# Chapter 6
# Emotional Design in the Virtual Environment

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**Abstract** In order to realize human-centric design, the design specification should be based not only on the functional aspects of the product but also on an emotional evaluation, such as the impression gained from the shape or the size of the designed model. A virtual environment in which the designed model is visualized interactively using a full-scale stereo image can be used effectively as a method of emotional evaluation. Design support and design evaluation using virtual reality, augmented reality, and tele-immersion technologies are discussed. The collaborative design between designers or between designer and customer is achieved using video avatar technology in the tele-immersion environment. In addition, a design education program that includes the emotional evaluation in the virtual environment is also introduced.

## 6.1 Introduction

Recently, human-centric design has been become an important concept in various fields. The specification for products designed for humans should be based not only on their functional aspects, such as their size and strength, but also on emotional qualities, including the impression the user derives from the shape and size of the designed product. Although rapid prototyping is often used to evaluate the shape of a design based on kansei and the emotional response of the user, it is difficult to make a full-sized model. Thus, there is a need for an evaluation method in which the user can visualize an actual sized model in the virtual environment using virtual reality technology [1]. This chapter discusses the current technology

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trends, which include recent research in design support, design evaluation, and collaborative design using virtual reality, augmented reality, and tele-immersion technologies.

## 6.2 Design in the Virtual Reality Environment

### *6.2.1 Interactive Visualization*

Virtual reality is a simulation technology that realizes an interactive virtual experience using high-presence images such as stereo or wide field of view images as well as sound and haptic sensation information. In order to achieve a virtual reality experience, special devices are being used. For example, interactive stereo images are represented using a goggle-type HMD (head mounted display) system that the user wears on his or her head or an IPT (immersive projection technology) system that uses projectors and multiple screens [2].

Figure 6.1 shows K-Cave, the CAVE-type immersive projection display developed at Keio University [3]. In Figure 6.2 the configuration of this system is shown. This display consists of multiple screens placed to the front, left, and right of the user, and also on the floor. A three-dimensional image space can be generated by projecting synchronized stereo images onto each screen. A stereo image is generated as follows: two DLP projectors with circular-polarizing filters are used for each screen to project passive stereo images. The user wears stereo glasses with the same polarizing filters in order to experience the stereo images, based on the binocular parallax by seeing the right eye image and the left eye image separately. In addition, an electromagnetic sensor that measures three-dimensional position and orientation information in space is attached to the glasses, which enables the images corresponding to the user's view position to be generated interactively by tracking the user's head position.

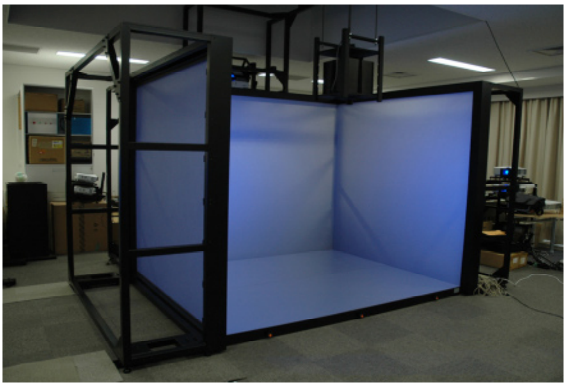

**Figure 6.1** Immersive projection display K-Cave

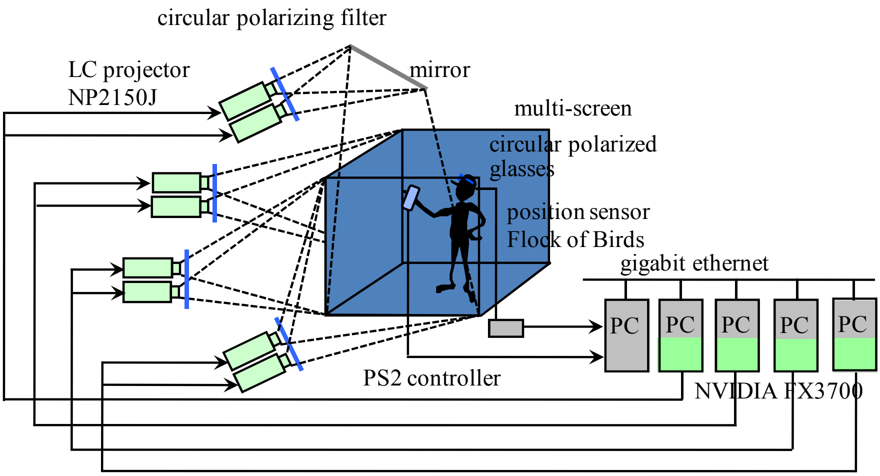


**Figure 6.2** System configuration of the K-Cave system

In this kind of virtual reality system, since the user can feel a sense of depth and obtain a sense of the size of the displayed image using the effect of binocular parallax, he or she can evaluate the size of the displayed object based on a sensation of the actual size. Moreover, since the image seen from the user's viewpoint is represented using tracking data, the displayed image can be seen from various directions interactively, enabling the user to evaluate its three-dimensional shape. Thus, it is expected that the virtual reality environment can be used as a support environment for kansei and emotional evaluation, in which the user can evaluate whether the sense of size or shape experienced from the model design satisfies his or her demands. Figure 6.3 shows an example where the user is looking at a three-dimensional full-sized model in the immersive virtual environment.

**Figure 6.3** Visualization of a three-dimensional model in the CAVE system

### 6.2.2 Haptic Sensation

Virtual reality technology utilizes not only visual sensation but also other sensations. When we recognize the shape and surface quality of an object, we usually touch the object and hold it in our own hands to get a feeling for it. Therefore, it is very important to use haptic sensation in the virtual reality environment together with visual information. Haptic sensation can be roughly classified into force feedback sensation and tactile sensation.

The force feedback device generates a reaction force from the object to the user's hand or fingertips so that the user can recognize the shape of the virtual objects. As a means of generating a reaction force, several methods have been proposed, including the use of a motor, string, master arm, or exoskeleton structure for the arm or finger. For example, commercial devices such as PHANToM, where the reaction force is represented through a pen, and CyberGrasp, which uses a hand exoskeleton structure, have been developed [4, 5].

Figure 6.4 shows a user wearing the force feedback device HapticGEAR in the CAVE system [6]. In this device, four strings are attached to the pen held in the user's hand, and the reaction force is generated by winding the strings from the corners of the frame on the shoulders using DC motors. This device has the advantage of being a wearable force display that can be used in the CAVE-type immersive projection display, though the direction of the generated reaction force is limited to the frustum shaped by the four strings. By using this device, the user can feel the reaction force from the visualized model and recognize its three-dimensional shape.

**Figure 6.4** Wearable force feedback device HapticGEAR

On the other hand, tactile sensation includes the sense of touch, the sense of temperature, and the feeling of the texture, such as the smoothness or roughness that we feel by tracing the surface of an object with our fingertip. The tactile display represents these kinds of sensations based on computer simulation. In order to generate a tactile sensation, several methods have been proposed and used, such as utilizing air pressure, a pager motor, a micro pin array, wind pressure, and electrical stimulation. Whereas the pager motor only represents the sense of touch, the micro pin array can represent the feeling of texture by controlling the stimulation pattern according to the movement of the user's fingertip.

Figure 6.5 shows a tactile data glove, named the VibroGlove [7]. In this device, 17 pager motors are attached to the data glove, on the palm and on each side of the fingers. This device can represent the sense of touch by vibrating the pager motor at the point touching a virtual object. In addition, since it can represent the movement of tactile stimulation by controlling the vibrating part, a flow field can be generated using tactile sensation. In this figure, the user is investigating the air flow around the model of an airplane using tactile and visual information, and the result of the evaluation can be used as feedback for the airplane design. Thus, the haptic sensation can be used effectively for designs based on an emotional evaluation.

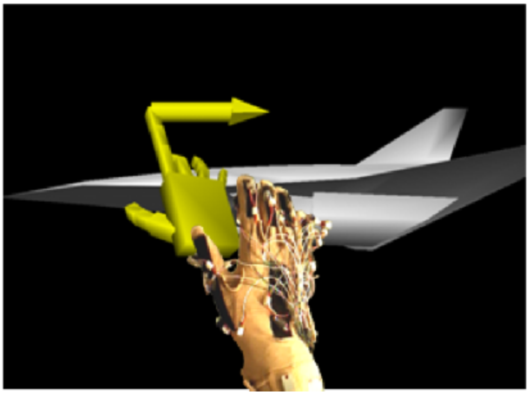

**Figure 6.5** Tactile data glove VibroGlove

## 6.2.3 Application of VR to Design

Virtual reality technology using three-dimensional space has been applied to product design in various research fields.

For example, in the field of architectural design, the user can evaluate a model of a building or office by visualizing it as a full-scale stereo image. Though the architectural strength or the seismic isolation structure can be evaluated using computer simulation, it is impossible to evaluate the sensation derived from the size or height of the building by looking at design data only. These sensations can be evaluated by experiencing an actual-sized model visualized in the virtual environment.

The virtual space can also be effectively used for evaluating furniture or equipment in a room. For example, when a kitchen is customized, the user can evaluate the position of a faucet or the height of a shelf based on his or her body size through their experience in the virtual environment.

Recently, in the car industry, a large-screen immersive projection display has often been used for evaluating designs and presenting them to customers. At the design stage, the immersive environment can be used to evaluate the position of the steering wheel or to design the front panel by visualizing them with full-scale models based on CAD data. In this case, the interaction, in which the position and color of the car parts can easily be changed in real time while the user is evaluating them sitting on a virtual driver's seat, is very valuable. Moreover, since it is also possible to present the car to the customer with a high-quality presence by visualizing a full-scale model of it, the virtual car can be exhibited with the various options available, creating a virtual showroom.

## 6.3 Design Using an Augmented Reality Environment

### *6.3.1 Integration of Virtual Image with Real World*

Augmented reality is a technology that integrates the virtual image with the real world, though the virtual reality generates the complete virtual world without the real scene. For typical augmented reality display systems, HMD and IPT are used. HMD systems for augmented reality are classified into optical see-through systems and video see-through systems. In an optical see-through system, the user can see the augmented reality world where the computer graphics image of the virtual world is integrated with the real world scene using a half mirror. On the other hand, in a video see-through system, the real scene is captured by a video camera attached to the HMD and the user sees the augmented reality image generated by superimposing a computer graphics image onto the captured video image.

The IPT system for augmented reality generally uses the optical see-through method by placing a large half mirror in the room, and the user can see an integrated scene of the real world and a reflected computer graphics image projected onto the floor or ceiling screen. This method is often called spatial augmented reality technology since it uses the actual space around the user as the augmented reality world [8].

### *6.3.2 AR View*

Figure 6.6 and Figure 6.7 show the appearance and system configuration of the spatial augmented reality display named AR View [9]. In this system, a large semi-transparent 2.0 m by 2.6 m mirror film is placed on the floor at an angle of 45 degrees, and an active stereo image with a wide field of view is projected onto the floor screen using two DLP projectors fixed to the ceiling. The user can experience the augmented reality world where the real object behind the half mirror film and the computer graphics image are integrated, by wearing LC shutter glasses with an electromagnetic position sensor.

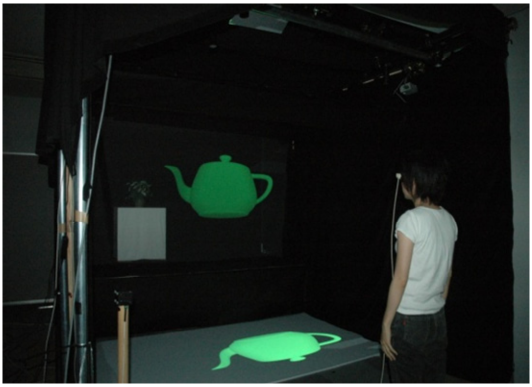

**Figure 6.6** Spatial augmented reality display AR View

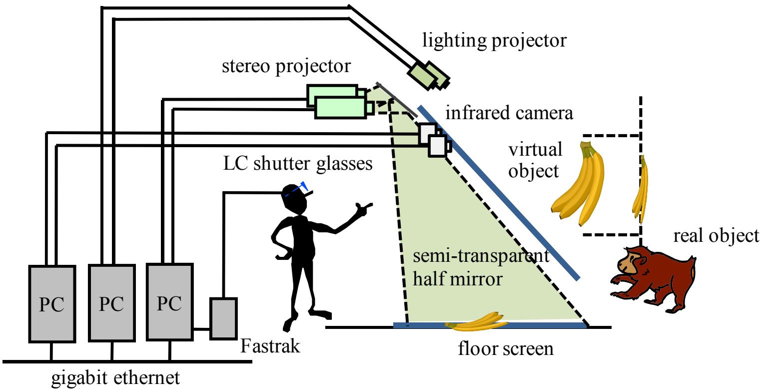


**Figure 6.7** System configuration of AR View

It is generally difficult for an augmented reality display using a semi-transparent mirror to represent the correct occlusion when virtual objects overlap real objects. When virtual objects are located behind real objects, the occlusion effect can be represented by rendering a black shadow on the virtual objects. On the other hand, when real objects are located behind virtual objects, parts of the real objects should be occluded. In this system, the correct occlusion effect is realized by using a lighting projector technique, as shown in Figure 6.8 [10].

This technique is used to illuminate the real object using projectors instead of standard light bulbs. In this system, low brightness LED projectors of 15 lumens are used. Since the real object is illuminated by a projector using white light, an occlusion shadow can be created on the real object where it overlaps the virtual object without illuminating it. In order to implement this method, it is necessary to create models of the shape of the virtual and real objects in the computer and calculate the shadow according to the movement of the user's head. Therefore, in cases where the shape or location of the real object is changed, an infrared multi-camera system is used to measure the shape of the real object and to realize the correct occlusion effect using the lighting projector.

By using this technique, an integrated scene of the designed model and real objects can be correctly represented.

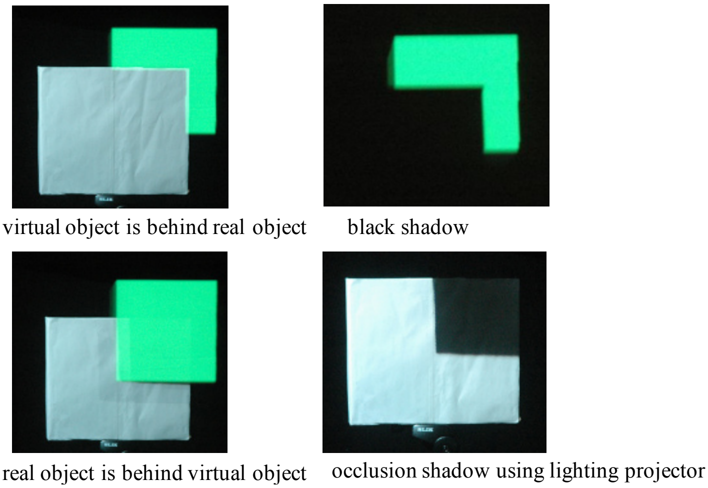


**Figure 6.8** Correct occlusion effect using the lighting projector technique

## *6.3.3 Application of AR to Design*

When augmented reality technology is applied to design support or design evaluation, a three-dimensional design model can be displayed together with a real world scene. In this case, there are various forms of integrating real objects and virtual objects, such as visualizing a three-dimensional object in real space or visualizing the design space around real objects.

For example, when a user is planning to buy furniture or an electrical appliance, he or she can evaluate whether these objects are suitable for their room, by looking at the visualized images of these products overlapping with their real room using the augmented reality devices. And when the user is thinking of buying a new house or a building under construction, it becomes possible to judge the ease of use of the room based on kansei and an emotional evaluation by visualizing the virtual house or building as a background to his or her real furniture or appliances.

## 6.4 Emotional Communication

In order to realize human-centric design, it is important to transmit emotional information between humans. When large-scale products or systems are developed, it is impossible for them to be completed by one person, and many people have to collaborate to carry out the work. Moreover, communication between the designer and the customer is also necessary to design easy to use products. In these cases, it is important to realize emotional communication, whereby the remote user can share not only design data but also kansei and emotional information such as what he is looking at or what he is thinking about.

In order to realize high-presence communication remotely, we are constructing a tele-immersion environment by connecting together several CAVE-like immersive projection displays and developing video avatar communication technology. The details and current status of the video avatar communication technology in the tele-immersion environment are discussed in the following sections.

### *6.4.1 Tele-immersion Environment*

In this research, several virtual reality displays were connected as shown in Figure 6.9 through the JGN2plus (Japan Gigabit Network 2 plus), which has a bandwidth of 20 Gbps, as the backbone for constructing the tele-immersion environment [11]. CAVE-type immersive projection displays at Keio University, The University of Tokyo, University of Tsukuba, and Kyoto University were used. In addition, super high-definition tiled displays at Keio University, Iwate Prefectural University, Kyoto University, and Osaka University were used [12].

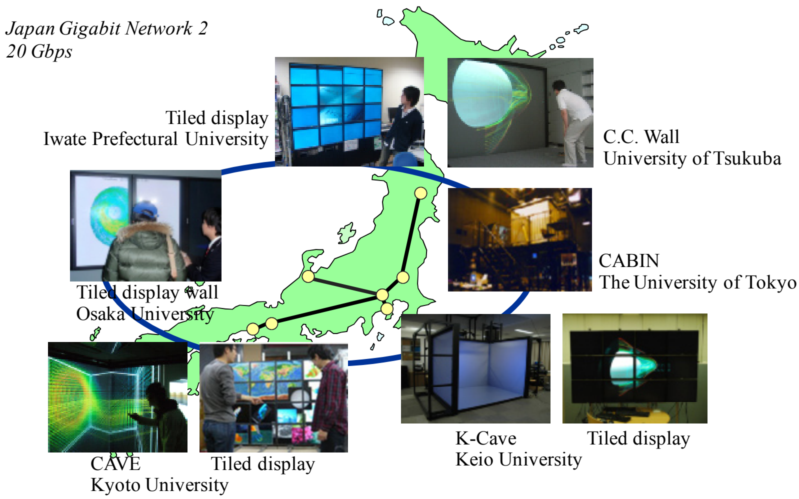


**Figure 6.9** Tele-immersion environment using the JGN2plus

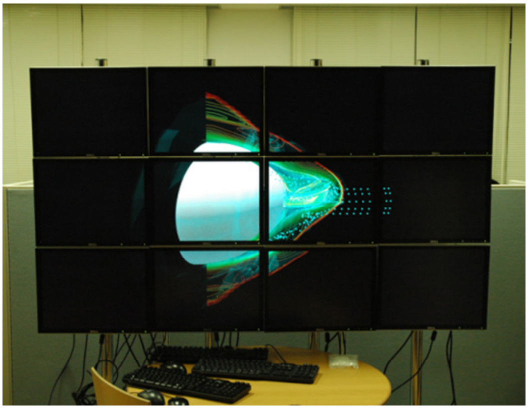

**Figure 6.10** Super-high-definition tiled display

In the networked CAVE display, visualization data can be shared in the immersive virtual environment with a wide field of view. On the other hand, the tiled display, which is constructed by arranging several LC monitors, can be used as a super-high-definition display environment with a large display area. Figure 6.10 shows the tiled display system at Keio University. Though the current tiled display does not support stereo images, it can be used effectively to display a large amount of information, including text and image data. This network environment can be used effectively for communication sharing of large-scale visualization data.

### *6.4.2 Video Avatar Technology*

For communication in the tele-immersion environment, video avatar technology was developed [13]. The video avatar can be used to achieve high-presence and emotional communication in the networked virtual environment. In this method, the user's figure is captured by a video camera and this image is transmitted to another site. At the receiving site, the user's image is segmented from the background and synthesized as a video avatar in the shared virtual world. By performing this process mutually between remote sites in real time, the video avatar can be used as a communication method.

Figure 6.11 shows the method of generating a video avatar. In this method, the user's image is captured by an IEEE1394 camera at 15 Hz. The background subtraction method that calculates the difference between the user's image and the background image captured beforehand is used to segment the user's figure from the background. In this case, since the view position of the user is measured by the position sensor at each site and is transmitted to the other site together with the user's image, the video avatar image can be placed at the position where the remote user is. The video avatar can be synthesized in the shared virtual world in real time by texture mapping the video image onto the video avatar model.

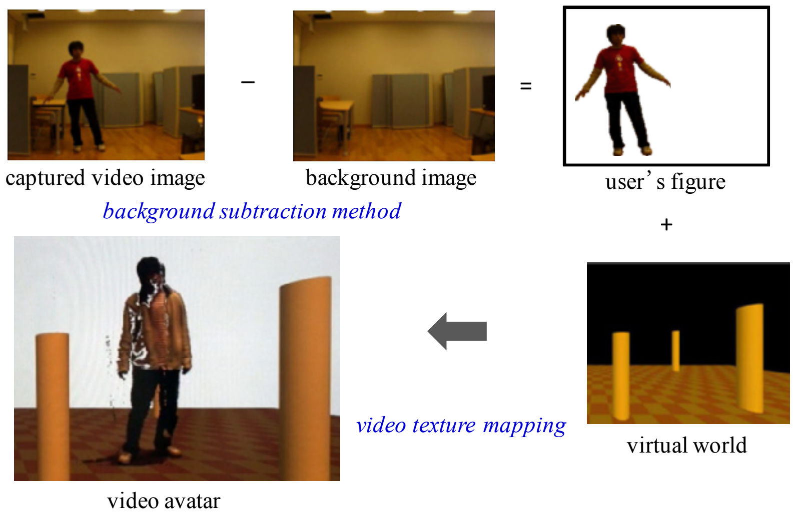


**Figure 6.11** Video avatar generation method

Various methods are used to create the video avatar model, such as a simple two-dimensional billboard model, a 2.5-dimensional surface model generated from a stereo camera image, and a three-dimensional voxel model reconstructed from multi-camera images. Figure 6.12 shows the construction methods of various video avatar models [14].

In the case of a two-dimensional video avatar (Figure 6.11 (a)), although the video avatar is placed at the three-dimensional position, the avatar itself is represented as a two-dimensional image, so that gestures such as pointing at objects with the index finger cannot be accurately transmitted to the other user. When the 2.5-dimensional video avatar is used (Figure 6.11 (b)), it can represent the three-dimensional gesture of the user because it has depth information. However, when observed from the side, the user sees a defective model of the avatar because it has

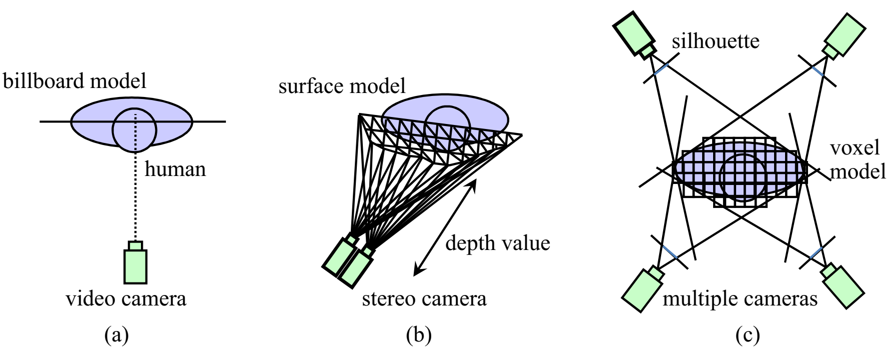


**Figure 6.12** Construction methods of the video avatar model: (a) 2D video avatar, (b) 2.5D video avatar, and (c) 3D video avatar

a shape model only for the camera direction. Therefore, when the representation of an accurate three-dimensional gesture is necessary for communication between multiple users, the only effective method is to generate the video avatar using the three-dimensional model.

Figure 6.11 (c) shows the method of constructing the three-dimensional video avatar using shapes from the silhouette method. This method can reconstruct three-dimensional voxel shapes from the intersection of back-projected cones of silhouette images that have been captured by multiple cameras. Though the representation of a voxel shape has large errors when few video cameras are used, the accuracy of the approximate shape model would be much higher if the number of cameras were to be increased. By selecting the video image captured from the direction closest to the other user's view position and mapping it onto the voxel model as video texture, a three-dimensional video avatar can be generated. Though the three-dimensional video avatar is superior to the two-dimensional or 2.5-dimensional video avatar in its ability for expression, it is inferior to them in image quality, since it depends on the accuracy of the voxel data, the calculation time for reconstructing the three-dimensional model, and the amount of transmission data. Therefore, several problems must be solved to represent a high-quality image of a three-dimensional video avatar in real time.

### *6.4.3 Video Avatar Communication*

Emotional communication in the shared virtual world is expected to be used effectively for the product design in various fields. For example, although a lot of people such as designers, experimental engineers, and computer scientists are engaged in the design phase, these people are not usually in the same location. Therefore, it is desirable that remote users can have discussions with each other while sharing visualized design data between remote places. In this case, the high-presence communication techniques that transmit emotional information are expected to be very effective.

In addition, communication is important not only between designers but also between designers and customers. The customer usually cannot evaluate whether the designed product satisfies his or her requirements before seeing the completed product. Moreover, the customer's requirements often change after he or she has seen the completed model. Therefore, this type of communication is expected to be an effective way for the designer and customer to discuss designs in the design phase while looking at visualized full-scale three-dimensional models in the shared space.

Figure 6.13 shows a remote user having a discussion with another user's video avatar while sharing the three-dimensional model in the networked CAVE environment. In this method, since each user can walk through freely in the shared virtual space, the positional relationship between them can be represented correctly, and they can discuss standing side by side looking at the visualized model from the same direction or stand face to face to look at the model from opposite directions. Thus, remote users are able to perform the kansei and emotional evaluation in the high-presence communication environment [15].

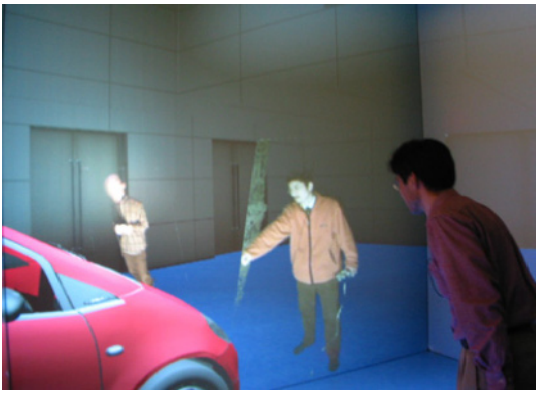

**Figure 6.13** Video avatar communication sharing the designed model

## 6.5 Education of Emotional Design

In order to spread the concept of human-centric design based on emotional evaluation, it is necessary that the designers themselves acquire it as a practical design method, and not just as a demonstration or experiment. Therefore, design education that includes not only the functional specification but also human-centric emotional evaluation is necessary.

For such a purpose, the authors are experimentally assembling a design education program, which includes emotional evaluation in virtual space, for a class in the graduate school. In this class, about 20 students are taking a seminar which includes emotional design in virtual space as well as geometrical and functional design using CAD and CAE Tools. For example, when a chair is designed, they are given the design parameters of favorite shape and appropriate size for the user's body, as well as functional specifications such as the weight of the chair, the strength needed to support the user's weight, and the stability for tilting.

The students first make a rough design of their favorite shape using the CAD system CATIA and confirm the three-dimensional shape in the stereo vision display. In this phase, they can recognize the difference between the impressions felt from the two-dimensional image and the three-dimensional stereo image, and they often change their design concept. After designing the rough shape, they calculate the weight of the chair, the strength for the user, and the stability for tilting by using the structural analysis function of CATIA. They then decide the dimensions and select the materials. Moreover, at this stage they also evaluate the height and area of the seat by visualizing a full-scale model in the K-Cave immersive projec-

**Figure 6.14** Evaluation of the designed chair using the K-Cave system

tion display environment. Figure 6.14 shows a student evaluating the shape and height of the seat by visualizing a stereo image in the K-Cave system. By conducting the functional and emotional evaluation repeatedly, the product that satisfies both functional and emotional specifications is designed. At the end of the class, each student has a presentation in the stereo display environment to explain the concept and the features of his or her design.

This class is considered to be useful to allow the students to gain an understanding of the importance of human-centric design based on an emotional evaluation, such as the user's impression of the size and shape of the product, as well as the functional design of its geometrical shape, strength, and structure. Some students actually repeatedly changed the sizes in the detailed model according to how they felt, or made big changes to the conceptual design after conducting an emotional evaluation in the CAVE environment.

In the design process, although the emotional evaluation is conducted in the latter half, since the current exercise is given according to the progress of the lecture, it should be conducted from the first stage of the rough design. Moreover, since the current CAD system for geometrical design and the VR system for emotional evaluation are separate systems, the data from the CAD system must be transmitted to the VR system to visualize it. In future, it will be necessary to develop and use an emotional design system that integrates the CAD environment and the visualization environment without the transmission of data.

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