# Virtual Human with regard to Physical contact and Eye contact

Asami Takayama[1], Yusuke Sugimoto[1], Akio Okuie1, Tomoya Suzuki[1] and Kiyotaka Kato[1]

[1] Tokyo Univ. of Science,1-3 Kagurazaka, Shinjuku-ku,Tokyo 162-8601, Japan
taka@katolab.ee.kagu.tus.ac.jp

**Abstract.** In the future a virtual human is expected to play important roles such as a character, an avatar and a robot in the amusement field. To realize a virtual human computer-graphics has advantages in cost and maintenance. However, a human feels a slight discomfort at the robot's face that is represented by using CG because a robot's head in the virtual world does not fit in the environment of the real world. To resolve the problem, we have proposed a robot's head by using CG and some sensors that respond to a surrounding environment. Here, focusing on physical contact, this paper proposes a robot’s head using CG and a touch screen panel. Also, we propose robot eyes that reflect a surrounding environment realistically toward the realization of eye contact. Some experiments show that the robot’s face changes according to an environmental change like a human in the real world.

## 1 Introduction

A computer game provides us with an adventure world that we cannot experience in the real world by operating a virtual human as a character in the virtual world. When we communicate with other people through an avatar on the Internet, the communication among humans is different from ordinary direct communication. In addition, a partner-type of robot is expected to be a new creature that is not a human and not an animal. It may provide us with pleasure and contentment.

Thus, a virtual human, which is the substitution of a human or a machine, is expected to be important for our lives. In the future, a virtual human is expected to play important roles such as a character, an avatar, and a robot in the amusement field. To create a virtual human, much research about a robot’s head has been actively done. A mechanical robot’s head is one solution for creating a virtual human. It is composed of mechanical parts such as artificial skin, artificial eyes, and so on. The head is equipped with many actuators that move the parts.

On the other hand, the utilization of computer graphics (CG) is another solution for creating a robot’s head [1]. Compared to the mechanical method mentioned above, because there is no mechanical parts used in constructing a CG robot’s head, it is easy to create a robot’s head at low cost. Moreover, CG has the ability to represent a variety of appearances. For example, the following uses can be applied:

- To change a character or a hairstyle immediately according to the situation,

- To exaggerate a facial expression as a cartoon character,
- To change the shape of a face or hair.

Thus, a variety of expressions for a robot's head may enable a human to communicate with an entertainment-friendly robot. A robot's head created using computer graphics has advantages in cost and maintenance compared with a mechanical one. However, people feel a slight discomfort at the CG-created robot's head because a robot's head in the virtual world does not fit in the environment of the real world.

To realize a computer-graphic method with realistic representation, which benefits from low cost, this paper proposes creating a robot's head using computer graphics and sensors. The face and hair of a robot head should be displayed realistically according to the peripheral environment. If this is not so, the robot will feel somewhat strange to the human who communicates with it. To resolve the problem, we have proposed creating a robot's head by using CG and sensors that respond to the surrounding environment as shown in Fig. 1 [2][3].

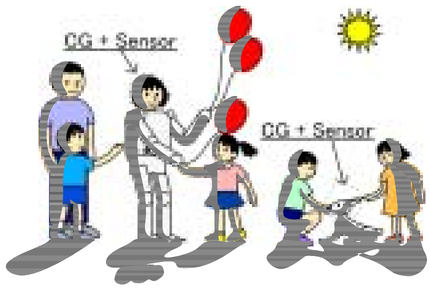



**Fig. 1.** Realization of robot's head using CG and sensors

The system had several kinds of sensors to detect the status of the peripheral environment, an estimator to calculate the status of unknown areas, and a display to represent the head of a robot. Light sources were calculated from a camera image and the appearance of the head was made to change according to the light sources. As a camera image had the information about light sources, the color, the size, and the position were calculated. In addition, the system estimated a peripheral environment by combining several pressure sensors with an analyzer using hydrodynamics. After measuring wind forces by several microphones that function as pressure sensors, it calculated the air flow surrounding the head of the robot and applied the flow to the hair. In this way, the wind-blown hair of a robot was displayed realistically. However, the previous system did not support physical contact and eye contact.

According to a report [4], physical contact is an important factor for humans when communicating with each other. Therefore, a human feels slight discomfort around a robot when touching it if the robot does not respond to physical contact. To support physical contact, this paper proposes a system that detects the pressure and position of the touched part on a touch-screen panel and modifies the geometric data of the robot's head.

Moreover, eye contact is also an important factor for humans when communicating with each other [4]. Therefore, a human feels slight discomfort around a robot when facing the robot if the robot does not respond to the surrounding object. Because eyes are the most impressive part, the robot's appearance should realistically respond to the surrounding object. In particular, the glint in the eyes and the size of the pupil can change the facial expression [5]. Thus, this paper proposes a system that captures the surrounding view and reflects it onto the robot's eyes with some physiological behaviors.

Through experimental results, this paper shows the effectiveness of the proposed system and discusses some problems to resolve for a virtual human with regard to physical contact and eye contact.

## 2 Manuscript Preparation

A system has several kinds of sensors, such as camera, a microphone and a touch screen panel, to detect the status of the peripheral environment, an estimator to calculate the status of unknown areas, and a display to represent the head of a robot. The system uses a few sensors and calculates the environmental status from the data. Our estimation is that it is important to display the head realistically.

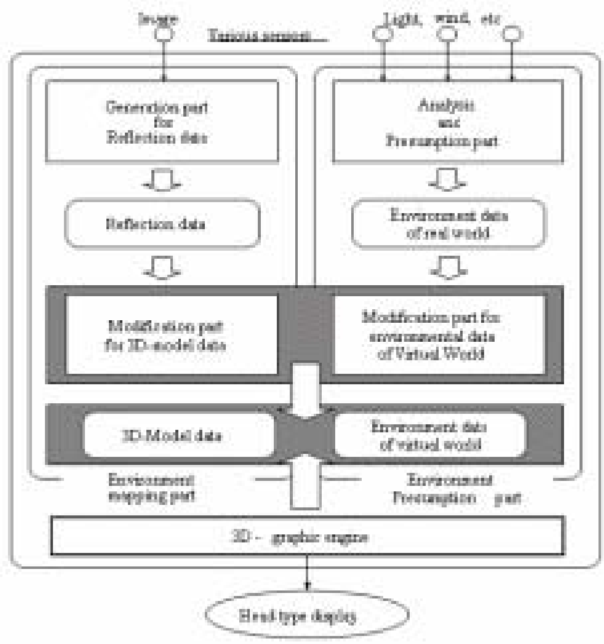



**Fig. 2.** System configuration

In the prototype system that light sources are calculated from a camera image and the appearance of the head is made to change according to the light sources. As a camera image has the information about light sources, the color, the size, and the position are calculated. Since eyes are a very important factor for a robot to communicate with a human, eyes should be rendered realistically in case of eye contact. So, getting a camera image and applying it to the robot's eyes, the reflection of a confronted human in the eyes is realized using texture-mapping technology. In addition, the system estimates a peripheral environment by combining plural pressure sensors with and analyzer using hydrodynamics. After measuring wind forces by plural microphones that function as pressure sensors, the system calculates the airflow surrounding the head of the robot and applies the flow to the hair. In this way, the wind-blown hair of a robot is displayed realistically. Physical contact is important for a robot to communicate with a human. The system uses a touch screen panel so as to realize the physical contact. When a human touch the robot's face, the touched part is caved in.

## 3 Robot's head using CG and a touch-screen panel

A robot uses a surface acoustic wave touch-screen panel as a touch-sensitive sensor that detects pressure intensity and coordinates at a touched position. Based on the data derived from the touch-screen panel, the shape of a robot's head is modified by moving the coordinates of the vertexes that compose the polygons of a 3D model.

### 3.1 Shape modification for skin

This section describes a method for modifying of the skin of a robot's face. Fig. 3 shows a skin model that is represented by a 3D polygonal model, and the close-up of the part. The model is composed of triangular polygons.

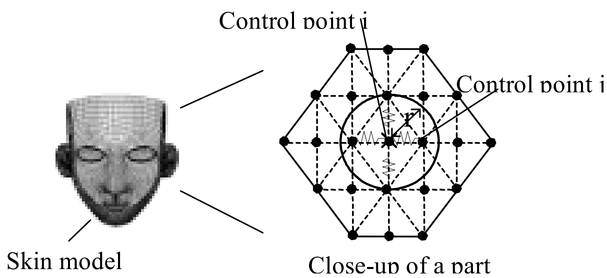



**Fig. 3.** Skin model

First, by pushing a touch-screen panel, the pressure and coordinates of the part applied are detected. Because the detected coordinates are two-dimensional, they are converted into three-dimensional ones in the virtual space. Assign the touched point in the 3D space as $A$.

Next, the distance between the touched point $A$ and each vertex $P_F$ of the polygons for a face model is calculated as $d_F = | P_F - A |$. Then, each vertex is moved according to the distance $d_F$. The moved vertex is calculated by

$$P_F' = P_F + (f + d_F) V, \quad (1)$$

where the moving direction of the vertex $V$ is backward in front of the screen, and f is the pressure obtained from the touch-screen panel.

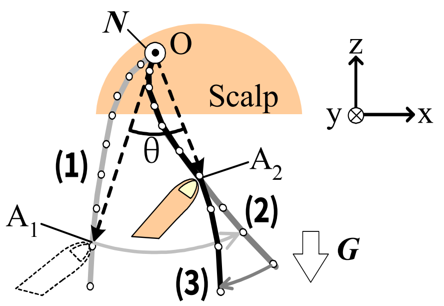



**Fig. 4.** Hair model

### 3.2 Shape modification for hair

This section describes a method for modifying the hair of a robot's head. Fig. 4 shows a scalp model and a hair model. The plural line segments that connect the vertexes represent the hair model.

As with the method for skin modification, based on the coordinates of the touched point $A$ and the pressure f, each vertex of the line segments of the hair model $P_{Hi}$ is calculated using the following equation:

$$P_{Hi}' = P_{Hi} + (f + d_{Hi}) V, \quad (2)$$

where $d_{Hi} = | P_{Hi} - A |$ is a distance between the vertex $P_{Hi}$ and the touched point $A$. Then, the updated coordinates of the vertexes move the line segments.

In the case when a finger continues to touch the hair, the hair model changes as follows:

1. First, find which hair is touched. Let $A_1$ to be a current touched point, and let $O$ to be the hairline of a touched hair.

2. Next, let $A_2$ to a touched point after the finger moves. And let $\boldsymbol{\theta}$ to be the angle that two vectors $OA_1$ and $OA_2$ make. Then, rotate the hair around the axis $N$, which is obtained from the vector product $N = OA_1 \times OA_2$.
3. Finally, apply the gravity $G$ to every vertex form the vertex that is the nearest to the touched point to the end of the hair.

## 4 Robot's eyes using CG and a camera

A robot uses a camera as a sensor in order to acquire a surrounding view and uses a light source as an image. By mapping the image texture onto the robot's eyes, the realistic reflection of the surrounding environment is represented. Moreover, to realize a physiologic response, the pupil diameter is varied according to the surrounding brightness, which is calculated from the camera image.

### 4.1 Realization of reflection

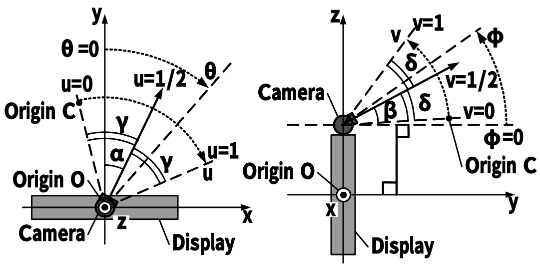



**Fig. 5.** Location of camera and display

Set each x-axis, y-axis, z-axis as follows:
The x-axis is horizontal leftward, the y-axis is forward, and the z-axis is vertical upward on a display. The camera angle in the xy plane is $\alpha$, and the angle in the yz plane is $\beta$. The viewing angle of the camera is $2\gamma$ in the horizontal direction, and $2\delta$ in the vertical direction. The camera can obtain an image of the range within $\alpha - \gamma \leq \theta \leq \gamma + \alpha$, $\beta - \delta \leq \varphi \leq \beta - \delta$ from viewpoint of the origin $O$. Moreover, the u-axis is horizontal rightward, and the v-axis is vertical upward on a texture plane, and the texture origin C(0,0) is at the bottom-left corner. The whole pixels of texture are defined as $0 \leq u \leq 1$, $0 \leq v \leq 1$.

The following describes the method of texture-mapping the surrounding image onto the robot's eyes. First, the texture image is generated from the camera image. Then, the texture coordinate (u,v) is calculated in relation to each vertex coordinate (x,y,z) of a polygon that composes a three-dimensional model. The two-dimensional coordinate (u,v) of the texture is obtained as

$$u = \frac{\theta - \alpha}{2\gamma} + \frac{1}{2}, \quad v = \frac{\phi - \beta}{2\delta} + \frac{1}{2} \tag{3}$$

Then, the three-dimensional coordinate of the existing 3D model is expressed as a Cartesian coordinate (x,y,z) and a polar coordinate ($\rho,\theta,\varphi$) as in Fig. 5. The relationship is given as follows:

$$\rho = \sqrt{x^2 + y^2 + z^2}, \quad \theta = \arctan(x / y), \quad \phi = \arcsin(z / \rho) \tag{4}$$

Therefore, there is the following relationship between each u, v, and x, y, z:

$$u = \frac{\{\arctan(x/y)\} - \alpha}{2\gamma} + \frac{1}{2}, \quad v = \frac{\left\{\arcsin\left(z / \sqrt{x^2 + y^2 + z^2}\right)\right\} - \beta}{2\delta} \tag{5}$$

The texture coordinate (u,v) is calculated by substituting the vertex coordinate (x, y, z) for the equation. Next, the blending ratio of the texture and color of the polygon's surface is decided based on the 3D model's material data on mirror reflectivity and transparency. Finally, texture mapping is applied to a 3D model using the acquired texture.

### 4.2 Realization of pupils and eyelids

The following description refers to the method of determining the pupil diameter and the distance between eyelids from the surrounding brightness, which is calculated from the camera image.

First, the whole pixels for RGB average $\bar{r},\bar{g},\bar{b}$. Then, the radiance value Y is translated from the acquired image in 8-bit YUV format because the image is expressed in 8-bit RGB format in this system.

$$Y = 0.299\bar{r} + 0.587\bar{g} + 0.114\bar{b}. \tag{6}$$

Then, assign the radiance value Y to be an indicator of the surrounding brightness. The diameter of a pupil "d" is given by the following equation because the diameter of a human's pupil is proportional to the logarithm of surrounding brightness. The symbols "max" and "min" represent the maximum and the minimum of the pupil diameter, respectively. The symbol "a" is a proportional constant.

$$\begin{aligned} d &= \max - a \times \log Y && when \quad 1 < Y < \sqrt[a]{10^{\max - \min}} \\ d &= \max && when \quad Y \leq 1 \\ d &= \min && when \quad Y \geq \sqrt[a]{10^{\max - \min}} \end{aligned} \tag{7}$$

Moreover, the distance between eyelids "s" is determined in relation to the pupil diameter "d" using the following equation. The eyelid is a constant w that is the distance between eyelids when a robot squints the most.

$$s = w \times \frac{\max - d}{\max - \min} \tag{8}$$

# 5 Experiment

## 5.1 Experimental methods

The following experiments are performed as a verification of the above-mentioned system. An overview is shown in Fig. 4.

1. Observe the change in the robot's head by touching the face of the robot.
2. Observe the change in the robot's head by stroking the hair of the robot.
3. Observe the change in the robot's head by moving the surrounding object.
4. Observe the change in the robot's eyes by moving a light source.

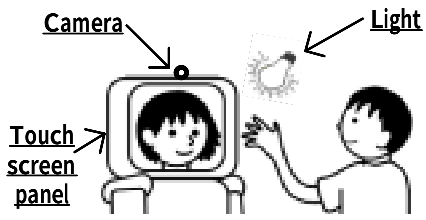



**Fig. 6.** Overview of the esperiments

## 5.2 Experimental results

**1. Changes when the robot's face is touched**

The changes when the robot's face is touched are shown in Fig. 7.1 and Fig. 7.2. Fig. 7.1 shows the changes when the right cheek is touched, and Fig. 7.2 shows the changes when the eyelid is pulled down.

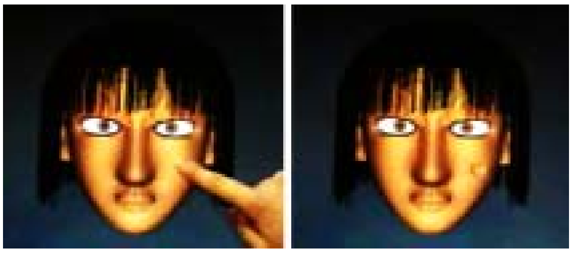


**Fig. 7.1.** Changes when the right cheek is touched

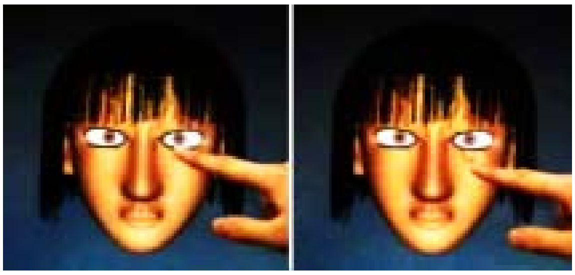


**Fig. 8.2.** Changes when the eyelid is pulled down

### 2. Changes when the hair of the robot is stroked

The changes when the robot’s hair is stroked are shown in Fig. 8.1 and Fig. 8.2. Here, Fig. 8.1 shows the changes when the robot’s fringe of hair is stroked from left to right, and Fig. 8.2 shows the changes when the robot’s hair is stroked from the ends to the roots.

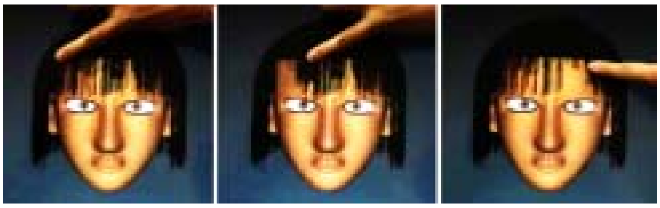


**Fig. 9.1.** Changes when the robot's fringe of hair is stroked from left to right

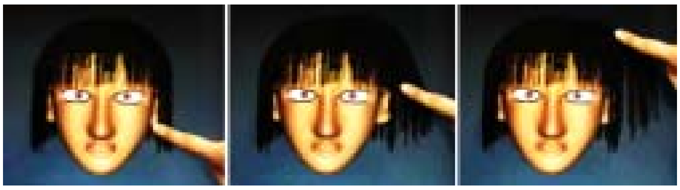
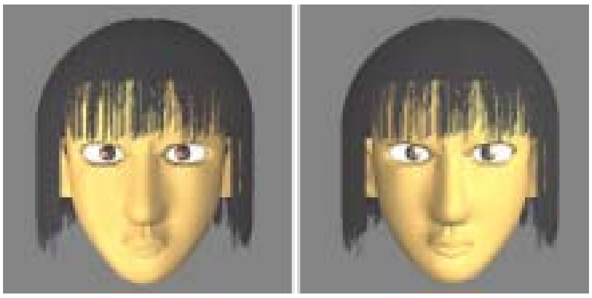


**Fig. 10.2.** Changes when the robot's hair is stroked from the ends to the roots

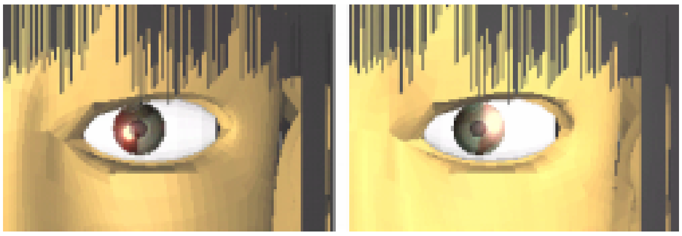
### 3. Changes when the surrounding object is moved

The changes when a light source is moved from the left to the right are shown in Fig. 9.1. The zoomed-in one is Fig. 9.2.



(a) The light is at the left (b) The light is at the right

**Fig. 9.1.** Changes in the head when the light source is moved

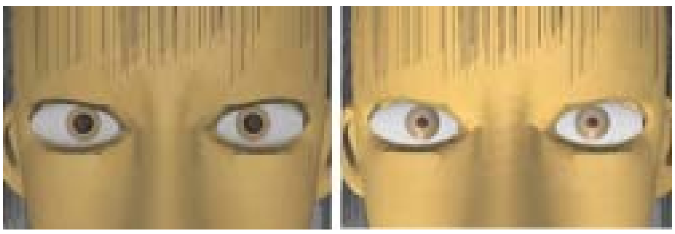


(a) The light is at the left (b) The light is at the right

**Fig. 9.2.** Changes in the eyes when the light source is moved (zoomed-in)

**4. Changes when the environmental brightness is changed**

The changes when the environmental brightness is changed are shown in Fig. 10.



(a) In the dark (b) In the light

**Fig. 11.** Close-up of the robot's eyes when the environmental brightness is changed

## 5.3 Considerations

**1. Changes when the robot's face is touched**

Fig. 7.1 and Fig. 7.2 show the following changes in the robot's face:

- The touched part caved in when a human touches the robot’s face.
- The harder the robot’s face is touched, the larger the area of skin caved in.

A human felt these changes to be realistic (similar to a real human) except for the discomfort of the hardness of the screen panel.

**2. Changes when the robot’s hair is stroked**

Fig. 8.1 and Fig. 8.2 show the following changes in the robot’s hair:

- The robot’s hair is raised from the hair root to the touched position, and hangs down from the touched part to the bottom.
- The harder the hair of the robot is touched, the more the hair is curved.

A human felt these changes to be similar to the changes in a human’s hair.

**3. Changes when the surrounding object is moved**

Fig. 9.1 and Fig. 9.2 show the following changes in the robot’s head:

- We can see ourselves in the robot’s eyes when sitting down in front of the robot face to face.
- The color and shape of a surrounding object appears on the surface of the eyes and the entire head of the robot.
- The closer a surrounding object comes to the robot, the larger the object’s image appears on the surface of the entire head.
- When a surrounding object moves, the object’s image on the surface of the head and the hair moves in the same direction.
- The image of the surrounding object that appears on the surface of the eyes is clearer than the one on the face and the hair.

A human felt these changes to be similar to the changes of the surrounding environment.

**4. Changes when the environmental brightness is changed**

Fig. 10 shows the following change in the robot’s eyes:

- The brighter a light source becomes, the smaller the robot’s pupils become.

A human felt this change to be similar to a real human.

## 6 Concludion

Physical contact and eye contact are important factors in creating a virtual human for amusement. This paper has proposed a new robot system that communicates with a human by physical contact and eye contact using computer graphics and sensors. From these experimental results, we can obtain the following conclusions:

1. The part of a robot’s face where a human touches caves in realistically according to the touch pressure. And, the hair of a robot realistically moves when being stroked.
2. A surrounding view and brightness obtained from a camera are realistically reflected onto the robot’s eyes. A human can see himself or herself in the robot’s eyes when communicating with it face to face.

Although these experiments are simple, we can say that it is expected that our idea could provide physical contact and eye contact in a practical way in the future because of the low cost.

Facial expression is important for a human when communicating with a virtual human. Because the prototype does not support facial expressions, a human feels slight discomfort when around the robot. A mental model and a physiologic model have to be introduced. And the improvement of a geometric model, especially a surface model, is also a key factor in creating realistic facial expressions.

## References


1. O. Hasegawa: "Roles of Visual Functions in Multimodal Interface and Their Applications," *IPSJ SIG-CVIM & SIG-HI Organized Session: HI-95 & CVIM-129-23*, pp.165-170 (Sep. 2001).
2. M. Arai, T. Suzuki and K. Kato: "Human-Robot Interface using Computer Graphics and Sensors," *6th Japan-France Congress on Mechatronics & 4th Asia-Europe Congress on Mechatronics September 9-12*, pp. 374-379 (2003).
3. T. Suzuki, M. Arai and K. Kato: "Realization of Robot's head using Computer Graphics and Sensors," *The Robotics Society of Japan the 21st Conf.*, p. 3F17 (2003).
4. Marjorie **F**. Vargas, T. Isimaru translation: "Nonverbal Communication," Shincyosya Co., pp. 15-17 (1987).
5. Y. Hukui: "Psychology of Look," Sougensya, (1984).