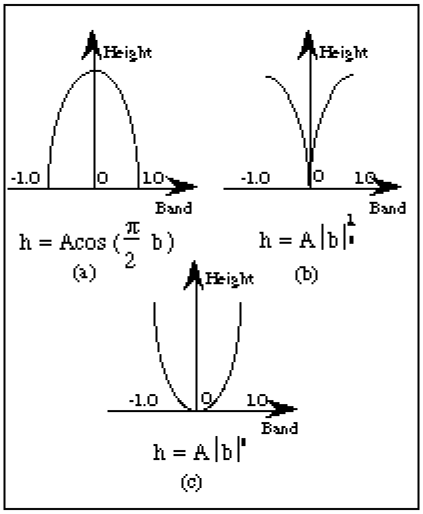


Figure 9: Examples of Bulge Shape Functions

Figure 10 shows some skin rendering examples combined with macro and micro structures with different bulge shape functions.

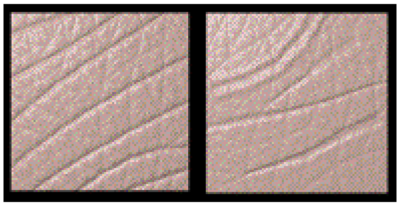
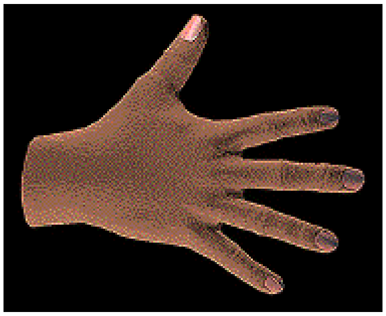


Figure10: Macro Structure of Skin

3.1.3. Example

We have also applied this method to a special region of skin: the hand. As the two sides of the hand have different texture patterns, one region is defined on the hand for each side: palm and back. A two layered micro wrinkle pattern is chosen to define the back of the hand, whereas, the palm lines and finger creases are defined as macro lines on the palm. Figure 11 shows the rendering results .



(a): Back of the Hand.

(b): Front of the Hand (Palm)

Figure 11: Rendering of Hand Skin

3.2 Dynamic Model

3.2.1. Biomechanical Model

Different biomechanical models of skin have been proposed in the literature [14]. For our purpose, we consider skin to be biaxial and imcompressible. The skin can not support negative stresses, and hence buckles easily [15].

As skin is thin and quite flexible, a plane stress elastic model is applied for each triangle. Each triangle employs a local coordinate system *(X,Y)* (see Figure 12). Generally, the *Y* direction corresponds to the direction of muscle contraction, and *X* to the potential wrinkle.

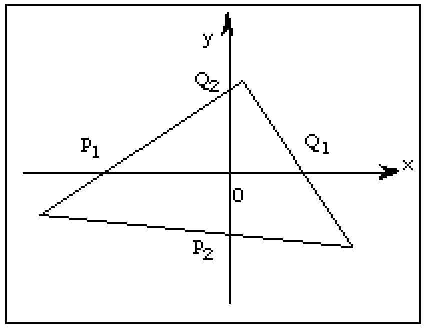


Figure 12: Local Coordinate System for a Triangle

For calculating the components of strain *(e_x, e_y, g_{xy})* for a triangle, we need three measurements in that triangle. In our case, these three measurements are strains along three lines defined on the triangle. For example, we have considered P_1Q_1 (along the *X* direction), P_2Q_2 (along the *Y* direction) and any one edge of the triangle as three lines for computing the strain. The strain value for a line at an angle q is given as [16].

$$s_\theta = s_x \sin^2\theta + s_y \cos^2\theta + \gamma_{xy} \sin\theta\cos\theta$$

Hook's law is used for computing the stress components on the triangle which are then used for calculating the in-plane force along its edges [17].

It is quite expensive to geometrically model all the wrinkles on the 3D skin surface (this would require very fine skin surface resolution resulting in enormous computation). Thus, we deform the skin mesh according to the biomechanical model as described, and we change the parameters for bump mapping to obtain the bulges from the texture image. Expressive wrinkles are defined as a curve tranverse to the muscle fibers. The wrinkles are then mapped to the texture image as described in Section 3.1.2. To get the deformation information , each point on the wrinkle polyline in a texture image has the corresponding triangle reference of the 3D skin surface. Due to the imcompressibility of the skin, under negative strains the skin buckles and bulges appear. A simple mapping function is used for obtaining the appropriate height value for the bulge function (Section 3.1.2) from the deformation or strain value. Figure 13 shows a line deformed from (a) to (b). The original length is l_0; after deformation it is *l*, and the deformation *d* as a bulge can be computed as (assuming linear case for bulge)

$$l_0^2 = l^2 + d^2$$

The height for the bulge function is computed as a function of strain and the bandsize. As during the animation, the strain values change, the height function changes accordingly.

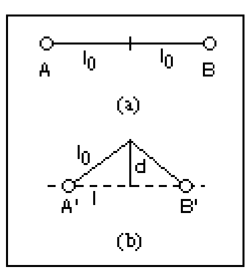


Figure 13: Approximation for the Height of Bulge.

3.2.2 Example

Figures 14 gives an example of expressive wrinkles animation.

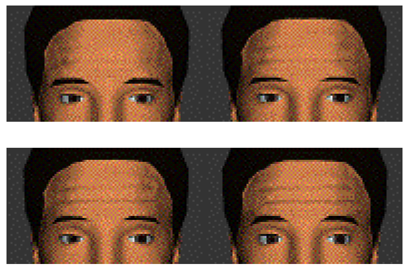


Figure 14: Wrinkle Animation

4. Conclusion

In this paper we have presented an approach for simulating wrinkles on human skin. In this approach the static model of wrinkles considers the rendering of the geometrical structure of the skin, and the dynamic model employs biomechanical deformation information. The models are applied for different cases: rendering of palm lines of hands, expressive wrinkles on the face. For example, in the static model of the palm lines, the furrows are described as curved lines and the ridges are defined as the intensity or depth of the curved lines. The dynamic model is used for expressive wrinkles. As wrinkles are induced by facial animation, they are defined according to the muscle anatomy and contraction. More specifically, the position of the wrinkle is defined on the muscle in its tranverse direction. An expressive wrinkle is generated as a mapping from the muscle. The bulge generated along the wrinkle line is decided by the skin deformation during the animation. There exists an accordance for the different kinds of wrinkles in the same region. Furrows of macro wrinkles are always along the furrows of micro wrinkle.

Solid modeling of human body based on actual medical data and biomechanical skin model with finite element analysis would offer the foundation for wrinkle formation and growth, but it will be computationally intensive. Thus, our approach simplifies the process and combines biomechanical deformations with rendering nuance of bump mapping.

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