Langwidere: A New Facial Animation System

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Abstract

This paper presents Langwidere, a facial animation system. Langwidere is the basis for a flexible system capable of imitating a wide range of characteristics and actions, such as speech or expressing emotion.

Langwidere integrates a hierarchical spline modeling system with simulated muscles based on local area surface deformation. The multi-level shape representation allows control over the extent of deformations, at the same time reducing the number of control vertices needed to define the surface. The head model is constructed from a single closed surface allowing the modeling of internal structures such as tongue and teeth, rather than just a mask. Simulated muscles are attached to various levels of the surface with more rudimentary levels substituting for bone such as the skull and jaw. The combination of a hierarchical model and simulated muscles provides precise, flexible surface control and supports easy generation of new characters with a minimum of recoding.

1. Introduction

In the field of computer generated characters, facial animation is particularly difficult because of the rather high expectations that people have when presented with a face that is "almost real".[1] An unwieldy level of detail is often needed for a reasonable model. Typically, the construction of new characters involves tedious and repetitive labor, and apart from any geometric consideration, animating a new character often requires recoding or changing and retuning many parameters.

A reasonable model for the human face requires a surface representation that is smooth, flexible, and can accommodate a large range of deformation both for configuring expressions and altering facial features.

[1] Note that most people have little trouble understanding the extremely simple facial expression of cartoon figures

Facial gestures have been simulated in polygonal and spline based surface representations by moving specific vertices or control points defining the skin using precise displacements in imitation of particular expressions or gestures [14, 15, 6]. This can produce the desired results, but new expressions will require a revision of all the involved degrees of freedom. A more general method of activation is to procedurally simulate the effects of individual muscles on skin [1, 16, 19, 21, 23], this allows expressions to be described (almost) independently of surface geometry.

Dynamic models simulating biomechanical properties of flesh and bone promises to be an even more general method to drive a facial model, by reducing the amount of special case handling, but because the expressions produced are specified indirectly through the mass and spring properties of the dynamic model, surface shape (such as surface creasing) may be difficult to control precisely.

"Langwidere" [3, 22] is the name of a princess of Ev (a kingdom adjacent to Oz) who could change her head like hats. As the story goes, she was not actually an evil person, only very vain and narrow-minded. The long-term goal of the Langwidere modeling and animation system is to provide this kind of flexibility and utility by allowing a single animation script to work with and drive any face built with the system. This paper describes the basic system and its use of a hierarchical B-spline structural model combined with a simulated muscle activation model.

1.1. Background

Frederick Parke's face model is the seminal work in the field of human character animation. The skin surface is represented by a carefully crafted, Phong-shaded polygon mesh. While polygon shading techniques create the illusion of a smooth surface, their polygonal nature is revealed in the profile and borders of the face. When animated, the coarseness of the mesh is revealed because the points of flexibility (the vertices and edges of the polygons) do not fully capture the structure of a human face. Also, actuating a polygonal model requires "explicit, direct control of specific facial vertices. Such direct control, while exhibiting certain favorable qualities, is restricting in terms of flexibility and creating generalized manipulation approaches." [6, p. 130]. Parke's model has parameters for the shape and size of the head. A different routine is used for each moveble part of the face.

Steve DiPaola's Facial Animation System (FAS) is an extension of Parke's model whose purpose is to provide an environment for the easy creation, manipulation, and animation of faces. New facial models are generated by digitizing live subjects or sculpted forms or by manipulating existing models with free form deformation, stochastic noise deformation, and simple vertex editing. New parameters for manipulating and controlling the face model are constantly being generated. FAS is based on Parke's polygonal model[2] and have the same limitations.

Keith Waters' muscle model process is one of the first systems to use simulated muscle activation [23]. The muscles are defined by a point of attachment, assumed to be fixed to bone, and a point of insertion, attached to skin. The simulated muscles deform the polygonal skin model by moving the vertices in a manner that mimics the effects of contraction on the skin. Waters, in co-operation with Demetri Terzopoulos developed dynamic skin model [20] using the same polygonal surface and muscle placement. Waters has also experimented with spline patches and comments: "for the modelling of the face patches have two advantages over direct polygonal descriptions: firstly the resolution can be selected for the structure, and secondly doubly curved surfaces can be generated." [24, page 230]

Waite's Facial Action Control Editor (*face*) used a 13×9 mesh of bicubic B-spline patches, and four Action Units composed of twenty-six muscles (thirteen pairs of symmetric muscles). Openings for the eyes, nostrils and mouth are cut into the surface using trimming curves [7, p.528]. As may be expected from the number of control points, this is not a very detailed model, but the author considers this "enough …for general face shaping with no additions.…"[21, page 53–54]

Pixar has an unwritten rule to "only use polygons for flat things" [19, p. 98] hence the choice of bicubic Catmull-Rom spline patches in constructing Billy, the baby in "Tin Toy". Triangular Bézier patches were also attempted, but severe wrinkling problems precluded their use. Wrinkling remained problematic, although less so after the switch from triangular patches to Catmull-Rom, though Billy still had a "north pole" singularity at the top of his head as well as major problems with the neck. To provide muscle action for Billy, Pixar used Waters' muscle model with modifications (adding rotational muscles to go with the linear, sheet and sphincter muscles developed by Waters) to allow flesh to warp around the jaw and the eyeball. Billy's face has forty-seven muscles.

[2] All of Parke's faces have the same number of vertices with the same topological arrangement.

2. Implementation

Polygonal models do not adequately approximate the look or flexibility of skin, thus Langwidere uses bicubic B-splines because they offer both smoothness and flexibility, and uses hierarchical B-splines because of the additional control provided with that formulation. Explicit manipulation of surface points is avoided using a procedural model of muscles acting upon the skin surface. These two major components of Langwidere are discussed in this section.

2.1. Hierarchical Splines

A spline is a loosely defined term referring to curve and surface representations defined with piece-wise polynomial functions [2]. A spline is defined by a set of points, called control vertices and a set of basis functions, that determine the shape of the curve or surface. There are numerous spline formulations, but in this paper we deal only with bicubic B-splines.

One shortcoming of using tensor-product B-splines for complex surfaces (such as the face) is that detail (in the form of more patches) can only be added by splitting an entire row or column of the entire surface. Thus more detail (and thus more control vertices) may be added where none are needed or desired. Refinement also changes the support area of the control vertices in the refined region, making it more difficult to make global changes to surface shape and adding more degrees of freedom to animate.

Hierarchical splines provide local refinements of a B-spline surface such that new patches are added within a specified region. Regions of local refinements are called overlays, and are the produced by midpoint refinement of the base surface and may be recursively defined resulting in a surface representation with multiple levels of resolution. A reference plus offset definition for each control vertex makes it possible to retain detailed surface features when broad-scale changes to surface shape are made (see [11, 10, 8, 9]). Hierarchical B-splines speed rendering because patches are not unnecessarily subdivided (they are rendered as one would render a traditional B-spline surface), and because the only information needed to define the surface is the location of individual edits, it is an extremely economical and compact way to represent a spline surface.

2.2. Facial Geometry

The basic facial model was constructed from an initial toroidal surface consisting of 18×4 bicubic patches using manual editing. The final shape is a 5-level hierarchical B-spline with 1584 individual bicubic patches Figure 1. (This surface is entirely defined by 783 non-zero offsets. Each offset consists of three floating point numbers and two integer indices. Note that it would take at least 14256 control vertices to define the same number of Bézier patches.) The surface models the entire neck and head, including internal features of the mouth - the hard palette, tongue and throat. Polygonal teeth and eyes are defined separately.

Just as the vertices of a polygonal model of a face must be carefully selected to provide the right amount of detail, in the right place, with the right connectivity, tensor-product splines are affected by the underlying quadrilateral domain of its parameterization. It is difficult to build features that cut diagonally across the domain. We chose to construct the model such that the hole of the basic toroidal form corresponds to the mouth opening (rather than attempt to build facial features from a planar surface) because this configuration places the isoparametric lines of the surface (e.g. the boundaries of the patches) along the major feature lines of the human face - the forehead wrinkles, nose, brow and eyes, mouth, jaw and jowls.

Construction of the basic model is fairly tedious and time consuming, but, because of the flexibility of the hierarchical form, once done the basic model can be quickly modified into a wide variety of exaggerated forms.

Figure 1. The Langwidere facial model at surface resolutions 0-4

2.3. Simulating Muscles

Animation of a facial model in Langwidere is specified by setting the activation level of muscle groups. The effect of muscle activation is simulated by mimicking the local surface deformation caused by a contracting muscle, and is built into the face so that if the surface shape changes, such as happens when the mouth opens or the head turns to the sides or up or down, the muscles will still work in a reasonable, predictable manner. As with the surface model, both realistic and exaggerated motion can be generated.

A muscle is defined by an insertion point, the end of the muscle fixed to skin; an attachment point, the end of the muscle fixed to bone; and an area of influence, the portion of the surface affected by the contraction. Figure 2 illustrates areas of influence for the various muscle types in Langwidere and shows the direction in which control vertices are displaced.

In a human face, a wide range of muscle types exist: rectangular, triangular, pyramidal, fan-shaped, and sphincter. Langwidere supports the following muscle types:

Fan: The fan muscle is fan-shaped, as the name implies, converging towards the attachment point. It is defined by an attachment point, an insertion point, and an angle of influence (see Figure 2 (a)).

Sheet: The sheet muscle's area of influence is rectangular. It is defined by an attachment point, an insertion point, and a width. The most obvious example is the *Lateral Frontalis*, one of the forehead muscles that raise the outer portion of the eyebrows (see Figure 2 (b)).

Sphincter: There are only two instances of sphincter muscles in a human face, the *Orbicularis Palpebrarum* (or *Orbicularis Oculi*) around each eye. These are the blink muscles. A sphincter muscle is elliptical and is specified by two foci and a length that defines its area of influence. Contraction is centered on the midpoint between the two foci (see Figure 2 (c)).

2.3.1. *Skin Bulge Due to Muscle Contraction.* Modelling the region of influence of each muscle is not enough; there are additional characteristics to consider. Flesh and muscles slide on a layer of fat over the bones and cartilage that give structure to the face. Where the muscles are short simply decreasing the distance between attachment and insertion points will suffice. But with longer muscles, such as the Frontalis which slides over the forehead and top of the skull, this simple model just dents the surface.

In addition, when a muscle contracts, the muscle fibers shorten pulling the point of insertion towards the point of attachment, the muscle fibers become thicker and stiffer, making it less likely that the skin over the muscle will conform to the underlying bone or faciæ. Surface points pulled towards the attachment point must also be displaced outwards by the bulging muscle, with the area over the point of insertion experiencing the greatest displacement.

To simulate these surface behaviours, Langwidere uses three deformation types:

Type I. In a Type I contraction a "skin thickness" parameter is used to scale the displacement of the skin outwards along the vector normal to the surface (see Figure 3 (a)). The maximum outward displacement occurs at the point of insertion for all muscle types. Note that with all contraction types surface points are displaced indirectly through changes in the position of the control vertices defining the surface shape.

Type II. In a Type II contraction, each surface point in the region of influence is displaced outwards by the same amount it is pulled towards the point of attachment. Careful selection of the Type I skin thickness parameter produces similar results to Type II, but with a slightly different profile for each deformation (see Figures 3 (b) and 4 (b)). However, both methods tend to collapse the surface in areas of high curvature (see Figure 6 (a) & (b)).

Type III. In Type I and Type II contractions surface points simply move towards their attachment points.

Type III contraction calculates the directional derivative of the surface in the direction defined by the vector between the point being displaced and the attachment point projected to the tangent plane at that point. The surface point is displaced along this projected vector and scaled by the relative strain rate and contraction value to produce the final result (see Figure 6 (c)).

With this method surface displacements follow the curves of the face during contraction despite the lack of a skull model to guide the surface. Type III contractions work well on curved surfaces, but produces no muscle bulge on a flat surface (see Figure 5 (b)).

2.3.2. *Generalized Muscle Attachment.* In general, muscle simulation models define attachment and insertion points as locations in some local coordinate frame. In Langwidere attachment and insertion points are defined within and between the overlay layers of the hierarchical B-spline formulation. The less detailed levels of the hierarchy approximate the shape of the face (Figure 1) and are used as its underlying "bone" structure. When the shape of this underlying structure changes, such as when the jaw opens (see [9] for details of this mechanism) the attachment points also move and any previously defined muscle groups continue to work in a reasonable way.

2.3.3. *Muscle Interaction.* Because muscles may affect a large region of the face, each muscle area of influence will likely overlap with another and without special case handling (see Figure 7) the resulting deformation will look wrong. In Waters' PhD. thesis, muscles interact by adding the displacement contributed by each muscle at each surface point. Because all movements are simply displacements there is a danger of displacing surface points to "impossible" degrees, and Waters recommends "preprocessing the structure" to ensure that this does not occur [23].

In later works, Waters suggests simply recalculating the area of influence for each active muscle and accumulating displacements without any regard for interaction. Users of this system report that this approach "produces usable results for the major facial muscles (of which there are 16 in total) [12].

If we were simulating muscle action on a surface point using forces, the magnitude and direction of a combined force would be found simply by summing the participating forces.

In Langwidere the magnitude and direction of the combined influence of several muscles is calculated separately. The direction is found by adding the displacements, and the magnitude by the length of the largest participating displacement or the total added distance - whichever is smaller (see Figure 9 and Figure 8 (d)).

The magnitude is truncated because, even at maximum displacement, each muscle can only shorten a certain amount. If the muscles are pulling in exactly the same direction it makes no sense for the total displacement to pull the surface past the furthest attachment point (as would occur if the displacements were simply added). Similarly, if the muscle are pulling in opposite directions with equal magnitude, the resulting displacements should cancel out.

2.3.4. *Normalizing the Muscle Pull Parameter.* A fully contracted muscle can shorten to 75% of its original rest length [17, pp. 22–23]. When the muscle shortens, its volume remains constant, so its cross-section thickens as its length decreases. The effect of the muscle on the surface of the skin is to pull the surface from the area of the insertion point towards the attachment point. The contraction towards the attachment point is accompanied by a corresponding outward displacement of the surface caused by the thickening of the muscle as well as the flesh (fat and skin) above it.

By normalizing muscles we allow animation scripts to be unconcerned with the scale of the model and much less bound to a particular model since the contraction values need only be related to the muscle as a biological unit.

3. Results

Waters' muscle model process is a good beginning, but cannot handle all the muscles on the face properly because it does not take into account the underlying skeletal structure supporting the flesh. (Note that we are comparing procedural models here, not ones based upon biomechanical properties). A Type I, modified Waters', contraction is used for short muscles that do not encounter areas with a high degree of curvature. Type III, gradient-based displacement, and contraction is used for longer muscles over areas of high curvature.

Some of the expressions and variety of models achieved with Langwidere are shown in Figures 10, 11, and 12.

4. Conclusions

Hierarchical splines and simulated muscles combine to create a system of considerable power and flexibility. Anatomically faithful placement of the simulated muscles allow natural expression generation as defined by the Facial Action Coding System [**?**] (see Figures 13 and 14), the most widely used facial animation notation scheme.

5. Future Work

Some muscle types found in the face, while they can reasonably be approximated by other muscle types, still have yet to be implemented in Langwidere. These are as follows:

Triangular The triangular muscle is similar to the fan muscle, but converges towards the insertion point. An example would be the *Depressor Anguli Oris*, a triangular muscle which pulls the corner of the mouth down towards the jaw. Currently triangular muscles are simulated by sheet muscles.

Pinned There is only one instance of a pinned muscle in the expressive muscles of the face, the *Compressor Naris*. Both ends of this muscle are fixed to immovable bone. The muscle flattens and pulls towards both the attachment and insertion points. This is currently being simulated by two gradient fan muscles that meet at the bridge of the nose.

Floating The various segments that comprise the *Orbicularis Oris* are not attached to bone or cartilage like most other muscles in the face, instead they are attached to skin and muscle via fasciæ. Since neither attachment nor insertion points are fixed, contraction occurs around the midpoint between the two. This is currently being simulated by fan muscles.

Some other elements that belong in a complete facial animation system are:

- automatic script generation with periodic actions such as blinking and swallowing
- automatic speech synchronization by linking to a speech synthesizer
- parameterize emotions and expressions
- backward engineer a skull model using forensic reconstruction techniques.
- add growth and aging functions to modify heads

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images/fan.ps

(a)

images/sheet.ps

(b)

images/sphincter.ps

(c)

Figure 2. Areas of influence and directions of pull

images/skin-pull.ps

(a)

images/linear-skin.ps

(b)

Figure 3. Type I muscle contraction

images/prop-pull.ps

(a)

images/linear-prop.ps

(b)

Figure 4. Type II muscle contraction

images/grad-pull.ps

(a)

images/linear-grad.ps

(b)

Figure 5. Type III muscle contraction

images/sphere-skin.ps

(a)

images/sphere-prop.ps

(b)

images/sphere-grad.ps

(c)

Figure 6. Muscle contraction types on a curved surface

images/add-mus-01.ps

(a)

images/add-mus-10.ps

(b)

Figure 7. Why muscle interaction code is needed

images/waters-blend.ps

Figure 8. Non-interactive muscle pull addition

images/blend-pull.ps

(a)

images/wide-blend.ps

(b)

Figure 9. Adding muscle pull vectors

images/al3-front-shade.ps

images/chuck-sneer.ps

Figure 10. Examples of models and expressions I

images/Be2-fear-colour.ps

images/alien-worried.ps

Figure 11. Examples of models and expressions II

images/al3-frown.ps

images/al3-open-smile.ps

Figure 12. Examples of models and expressions III

images/al3-sad.ps

Sadness

images/al3-surprise.ps

Surprise

images/al3-fear.ps

Fear

Figure 13. Examples of models and expressions IV

images/al3-happy.ps

Happiness

images/al3-anger.ps

Anger

images/al3-disgust.ps

Disgust

Figure 14. Examples of models and expressions V