Live Facial Expression Generation based on Mixed Reality

Hiromi T. TANAKA, Akira ISHIZAWA, and Hiroaki ADACHI

Computer Science Dept., Ritsumeikan University, Japan

Abstract

Virtual reality technology provides a new methodology for visualization with realistic sensation, and has attracted special interests of human interface, visual communication communities. The key issue there is how to represent and reconstruct *human* naturally and realistically. Accordingly, recent study of facial expression has been received growing attention and intensively investigated. In this paper, We propose a hybrid approach to Live facial expression generation based on mixed reality. We first propose a novel approach to mixed reality, we call Augmented Virtuality, which enhances and augments the reality of complex and delicate live motions of the object in the virtual space, by projecting portions of live video images observing the deformation and motion of the object onto the surface of its static CG model. We also propose a new method of adapting color properties for smooth merging of real and virtual spaces, and also propose a new method of extraction of the region effective for merging, based on the optical flow analysis of both range and color images in which in the virtual space, shape and texture changes are observed. We apply this technique to real time generation of realistic eye expression. We then propose the homotopy sweep method for surface deformation using 3D control vectors, and apply this technique to the animation of mouth/lips expression. Our approach has the advantages of descripting the geometric shapes and the deformation of circular muscle simply, and of reconstructing realistic deformation efficiently. Experimental results demonstrate the effectiveness of the proposed hybrid approach in representive and visualizing live facial expression in real time.

1 Introduction

Virtual reality technology provides a new methodology for visualization with realistic sensation, and has attracted special interests of human interface, visual communication communities. The key issue there is how to represent and reconstruct *human* naturally and realistically. Accordingly, recent study of facial expression has been received growing attention and intensively investigated in the field of human interface, computer vision, and psychology.

Generally, facial expression are generated by deformation of facial muscles such orbicularis oris, orbicularis oculll, and venter frontalls. Many previously proposed approaches [7, 8, 9] for the facial expression problem, have been based on the analysis of facial feature points such as Facial Action Cording System(FACS). And facial expressions have been generated by deforming the face wireframe model according to the displacement of such feature points. However, individual structure of every different facial muscle and its delicate and complex motions have not been described correctly and efficiently with such feature points.

In this paper, we propose a novel approach to live facial expression generation based on mixed reality, which merges live video images in a 3D face CG model to represent and reconstruct the fine details of live facial expression.

First, we propose a novel approach to mixed reality, we call Augmented Virtuality(AV), which enhances and augments the reality of complex and delicate live motions in the virtual space, by projecting portions of live video images which observes the deformation and motion of the object, onto the surface of its static CG (Wireframe) model.

We apply this technique to real time eye expression generation. Consequently, live eye expressions are realized and visualized in real time in the virtual space by continuously projecting video images onto the 3D face model.

Next, we propose a smooth surface deformation method based on the homotopy sweep technique, which deforms a surface by interpolating continuous transition between coarsely sampled time-varying cross-section contours with three dimensional velocity vectors.

The homotopy sweep method was originally proposed for solid surface generation using the continuous transition among a set of two cross-section contours, where the three dimensional shape and volume are described as a "swept volume" of two dimensional cross-section contours along a space curve called a trajectory. In this work, we extend the homotopy sweep method to surface deformation by replacing "the space-trajectory" by "time-trajectory". We then successfully apply the proposed method to real time animation of mouth/lips expression. Our approach to adapt the homotopy sweep method, is based on that mouth/lips expression is composed of deformation of circular muscle around the mouth and these muscles can be modeled as a set of closed contours.

Experimental results show the effectiveness and feasibility of the proposed approach to live facial expression generation in realtime.

2 Image (Projection) - based Eye Expression Generation

2.1 Representing and Visualizing Live Motions with Augmented Virtuality

In this section, we introduce a novel approach to mixed reality, we call Augmented Virtuality(AV), which enhances and augments the reality of complex and delicate live motions in the virtual space, by projecting portions of live video images which are observing the deformation and motion of the object, onto the surface of its static CG (Wireframe) model.

This technique extends the use of real image to the *dynamic* region, and releases the complexity of 3D modeling to represent live motion of the object, and also provides to present the stereoscopic images from arbitrary directions. First, we extract merging regions from the video images which observe live motions, that is, effective for merging, based on the optical flow analysis of both range and color real images. We then adapt properties of color texture image of the CG model to that of the merging region, according to the changes in the color values of the corresponding regions. This process decreases the contrast along the boundary of the merging region and achieves smooth merging of real and virtual spaces in real time. The novelty of our approach is that merging regions from real video images are extracted based on the optical flow analysis of images observing both shape and texture changes of the objects.

We apply this technique to real time generation of live eye expression. Consequently, live facial expressions are realized and visualized in real time in the virtual space by continuously projecting video images onto the 3D face models.

2.2 Region Effective for Merging

First, we define a *region effective for merging (REM)* in which our technique works effectively to enhance the reality of 3D CG model in representing and visualizing live motions.

When we evaluate cost and quality in generating dynamic views, live video images are not sufficient to represent dynamic changes, if the 3D shape deformation of the region occurs in large scale, moreover, if such deformation can be generated easily. On the other hand, video images is efficient, as a texture image on the region in which complex and delicate motions occur over solid and static surface structure. In short, we define REMs as regions where the 2D texture changes are much lager and more complex than 3D shape deformation. In the following, we describe REM in case of a face surface.

2.2.1 3D shape Deformation Analysis

As the analysis of 3D shape deformation, we refer to the result of face surface segmentation based on the motion analysis reported by Ueno [6], where a face surface was divided into 4 parts as shown in Figure 1.

As Figure 1(a) shows, the candidates regions for REMs are extracted as regions with sliding motion or stable regions(Figure 1(a) and Figure 1(d))

2.2.2 2D texture Change Analysis

The apparent velocity of the object is computed as optical flows from spatio-temporal gradients of the image intensities, with the condition that the object moves keeping the distribution of the image intensities unchanged. The optical flow $\mathbf{v} = (u, v)$ is defined from the following equation.

$$\frac{\partial \rho}{\partial x} \cdot \frac{dx}{dt} + \frac{\partial \rho}{\partial y} \cdot \frac{dy}{dt} + \frac{\partial \rho}{\partial t} = 0 \qquad (1)$$

where ρ is image intensity, $u = dx/dt$ and $v = dy/dt$ denote the x and y elements of the velocity respectively.

Figure 2 shows the result of the optical flow analysis computation from video images of facial expressions. The candidates for REMs are extracted over eye region, as shown in Figure 3(b).

2.2.3 Extraction of REMs

From the result shown in Figure 3(a) and Figure 3(b), REM is extracted over the eye region, and shown in Figure 3(c). Then REM is manually selected on the wireframe model by considering symmetry, as shown in Figure 3(d)

2.3 Adapting Color Properties

The difference in color tone is outstanding along the boundaries of the merging region, because the different lighting conditions cause significant changes in color properties between the texture image of 3D CG model and the live images.

We describe the method of adapting color properties for smooth merging of virtual and real spaces. In order to reflect *live states* of the objects to the virtual space, we adapt properties of color texture image of the CG models to that of the live video image, according to the changes in the color values of the corresponding regions.

2.3.1 Color Adaptation Algorithm

We define the reference color of REM to measure the difference in the color tone which is dominant in quantity and also in quality in representing live states of the object (e.g. a skin color for human). We extract the reference color based on the HSV (H:hue, S:saturation, V:value) color histogram analysis. The algorithm is shown below.

1. RGB to HSV conversion of input images.
2. Computing the color histograms on each H, S, V value in the REM
3. Finding a peak value of H, and average values of both S and V
4. Adapting color properties based on the equations as shown below,

$$\begin{aligned} H_{-CG} &= H_{-CG} + \Delta H \\ S_{-CG} &= S_{-CG} \cdot \Delta S \\ V_{-CG} &= V_{-CG} \cdot \Delta V \\ \Delta H &= Hpeak_{-video} - Hpeak_{-CG} \\ \Delta S &= Saverage_{-video} / Saverage_{-CG} \\ \Delta V &= Vaverage_{-video} / Vaverage_{-CG} \end{aligned} \quad (2)$$

5. HSV to RGB conversion of adapted texture image of the CG model

2.4 Computation Steps

Figure 12 and Figure 14 shows two input images: a color texture image of the CG model; and a live video image by a CCD camera shown in Fig.14(b).

step1. Extract REMs from live video images

step2. Extract the dominant color of REM

step3. Adapt color properties of the whole color texture image of the CG model to that of the video image

step4. Merge a portion of video images in the color texture image of the 3D CG model

step5. Display the 3D CG model, i.e, the static wireframe mapped with dynamic changing texture

Figure 14(a) shows our experimental video camera mounted on the helmet to observe a fixed region independent of the object's motion, as shown in Figure 14(b). It results in avoiding feature corresponding problems in real time.

In step 1, the complexity of the texture changes in different facial expressions is analyzed from optical flow analysis. The texture change of around eyes region is significant as observed from the optical flow in Figure 2 where Figure(a) and Figure(b) show the directions and magnitude of the optical flow respectively. In addition to that, the deformation of 3D shape is small in the region around eyes as shown in Figure 1. Compared with other regions that are important in generating facial expression, the shape deformation in eyes region is smaller than the texture change. Therefore, the region of spectacles shape around eyes is extracted for merging to the virtual space.

3 Deformation-based Mouth / Lips Expression Generation

3.1 Homotopy Sweep-based Surface Deformation

The homotopy sweep method was originally proposed for solid surface generation using the continuous transition among a set of two cross-section contours, where the three dimensional shape and volume are described as a "swept volume" of two dimensional cross-section contours along a space curve called a trajectory [10] (cf. Figure 5).

The technique provides a convenient and intuitive control of surface generation, and allows the generalized cylinders to be modeled with a smaller set of input parameters. The problem is, however, how to determine the path connecting two adjacent contours, out of infinitely possible ones. In this work, we extend the homotopy sweep method to surface deformation by replacing "the space-trajectory" by "time-trajectory". In this section, we describe the method to control and find the path with the use of a scaling function of 3D control vectors along the contours. We then successfully apply the proposed method to real time generation of mouth/lips expression. Our approach based on that mouth/lips expression is composed of deformation of circular muscles around the mouth and these muscles can be modeled as a set of closed contours.

3.2 Definition

Let O be the origin of the world coordinate system, A be a point on a contour C_1 and B be a corresponding point of A on the contour C_2 after a unit sampling period Δt(cf. Figure 6). The points A,B are defined in the local cylindrial coordinate system (O,$\mathbf{Ur}(\theta)$,$\mathbf{U}_\theta(\theta)$,$\mathbf{Uz}(\theta)$) at A, where the x, y, and z axises are defined by $\mathbf{Ur}(\theta) = \frac{\mathbf{OA'}}{\|\mathbf{OA'}\|}$,$\mathbf{U}_\theta(\theta)$ and $\mathbf{Uz}(\theta) = \mathbf{Ur}(\theta) \times \mathbf{U}_\theta(\theta)$ respectively. Then A on C_1 and B on C_2 are given by

$$\begin{aligned} A = C_1(\theta) &= [C_{1r}(\theta), 0, C_{1z}(\theta)] \\ B = C_2(\theta) &= [C_{2r}(\theta), C_{2\theta}(\theta), C_{2z}(\theta)] \end{aligned}$$

We define the homotopy in the local system to give the 3D deformation. Then a path $M(\theta, t)$ between

A and B is given by (cf. Figure 6),

$$\mathbf{OM}(\theta,\mathbf{t}) = r(\theta,t)\mathbf{U_r}(\theta) + \theta(\theta,\mathbf{t})\mathbf{U}_\theta(\theta) + \mathbf{z}(\theta,\mathbf{t})\mathbf{U_z}(\theta) \quad (3)$$

where $r(\theta,t)$ is the homotopy value in $\mathbf{Ur}(\theta)$ direction, $\theta(\theta,t)$ is the homotopy value in $\mathbf{U}_\theta(\theta)$ direction, and $z(\theta,t)$ is the homotopy value in $\mathbf{Uz}(\theta)$ direction.

3.3 Surface Deformation by Homotopy Sweep Method

The interpolation between the two values C_{1r} and C_{2r} in the $\mathbf{Ur}(\theta)$ direction is computed from Eq.(4).

$$r(\theta,t) = (1-R_n(t))(1+Sc_1(\theta,t))C_{1r}(\theta) + R_n(t)(1+Sc_2(\theta,t))C_{2r}(\theta) \quad (4)$$

where $0 \le t \le 1$ R_n is a blending function given by Eq.(7), and Sc_1 and Sc_2 are scaling functions for the contours C_1 and C_2 are used in our proposed scaling function Eq.(8), which allow to control the contour deformation in arbitrary 3D directions.

The interpolation between the two values *0* and $C_{2\theta}$ in the $\mathbf{U}_\theta(\theta)$ direction is computed from Eq.(5).

$$\theta(\theta,t) = (1-R_m(t))(1+Sc_1(\theta,t))N + R_m(t)(1+Sc_2(\theta,t))(C_{2\theta}(\theta)+N) - N \quad (5)$$

where $0 \le t \le 1$ N is an offset value which make the scaling function effective at t=0, and is used in the interpolation from the interval $[0, C_{2\theta}(\theta)]$ to $[N, C_{2\theta}(\theta)+N]$, a blending function R_m is given by Eq.(7) and the scaling functions Sc_1 and Sc_2 are computed from Eq.(8).

The interpolation between the two values C_{1z} and C_{2z} in the $\mathbf{Uz}(\theta)$ direction is computed from Eq.(6).

$$z(\theta,t) = (1-R_k(t))(1+Sc_1(\theta,t))C_{1z}(\theta) + R_k(t)(1+Sc_2(\theta,t))C_{2z}(\theta) \quad (6)$$

where $0 \le t \le 1$a blending function R_k is given by Eq.(7) and Sc_1 and Sc_2 are the scaling functions defined in Eq.(8).

3.4 A Blending Function

A Blending function $R_n(v)$ which arbitrarily controls surface deformation between the contours C_1 and C_2 with parameter n, with G^1 geometric continuity, is given by[10].

$$R_n(v) = \frac{(1+n)v^2}{(1+n)v^2 + (1-n)^2} \quad (7)$$

where $0 \le v \le 1$, $-1 \le n$

Figure 7 shows the graph of a blending function when the parameter n changes, Figure 8(a) shows the generalized cylinder of n = -0.9, and Figure 8(b) shows the generalized cylinder of n = 9.

3.5 A Scaling Function with 3D Control Vectors

With the proposed scaling function, however the control is not allowed to arbitrary directions along the contour. We solve this limitation by adding another weight parameter k to specify a valid range where the control vectors are effective. Then scaling functions with 3D control vectors for C_1 and C_2 are given by

$$Sc_1(\theta,t) = t(t-1)(\frac{t}{k_1}-1)\mathbf{p_1}(\theta)$$
$$Sc_2(\theta,t) = -t(t-1)(\frac{t}{1-k_2}-1)\mathbf{p_2}(\theta) \quad (8)$$

where $0 \le k_1$, $0 \le k_2$ Sc_1 and Sc_2 are the scaling functions for the contours C_1 and C_2, the parameter k is a weight parameter($0 \le k$), $\{\mathbf{p_1}(\theta)\} = \{(\mathbf{p_{1r}}(\theta), \mathbf{p_{1\theta}}(\theta), \mathbf{p_{1z}}(\theta))\}$, and $\{\mathbf{p_2}(\theta)\} = \{(\mathbf{p_{2r}}(\theta), \mathbf{p_{2\theta}}(\theta), \mathbf{p_{2z}}(\theta))\}$ are 3D control vectors along C_1 and C_2 respectively.

Figure 9 demonstrates the property of a scaling function applied to free-formed surface generation, where tangent vectors along cross- section contours are used as a set of 3D control vectors.

3.6 3D Control Vectors

The following form of 3D control vectors $\mathbf{p_1}$, $\mathbf{p_2}$ are provided along contours C_1 and C_2 in the local coordinate system, as shown in Figure 6.

$$\mathbf{p_1}(\theta) = \begin{bmatrix} v_{1r}(\theta)/C_{1r}(\theta) \\ v_{1\theta}(\theta)/N \\ v_{1z}(\theta)/C_{1z}(\theta) \end{bmatrix}$$
$$\mathbf{p_2}(\theta) = \begin{bmatrix} v_{2r}(\theta)/C_{2r}(\theta) \\ v_{2\theta}(\theta)/(C_{2\theta}(\theta)+N) \\ v_{2z}(\theta)/C_{2z}(\theta) \end{bmatrix} \quad (9)$$

3.7 Algorithm

We have applied the proposed homotopy sweep method to the real time animation of mouth/lips expression.

step1 Sample key frames at every Δt from input video images according to the given sampling rate.

step2 Obtain the mouth/lips contour using 3D coordinates of marker points

step3 Compute the homotopy sweep using 3D control vectors computed along the contour

step4 Deform the 3D mouth wireframe model of mouth/lips region based on the interpolation in step3

step5 Display the 3D deformed wireframe model

3.7.1 The Mouth Model of Circular Muscle

Figure 10(b) shows a wireframe model of a mouth/lips region considering the circular muscle structure. This model consists of four nested contours along circular muscle fibers. P_0 corresponds to marker points on the outer and inner contours (cf. marker points in Figure 10(a)). Our homotopy sweep method deforms the surface according to displacement of four marker points at every Δt.

The inbetween points between the outer and inner contours (A1,A2) is correspond to $\frac{A_0A_1}{A_0A_3} = \frac{1}{3}$ and $\frac{A_0A_2}{A_0A_3} = \frac{2}{3}$ because the the ratio of displacements of circular muscle is constant along the muscle fibers.

The inbetween points on the same contour (P_1-P_9) is correspond to a point on an ellipse approximated from the four markers. In addition, the 3D shape of the muscle fibers is estimated using a cosine curve.

We compute the inbetween points on the same contour and different contours with displaced the homotopy sweep method.

4 Experiment

Figure 13 shows our hybrid system of live facial expression generation based on mixed reality technique.

We have implemented the proposed algorithm in C language on a SGI Indy R4600, and applied the algorithm to the real time generation of live facial expression. We used a CCD camera Panasonic WV-KS102 mounted on the helmet for video image acquisition. The acquired image was 628 x 492. We have obtained both range and color texture images of size 512x512 using the Cyberware Digitizer to construct a 3D CG face model.

We first analyzed the color change of the facial expression image as color texture analysis as shown in Figure 2. We nominated the region (a) in Figure 1 as the REM based on definition in Section 2. In current stage we extracted the REM manually, as shown in Figure 3, based on the definition in Section 2.

Secondly, we analyzed color in the REM and extracted the skin color as the reference color by the color histogram. Then, we adapted the color properties of (texture image of) 3D CG model for smooth merging. The result of this adaptation is shown in Table 1.

Finally, we presented the model merged with video images in Figure 4.

We also aquired images in which an examinee pronounces a set of single vowels "a", "i", "u", "e", "o". We selected each image as a key frame and we gave $\frac{1}{4}$ of displacement between the present frame and the previous frame.

Nextly, we computed the homotopy sweep between the two key frames. We have used the following parameters to compute the homotopy sweep.

- The parameter n of blending function is 0
- The parameter k of scaling function is 0.5
- The number of generated frames between two key frames is 20

Figure 11 shows original images and systhesis images.

Figure 15 shows the final result of the hybrid system in the receiver side.

5 Conclusion

We proposed a hybrid approach to Live facial expression generation based on mixed reality. We first proposed a novel approach to mixed reality, we call Augmented Virtuality, which enhances and augments the reality of complex and delicate live motions of the object in the virtual space, by projecting portions of live video images observing the deformation and motion of the object onto the surface of its static CG model.

We also proposed a new method of adapting color properties for smooth merging of real and virtual spaces, and also proposed a new method of extraction of the region effective for merging, based on the optical flow analysis of both range and color images in which in the virtual space, shape and texture changes are observed. We applied this technique to real time generation of realistic eye expression.

We then proposed the homotopy sweep method for surface deformation using 3D control vectors, and applied this technique to the animation of mouth/lips expression. Our approach has the advantages of descripting the geometric shapes and the deformation of circular muscle simply, and of reconstructing realistic deformation efficiently.

Experimental results demonstrated the effectiveness of the proposed hybrid approach in representive and visualizing live facial expression in real time.

References

[1] H.D.Foley, A.V.Dam: Fundamentals of Interactive Computer Graphics. Addison-Wesley (1982)

[2] M.Bajura, H.Fuchs: Merging Virtual Objects with the Real World. Proc.'92 SIGGRAPH (July 1992) 203-210

[3] P.Milgram: Applications of Augment- ed Reality of Human-Robot Communication. Proc.Int.conf.'93 IEEE/RSJ

[4] P.Milgram: A class of displays on the reality-vituality continuum. SPIE Vol.2351 Telemanipulator and Telepresence Techonologies (1994)

[5] P.Milgram: A Taxonomy of Mixed Reality Visual Display. IEICE TRANS. INF. &SYST. Vol.E77-D No.12 (1994) 1321- 1329

[6] M.Ueno et al.: A Construction of High Definition Wire Frame Model of Head and Its Hierarchical Control for Natural Expression Synthesis. Tech. Rep. IEICE PRU92-77 (1992-12) 9-16

[7] C.S.Choi, H.Harashima, T.Takebe: Analysis of Facial Expression Using Three-Dimensionnal Facial Model. IEICE TRANS. INF. &SYST. D-II Vol.J74 No.6 Jun 1991 766-777

[8] K.Aizawa, H.Harashima, T.Saito: A Model-Based Analysis Synthesis Image Cording Scheme. IEICE TRANS. INF. &SYST. B-I Vol.J72 No.3 Mar. 1989 200-207

[9] M.Kaneko, A.Koike, Y.Hatori: Synthesis of Moving Facial Images with Mouth Shape Controlled by Text Information. IEICE TRANS. INF. &SYST. D-II Vol.J75 No.2 Feb. 1992 203–215

[10] C.Tai, K.Loe, T.Kunii: Integrated Homotopy Sweep Technique for Compu- ter-Aided Geometric Design. Computer Vision Springer-Verlag 1991 583–595

[11] L.Moubaraki, H.Tanaka, Y.Kitamura, J.Ohya, F.Kishino: Homotopy-Based 3D Animation of Facial Expression. Tech.Rep.IEICE IE94-07Jul.1994 9-16

[12] M.Kaneko, Y.Hatori, A.Koike: Coding of Facial Images Based on 3-D Model of Head and Analysis of Shape Changes in Input Image Sequence. IEICE TRANS. INF. &SYST. Vol.J71-B No.12 Dec. 1988 1554-1563

[13] K.Mase, A.Pentland: Automatic Lipreading by Opitical-Flow Analysis. IEICE TRANS. INF. &SYST. D-II No.6 Jun 1990 796–803

Table 1: Result of Adapting Color Properties

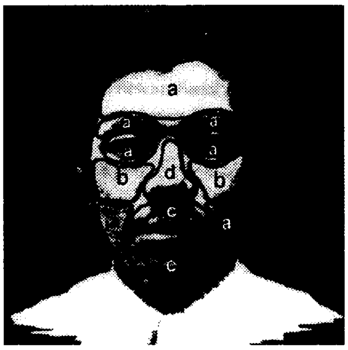
	H peak	S average	V average
Video Image	10.00	0.579	0.775
3D CG Model	15.00	0.344	0.345
Result	10.00	0.582	0.710

(H: hue, S: saturation, V: value)

Table 2: Processing Speed

Process	Process Type	FPS
Sender	Video Image Input	30
	REM Color Change Detection	17
	Mouth/Lips Motion Detection	1.2
	Change Parameters Transmission	20
Receiver	Change Parameters Input	20
	Texture Color Adaptation	0.3-30
	Mouth/Lips WF Deformation	15
	Facial Expression Generation	7

(FPS: Frames / Second)



(a). region mainly sliding along the surface

(b). region bulging or sinking against the surface

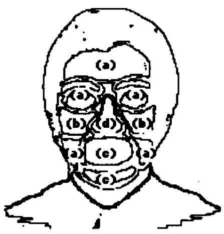
(c). smoothly deforming region

(d). stable region

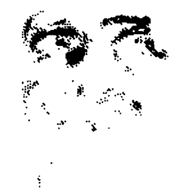
Figure 1: Face Segmentation (Ueno p15: Figure 8)

(a) Optical Flow (b) Magnitude of Optical Flow

Figure 2: Optical Flow Analysis

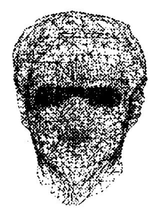


(a) Face Segmentation



(b) Magnitude of Optical Flow

(c) Extraction of REM



(d) REM on Wireframe

Figure 3: Region Effective for Merging (REM)

(a) Before Color Adaptation

(b) After Color Adaptation

Figure 4: Color adaptation result

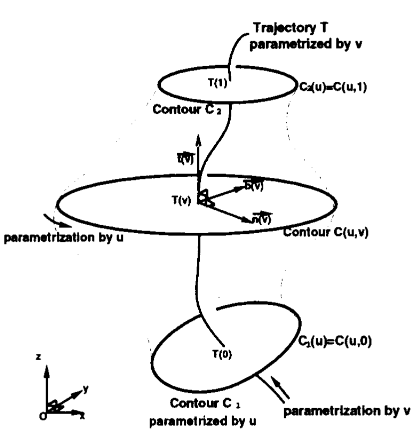


Figure 5: Definition of Homotopy Sweep Method

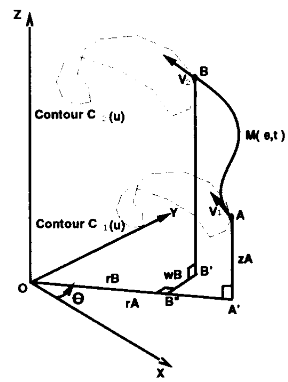


Figure 6: Cylinder Frame for Interpolation

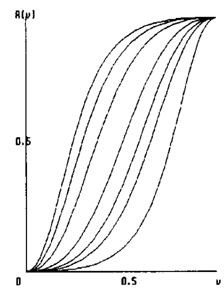
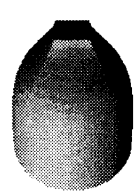


Figure 7: Blending Function R_n for Interpolation n=−0.9,−0.7,−0.5,0,2,5,9

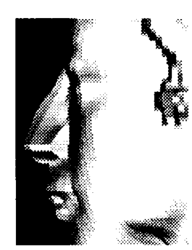


(a)n=−0.9,$S_1=S_2=0$

(b)n=9,$S_1=S_2=0$

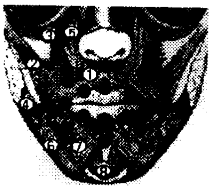
Figure 8: Generalized Cylinders based Homotopy Sweep Method

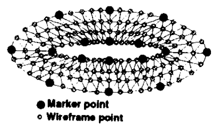
(a) Original



(b) Interpolated

Figure 9: Face Surface Modeling with Homotopy Sweep





(b) Wireframe Model

(a)1.Orbicularis oris 2.Zygomaticus major 3.Zygomaticus minor 4.Risorius 5.Levator labii superioris 6.Depressor anguli oris 7.Deprssor labii inferioris 8.Mentalis ● Marker points

Figure 10: Marker Points and CG Model

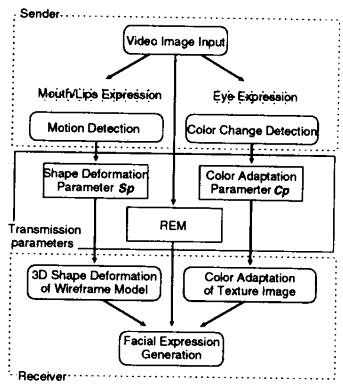
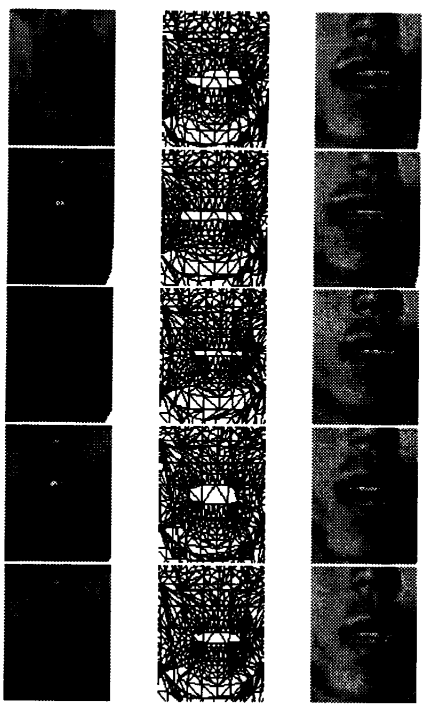
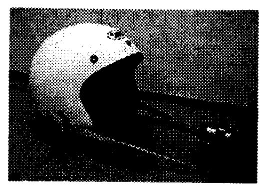


Figure 13: Hybrid System for 3D Facial Animation

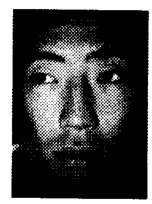


(a)Original (b)Model (c)Synthesized

Figure 11: Mouth/Lips Expression Animation With Homotopy Sweep



(a) Helmet Mounted Camera



(b) Video Image

Figure 14: Helmet Mounted Camera and Video Image

(a) Surface Model

(b) Color Texture Image

Figure 12: 3D CG Model

Figure 15: Facial Expression Animation Results