Modeling of Vascular Expressions in Facial Animation

Prem Kalra and Nadia Magnenat-Thalmann

MIRAlab, CUI,
University of Geneva
1211, Geneva

Abstract

Most of the earlier and existing computational models for facial animation consider only muscular expressions. In this paper we address and emphasize issues related to modeling of vascular expression. The proposed model enables visual characteristics such as skin color to change with time and provide visual clues for emotions like paleness and blushingg. An emotion is defined as a function of two signals in time, one for spatial changes (muscular effects) and the other for the color (vascular effects). For different regions of the face, the atomic vascular action is modeled as an image mask with its shape and the shade defined by Bezier functions to manipulate the texture image.

1. Introduction

The face is a multisignal and multimessage system [3]. The face provides more than one kind of signal to convey different kinds of messages. This system communicates information via four types of signals [1]: *static facial signals* represent relatively permanent features of the face such as the bony structure and skin color that contribute to an individual's appearance; *slow facial signals* include changes in the facial appearance which occur gradually over time, such as developments of permanent wrinkles, changes in muscle tone, skin texture due to age; *artificial signals* represent exogeneously determined features of the face, such as eyeglasses and cosmetics; and *rapid facial signals* represent phasic changes in neuromuscular activity that may lead to visually detectable changes in the facial appearance. All four classes of signals contribute to facial recognition. The face is a multimessage system in the sense that it broadcasts messages about emotion, mood, attitude, character, age, sex, race and some other matters as well.

In the context of rapid facial signals, previous research has primarily considered sources of verbal and non-verbal communications arising from muscular actions. Little attention has been given to other modalities of changes in the facial appearance such as a change of skin color over time caused by an emotional state. These are particularly missing in the existing computational models of facial animation. This paper includes such changes in particular expressions caused by vascular effects. We provide another dimension to be incorporated in the design of a computational model of facial animation which depicts additional visual cues for facial expressions.

This paper is organized as follows. First, we provide in Section 2, an overview of our system of facial animation where we outline its design components and structure embedding different activities for facial animation. Section 3 describes briefly the vascular system of the human face; physiological study of the vascular system gives the necessary characteristic information for computer synthesis. In Section 4, we discuss facial efference due to vascular emotions; two typical examples of blushing and pallor are illustrated. Here, a model for emotion is introduced to incorporate changes in visual characteristics such as skin color during a facial episode stimulated from vascular emotion. Section 5 includes a discussion where an analysis of the present state of modeling vascular expressions is given with its further scope. Finally, some concluding remarks are presented.

2. System Overview

Design of a facial animation system in general like other animation systems considers spatial and temporal characteristics. Spatial characteristics refer to the specification of the position (x,y,z) and model of a face which, in our context of computer animation, pertains to specification of the geometry of a face. Facial modeling decides the spatial characteristics. A significant part of facial modeling is the exploration and development of techniques to measure or otherwise collect data for describing and representing faces. In the context of facial animation, spatial characteristics are regarded as the structural characteristics of the face which include representation of anatomical details for modeling.

Temporal characteristics are concerned with adding a dimension of time to the model. These are related to the techniques for specifying and controlling the motion of the face and the dynamics involved. A major goal of this activity is to develop systems which allow the animator to easily control facial expressions evolving over a period of time using fast, natural and effective methods.

There is one more component which should be included in the design of the facial animation system: visual characteristics. Visual characteristics provide graphical display and give information on rendering attributes such as skin color, texture, pigmentation, luminance etc., of a face. Though shape and form are also "visual" attributes, throughout the remainder of the text, we will use the term to refer to characteristics that are more related to rendering and visualization of shapes.

Our prototype system for facial animation encapsulates different groups of activities of facial expressions and offers a better cross-sectional understanding of the complex problems involved in the computational model of facial animation. The system for facial animation resolves the difficulty and complexity of the system by providing a multi-level structure to the system where each level is independently controllable. The particular interest is to establish the relevant links and natural mappings from a high level of motion specification arising from emotions and speech to a low level manipulation where distortion of the facial model occurs. The system is interactive, aimed at rapid feedback to increase productivity. The system is an open system where one can try several possibilities and can experiment with different input accessories and choose the one which is subjectively the 'best.' In addition to the spatial and temporal characteristics embedded in the system, we also incorporate visual or rendering characteristics such as skin texture and color,. by which one is able to obtain realistic results and to control and manipulate visual attributes during facial movements.

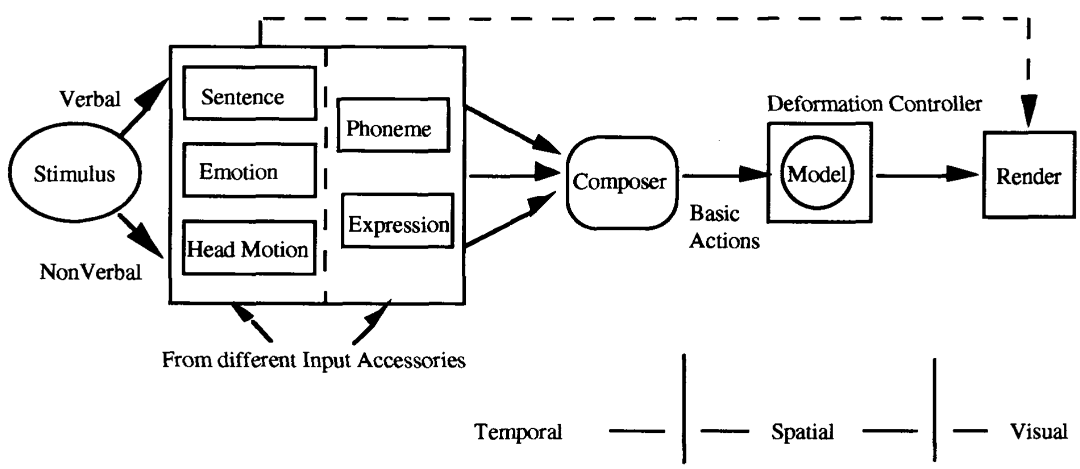

Figure 1: The overview of the system.

Figure 1 shows the overview of the design of such a system. The sources of stimuli arising from verbal or non-verbal communication for facial motion may be encapsulated in the different abstraction levels like emotions, head movements and sentences, or expressions and phonemes. Different input accessories may be used to contain and process the information about these abstract entities. The composer performs actions like, blending or filtering, to the incoming basic units of action and produces an array of the elementary actions to feed to the facial model where the actual deformation occurs. Finally, each instance of the face is rendered using the rendering module. The elementary actions in our system are the Minimum Perceptible Actions (MPAs) [6] similar to the Action Units of Facial Action Coding System (FACS) [4]. These MPAs reflect the activities of different zones of the face as aggregation of muscle actions for those zones. Different zones of the face are, for example, Eyebrows, Eyes, Cheeks, Nose, Jaw, Mouth, and the complete Head. An additional zone of Tongue has also been added which primarily shows the execution of certain phonemes like "ll" or "dd." This is particularly useful when a precise simulation of speech is desired. The included muscle actions for different MPAs are simulated using rational free form deformations [7]. The higher level entities such as phonemes and expressions are further defined as set of MPAs. For realistic rendering we use texture mapping.

The dotted line to the rendering module from the higher level entities in Figure 1 shows the necessity of a form of rendering attribute control for vascular effects that is similar to the specification of the spatial attributes of muscular effects. In this paper we have addressed and emphasized some of these issues. The next section provides a very brief description of the vascular patterns in the skin of human face. Though our attempt is not to model the exact anatomy of the blood vessels, this gives an insight for the computer modeling and synthesis of vascular effects in a global way.

3. Vascular System

The skin of the face is richly vascular. The great number of blood vessels and the high level of enzyme activity in the skin of the face probably reflects elevated metabolic activity. Different morphologically types of branching are found in the face. Moretti et al. in [9] studied vascular patterns in the skin for different regions of the face. Their region based approach shows that regions like the nose and forehead have bilateral branches at sharply acute angles called "fronds," and that regions like the cheeks and jaw have unilateral branching at nearly right angles called "candelabra." Some regions find intermediate types of branching between the "frond" and "candelabra." Different regions also show different patterns in the capillary supply to the skin. There are great regional differences and any one region varies greatly from one person to another, especially with age. All these regional differences may indicate why certain regions show externally more activity than others. For example, the action of blushing is revealed more from the cheeks, ears and the forehead than from the rest of the body parts.

4. Vascular Emotions

The outcome of the vascular effects is externally perceived by a change in skin color. There can be two major reasons for a change in the color of a face: physical conditioning or emotional state. Physical conditioning refers to change in color: e.g., reddening when physical exercise or strain occurs. Emotional states can also influence the color attributes of the face. In either situation, change in color is due to the change in blood circulation. Our primary interest is to incorporate the change in color due to an emotional state. We have considered two emotional states where change of color is visible: blushing and pallor. These emotional states are relatively involuntary and uncontrollable and can be described as vascular phenomenon.

4.1 Blushing

Blushing is the most peculiar and the most human of all expressions [2]. Blushing occurs when emotions are intense, often sending a surge of blood through the main artery. It may occur when a person is ashamed, wishes to flee, hide, conceal a previous act, or confound someone's possible deprecating attribution [17]. It occurs when one least desires it to occur, it is not readily subject to voluntary control, and again it is vascular and not due to muscular expression [14]. Although blushing appears to be a reflex, coming on involuntarily, it requires a certain social context in which one draws the attention of others.

(See color plates, p. 201.)

Blushing is a transient feeling of warmth and/or skin color change associated with the occurrence of acute self-consciousness; this is distinct from flushing, which may accompany other emotional or physical states. (Flushing is a transient reddening of the face and of some other areas including neck and upper chest [15]. Facial flushing can be induced by stimulating central control centers, brainstem vasomotor centers, or peripheral vasodilatory mechanisms as characterized by Wilkin in [15]. Intense and frequent flushing in susceptible persons can cause a cluster of physical signs called "rosacea"). Here, we are concerned with one specific form of facial warming and color change: blushing, or the transient emotive response of acute self-consciousness. Blushing may be distinguished from flushing in terms of the nature of the eliciting stimulation. Blushing is induced by social stimulation whereas flushing is induced by physiologic or pharmocologic stimulation. Exact physiological mechanisms of blushing are not yet well understood [14]. The control of vasodilatation is achieved by increased activity in nerves that dilate blood vessels and then causes a rash like reddening which may persist after a transient blushing episode.

Some recent studies have helped obtaining some information about psychophysiological profile of the blushing response (i.e. the measurement of blushing). Shields et al. in [14] have found in their experiment that a typical blush is believed to appear quickly. For a majority of cases, blushing occurred within 2 secs of the stimulus, with duration of up to 15 minutes and a median of 20 secs. For most people blushing occurs in a region of cheek. In another study by Shearn et al. in [13] some measurements of facial temperature and coloration for parts such as cheeks and ears are taken. They perform polygraph recordings for cheek plethysmograph, ear plethysmograph, cheek temperature and finger skin conductance. Two types of stimulation are considered: non-blush stimulation (a situation which can arouse but will not cause blushing) and blush stimulation. Their observations show that for certain subjects there was not a direct correlation between the temperature and the coloration measurement, particularly for cheek regions. They believe that the cheek reddening detected by their photoplethysmograph probe offers a more direct measure of blushing than the temperature.

4.2 Pallor

Pallor occurs during temporary cerebral anemia and contractions of the facial capillaries remedies it by increasing cerebral blood flow. Pallor may occur due to shock, fear or pain. These actions diminish facial blood flow and redirect it to the brain to ease and recuperate. The measurement of pallor has not been seen in the literature. The psychophysiological analysis of pallor may provide similar findings as for blushing --- which regions are more prone to show paleness and what is the temporal pattern of pallor. However, our informal observation shows that pallor has acquired much less attention in the psychophysiological analysis as compared to blushing.

For the computational model, the primary element of interest is to identify the essential characteristic that manifests the phenomenon. We consider that for vascular emotions the skin color or tone determines their occurrence. In the next section, we present our model of emotion which includes color variation during the execution of vascular emotion.

5. The Model

Generation of realistic faces demands skin color change depending on the emotional state of an individual. The existing facility in the system needs to be extended so that the color of selected portions of the face can be varied with time, allowing us to provide emotional visual cues such as paleness due to fear, and blushing due to embarrassment. Patel in [11] has briefly included the skin tone effect as a change of color of all the polygons during an emotion. However, there does not exist as such a computational model of emotion which includes these visual characteristics and their pattern of change during their execution.

As we know that emotional expressions due to muscular actions are well studied, we can revisit their definitions and explore if a similar approach can be adopted. An emotion is defined as an envelope containing four stages during expressive episode of a face [4]. These stages are: attack, decay, sustain and release. To compute the envelope, one can provide an instance of expression (static facial snapshot) for the commencement of each intermediate stage and perform an interpolation. The four stages of emotion in fact determine the dynamic pattern of emotion. From the studies and experiment undertaken for the vascular emotions (particularly blushing), it is evident that a

(See color plates, p. 201.)

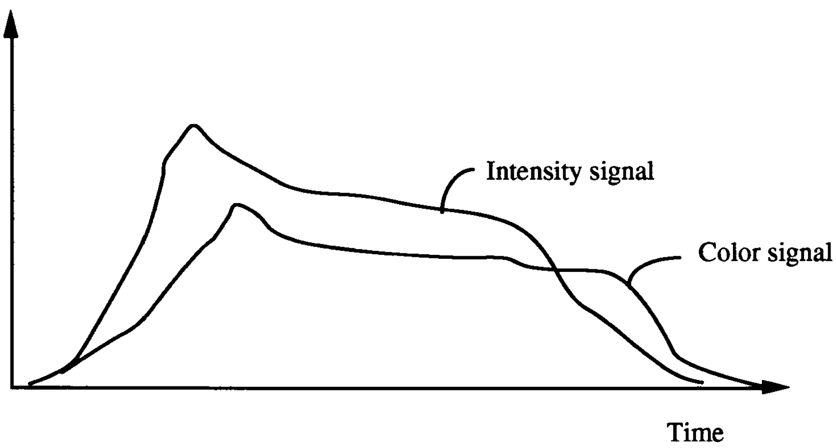

Figure 2: Emotion as Intensity and Color Signals over Time.

similar envelope exists. The pattern of the included stages, is however, not so well determined.

In our model we redefine emotion as a function of two signals in time, one for its intensity for spatial changes and the other for the color. At any instance of time, the state of emotion e_t can be defined as

$$e_t = k\, f_t\,(s,c),$$

where k is a constant, s is the parameter for spatial intensity and c is the parameter for the color signal. Figure 2 illustrates an episode of a face with emotion over time having signals for its spatial intensity and the color attributes. Emotions showing only spatial changes due to muscular activities, and the emotions showing only color changes due to the vascular activities can be considered as special cases of the above definition. There are instances where both are visible. For example, the feeling of embarrassment may not only entail coloration of the face but may also have head tilts and eye movements. The exact synchronization of their apex and release are not yet evident. Presumably, vascular effects sustain much longer than the muscular effects.

For vascular expressions, there does not exist a coding scheme yet which decomposes the expressions into some discrete actions, like FACS does for muscular expressions. We propose a similar approach to that adopted earlier for generating expressions due to muscle actions. That is, we define Minimum Perceptible Color Action (MPCA) analogous to the MPA which embodies the necessary parameters to change the color attributes due to blood circulation in blood vessels of different parts of the face. However, our intentions are not to provide a model for the flow of blood through the blood vessels. Instead we wish to map parametrically the change of color to the vascular activity in that region.

As we use texture mapping for the rendering, we can manipulate the visual characteristics of the image to be mapped onto the model for giving us the desired effects for the different portions of the face in the model. The process of texture mapping ascertains the position of facial features between the model and the image [8]. Thus, for the computational model, an image mask is considered to devise MPCAs. A shape inside the mask is defined which gives the region to be affected when the mask is applied onto the texture image. Then a shade function for this region is defined. Each pixel inside this region of the mask may represent a percentage factor to be used for modifying the color attributes, such as saturation value, when applied to the texture image. The following sections provide details of defining the shape inside the mask, scan conversion and pixel valuation.

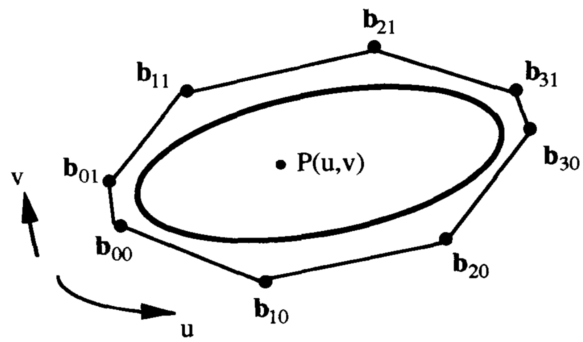

Figure 3: A Planar Bezier Patch with Degree 3x1.

5.1 Mask Shape

Mask shape is defined inside a rectangular window. The shape is considered as a Bezier planar patch. The motivation to use Bezier patches stems from the brush stroke design used in the systems by Nishita et al. in [10].

A Bezier patch of degree mxn in the u and the v directions can provide the outline and the shape of the mask. A point inside the Bezier patch is obtained using the following relation:

$$P(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{n} \mathbf{b}_{ij} B_i^m(u) B_j^n(v)$$

where $\mathbf{b}_{ij}$ are the coordinates of the control points and B_i^m and B_j^n are the Burnstien polynomials. Figure 3 shows an example of a planar Bezier patch with 3x1 degree. There are two advantages of using Bezier patch representations. The first is that users can define the shape as per their choice by appropriately moving the control points; the shape is not limited to defined entities such as squares, circles etc. Secondly, the parameters (u,v) for each point inside the mask can be used to associate relevant information with the pixel. For example, it can provide a distribution function to obtain the saturation factor for each pixel color inside the mask.

5.2 Scan Conversion

One of the limitations of using a parametric representation of curves and patches is that it is difficult to obtain the exact scan line intersection. By limiting the degree, one can find the analytical solution to get the exact intersection. However, in our context we believe that a simple approximation of the intersection is adequate. We polygonize the patch to find the intersection, and within the polygon (quadrilateral) we consider the two triangles of the quadrilateral and employ linear interpolation to obtain the (u,v) values using barycentric coordinates. In order to optimize the algorithm, we define a bounding rectangle around the quadrilateral.

5.3 Pixel Valuation

By "pixel valuation" we refer to the computation of a value for each pixel inside the mask. This value, a real number, is used for modifying the color attributes of the texture image. For example, this may represent the saturation of color or luminance value in another context. The approach for computing pixel valuation is similar to that employed by Nishita et al. in [10] for determining the shade variation for the brush. A Bezier function of u and v is used to obtain the pixel valuation, and the function may be defined as follows.

$$q(u,v) = \sum_{j=0}^{n} \mathbf{g}_j B_j^n(v) \sum_{i=0}^{m} \mathbf{h}_i B_i^m(u)$$

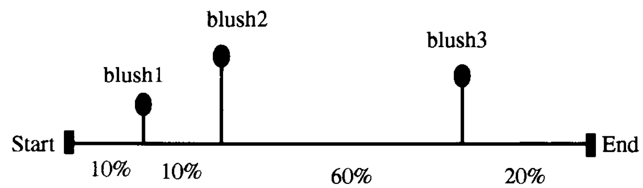

Figure 4: Hypothetical Span of a Vascular Emotion.

where $\mathbf{g}_j$ and $\mathbf{h}_j$ are the control points and B_i^m and B_j^n are the Burnstien polynomials. One of the reasons for using a planar patch to determine the mask shape is to have two parameters u and v. A closed curve like NURBS (Non-Uniform Rational B Spline) may also be used [16] but, would give a single parameter to manipulate the pixel valuation.

For vascular expression, the regions considered are the Forehead, Ears, Cheeks, Nose and the complete Head. An interactive tool is provided for building the MPCAs for the different regions i.e. defining the shape and shade of the mask for that region. The user can construct the shape of the mask defined by the control polygons of the Bezier patch and the bi-directional shade function for that shape by manipulating the Bezier control polygons. For animation, an emotion then can be defined using the similar multi-level structure approach used for muscular expressions. That is, an emotion can be defined as grouping of some key vascular expressions with their respective intensities and relative duration as below (also see Figure 4).

```
[emotion blushing
  [stage1 duration 10] [expression blush1 intensity 0.9]
  [stage2 duration 10] [expression blush2 intensity 0.8]
  [stage3 duration 60] [expression blush3 intensity 0.6]
  [stage4 duration 20]
]
```

The stages included may be correlated to the stages of "attack," "decay," "sustain," and "release," however, as there is no study conducted which reveals the pattern of such type of emotions we keep them as stages. The expressions blush1, blush2, blush3 are defined in terms of the MPCAs. For example blush1 may be defined as follows.

```
[expression blush1
        [mpca forehead intensity 0.47]
        [mpca cheeks intensity 0.87]
        [mpca ears intensity 0.57]
]
```

5.4 Examples

We propose a method where the image(s) to be texture mapped can be manipulated to incorporate the ability to change color attributes for the portion of interest. 2D manipulation of images is simpler and more effective than changing the color attributes of the 3D model. In addition, most image processing techniques may be used for manipulating the image.

Such a model further enhances the behavioral aspects of facial animation. Color Photo 1 and 2 show two sequences of images obtained from the 3D model illustrating vascular emotions. In the first sequence (Color Photo 1) the saturation color value for certain regions of the face are changed to simulate blushing. The second sequence (Color Photo 2) shows pallor associated with shock or fear. In this sequence the skin tone for the entire face is degraded.

6. Discussion

The preceding sections have described a computational model for vascular expressions for facial animation. The model is rather simple and considers only a few parameters. However, the underlying approach shows great potential for the enhancement of facial animation. Issues such as vascular effects, they may though seem secondary, play an important role in facial communication. Such a model can help in establishing the extent to which quantitative and/or qualitative aspects of vascular expressions vary. The model may further consider individual differences in other physiological characteristics and factors such as age and sex. The emotional model proposed can easily accommodate such empirical findings by placing the intermediate instances of the vascular expressions validated through empirical data. The model may be extended to incorporate an appropriate synchronization mechanism to time and order the sequence of different actions for different parts. Observations such as "blushing commonly starts at the cheeks, spreads to the ears and neck" may then be easily included. The effect of social context may be added. For example, in a study by Shearn et al. in [13], it is observed that blushing increased as audience size increased from one to four.

Other overt emotional responses like sobbing and weeping are also closely tied to vascular process. Blood circulation is implicated in the actions of the diaphragm that cause sobbing or laughing, or in tears shed when weeping or laughing. Modeling of these features would further add functional and visual realism to facial animation. The entire emotional process can then in fact be conceptualized as being triggered by an internal sensory or cognitive event that leads to peripheral muscular, glandular, or vascular actions that in turn result in a change of subjective mood.

7. Conclusion

Ekman and Oster in [5] remarked that blood flow, skin temperature, and coloration changes in the face are some of the measures that so far remain unexplored. In this paper we emphasized consideration of such measures to redress this oversight.

Generation of realistic faces demands skin color change depending on the emotional state of an individual. The system includes visual characteristics so that the color of the face can be varied with time to provide emotional visual cues such as paleness due to fear, or blushing due to embarrassment. An emotion is defined as a function of two signals in time, one for intensity catering to muscular expressions and the other for the color due to vascular expressions. For different regions, the atomic vascular action (MPCA) is modeled as an image mask with its shape and shade defined by Bezier functions.

Acknowledgment

We are thankful to Hans Martin Werner for editing the manuscript. The research is supported by Le Fonds National Suisse pour la Recherche Scientifique.

References

[1] Cacioppo J, Hager J, Ekman P (1992), The Psychology and Neuroanatomy of Facial Expression, In Final Report to NSF of the Planning Workshop on Facial Expression Understanding (Eds. Ekman P, Huang TS, Sejnowski TJ, Hager JC), pp. 9-13.

[2] Darwin C (1872), The Expressions of the Emotions in Man and Animals. New York: Greenwood Press.

[3] Ekman P, Friesen WV (1975), Unmasking the Face: A Guide to Recognizing Emotions from Facial Clues. Prentice Hall.

[4] Ekman P, Friesen WV (1978), Facial Action Coding System: A Technique for the Measurement of Facial Movement. Palo Alto, California: Consulting Psychologists Press.

[5] Ekman P, Oster H (1979), Facial Expression of Emotion, Annual Review of Psychology, 20, pp. 527-554.

[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 Kunii TL) pp. 189-198.

[7] Kalra P, Mangili A, Magnenat-Thalmann N, Thalmann D (1992), Simulation of Muscle Actions using Rational Free Form Deformations, Proc Eurographics '92, Computer Graphics Forum, Vol. 2, No. 3, pp. 59-69.

[8] Kalra P, Magnenat-Thalmann N (1993), Simulation of Facial Skin using Texture Mapping and Coloration, Proc ICCG '93, Bombay India, In Graphics, Design and Visualization (Eds Mudur SP and Pattanaik SN), pp. 365-374.

[9] Moretti G, Ellis RA, Mescon H (1959), Vascular patterns in the skin of the face, The Journal of Investigative Dermatology, 33: 103-112.

[10] Nishita T, Takita S, Nakamae E (1993), A Display Algorithm of Brush Strokes using Bezier Functions, Proc. CGI '93, Lausanne, Switzerland, (Eds Magnenat-Thalmann N and Thalmann D), pp. 244-257.

[11] Patel M (1992), FACES, Technical Report 92-55 (Ph.D Thesis), University of Bath, 1992.

[12] Shearn D, Bergman E, Hill K, Abel A, Hinds L (1990), Facial Coloration and Temperature Responses in Blushing, Psychophysiology, Vol. 27, No 6, pp. 687-693.

[13] Shearn D, Bergman E, Hill K, Abel A, Hinds L (1992), Blushing as a Function of Audience Size, Psychophysiology, Vol. 29, No 4, pp. 431-436.

[14] Shields SA, Mallory ME, Simon A (1990), The Experience and Symptoms of Blushing as a Function of Age and Reported Frequency of Blushing, Journal of Nonverbal Behavior 14(3), Fall 1990, pp. 171-187.

[15] Wilkin JK (1983), Flushing Reactions, In Rook AJ, Maibach HI (Eds), Recent Advances in Dermatology, Vol. 6, pp. 157-187, New York: Churchill-Livingston.

[16] Willis P, Oddy R (1992), Rendering NURB Regions for 2D Animation, Proc. Eurographics '92, Computer Graphics Forum, Vol. 11, No. 3, pp. 35-44.

[17] Zajonc RB (1985), Emotion and Facial Efference: A Theory Reclaimed, Science, Vol. 228, April 1985, pp. 15-21.