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"INTERATIVE SPATIAL COPY WALL" REPRESENTING BODILY ACTIONS OF REMOTE PERSON IN PSEUDO THREE DIMENSIONS

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ABSTRACT

A requirement of communication technology creating a sense of bodily presence of a remote person is anticipated to increase more than ever. However, this type of communication technology has underdeveloped so far. In order to create such a sense, we have proposed two methods to integrate (1) a video avatar and a robot avatar, and (2) a video avatar and movements of physical object which is operated by a remote person. For creating a sense of presence of a remote communication partner, we have proposed a novel concept "Interactive Spatial Copy Wall" display system based on features of two methods, which represents a pseudo three-dimensional shape of a remote communication partner with movable cylinders. In this paper, we describe our further-advanced "Interactive Spatial Copy Wall" display system to represent bodily actions of remote person's upper body in real time. For this advancement, we have designed a modified "Interactive Spatial Copy Wall" by focusing on power source, data communication and measuring three-dimensional appearance of a remote person. Consequently, this revised "Interactive Spatial Copy Wall" display system achieves to represent bodily actions of remote person's upper body in pseudo three dimensions, corresponding to hundreds of movements of installed cylinders.

KEY WORDS

Tele-communication, tele-presence, avatar, bodily action, pin display, and embodiment

1. Introduction

A few communication systems have been proposed and received attention to support a sense of connectedness among remote families and a remote watching an elderly person living alone in several years [1][2]. An ever-increasing demand for developing a communication technology to create a sense of bodily presence of a remote person and as if the remote people were bodily-present at your space has recently been recognized [3]. However, such communication technology has been investigated insufficiently. For example, even when a real-sized image of a remote partner appears on a large screen at a local place, the psychological distance to the person in the screen differs from that in a face-to-face situation [4]. We consider that the image-only projection of a remote partner may create much less power of a sense of presence, resulting in an obvious feeing for the local partner that the remote partner is not with him.

In order to create a sense of presence of the remote people, we have paid a special attention on issues of physical presence of remote communication partner and bodily interaction with each other, leading to herein proposed mainly two methods.

First method is to integrate a video avatar expressing the fidelity of bodily action, and a robot avatar as the physical presence and for supporting physical interactions [5]. Based on this idea, authors developed Eye-Ball robot of which eye movements, blinking and nodding can be operated by a remote communication partner and on which video of the remote partner can be projected. Through communication experiments, we found that there was a possibility to create a sense of presence of a remote person by utilizing a robot. We found also that there were some difficulties of utilizing human-mimetic robot such as representing actions corresponding to (i) those of remote person in three dimensions and in real time, (ii) differences in sizes and shapes between a robot and a remote person, and (iii) group communication among remote people.

Second method is to integrate a video avatar expressing the fidelity of bodily actions, and movements of physical object, operated by the remote person [6][7]. We devised "Lazy Susan" communication system through which people can interact with the physical disk, the movements of which can be synchronized with the remote corresponding disk, and they can also share those interactions visually. We demonstrated that this system can enhance a power for sensing a presence of remote person in comparison to representing video of remote person.

Our research goal is to devise a display system and propose a method creating a sense as if a remote communication partner were bodily-present at the same place. Then we proposed another novel "Interactive Spatial Copy Wall" display system based on features of two methods and developed a face-sized "Interactive Spatial Copy Wall" display system, which represents a pseudo three-dimensional shape of remote partners with 96 of movable cylinders and remote participants can interact with each other by operating these movable cylinders [8].

In this paper, we describe the advanced "Interactive Spatial Copy Wall" display system which can represent bodily actions of upper body of a remote partner by measuring the bodily actions in three dimensions.

2. Previous face-sized "Interactive Spatial Copy Wall"

In this chapter, we review our "Interactive Spatial Copy Wall". Our idea came from a toy of pin display in Figure 1. This toy can represent a three-dimensional shape of a physical object by pushing the object onto hundreds of pins from behind. We apply this idea to a display system supporting the following bodily interactions;

1. Displaying mode
- The surface of the wall can represent an appearance of remote participants by moving cylinders.
- The surface of the wall can transform according to bodily actions of remote participants by moving cylinders.
- Video of remote participants can be cast over the surface of the wall.

2. Haptic interaction mode
- Local participants can interact with remote participants through pushing and pulling cylinders.
- Both participants can model a shape with cylinders collaboratively.

At the early stage of a development, we designed an appearance of "Interactive Spatial Copy Wall" display on whole size(500×700[mm], representing upper body), shape of pin (cylinder), size of cylinder (30[mm] in diameter), distance of moving cylinder (from 0 to 300[mm]), number of cylinder (approximately 200 cylinders), and arrangement of cylinders(horizontally and vertically by 40 [mm]) through building a full-scale mock-up wall made of styrene foam [8].

Then, we designed an architecture of "Interactive Spatial Copy Wall" display system based on modularity of physical structure and information processing [8]. Each cylinder module includes cylinder drive mechanism, cylinder position controller and communication controller. The cylinder drive mechanism includes one DC motor and one rotary encoder inside, and controls a motion of cylinder on a rack-and-pinion mechanism as shown in Figure 2. The position of cylinder (30[mm] in diameter) can be controlled from 0 to 250 [mm] (delay time 0.36[s], settling time 0.53[s]) based on PID control, and the cylinder can supply 2.9[N] at the maximum. The cylinder position controller is composed of microcomputer (PIC16F74), rotary encoder counter and motor driver. The microcomputer calculates PID parameter from the encoder counter data and the targeted value sent from a host computer, and transmits PWM signal to control positions of cylinder.

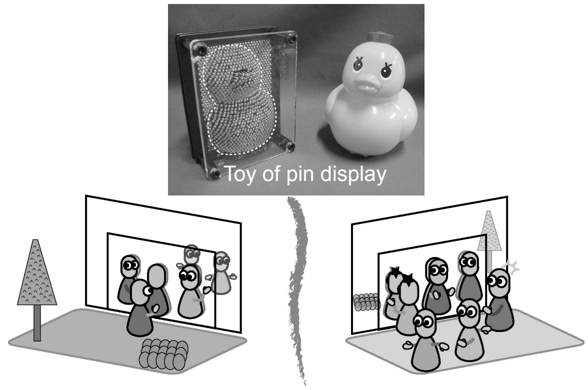


Figure 1. Conceptual image of "Interactive Spatial Copy Wall"

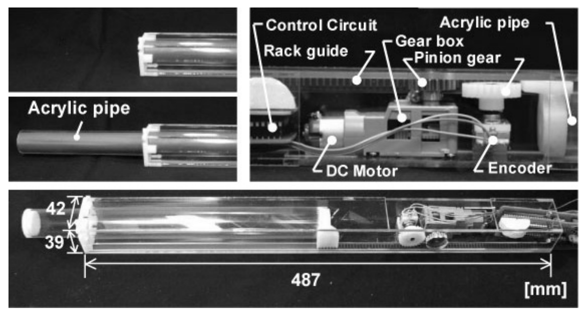
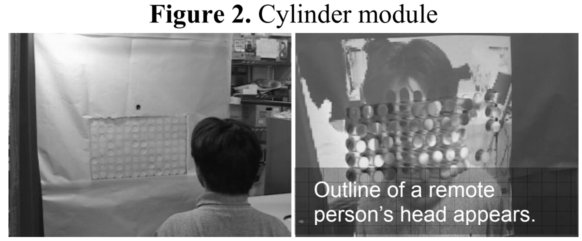
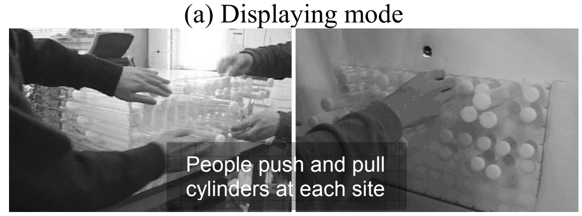


Figure 2. Cylinder module



(a) Displaying mode



(b) Haptic interaction mode

Figure 3. Two modes in previous "Interactive Spatial Copy Wall" display system

The display system can be constructed by integrating those multiple cylinder modules, which can communicate with host computer. Additionally, in order to measure three-dimensional appearances of a remote partner, two mutually perpendicular CCD cameras are installed in front of the system. Each camera captures the participant from the top- and side-view, and three-dimensional appearance can be calculated from those two videos. We integrated 96 cylinder modules and the video systems as shown in Figure 3. Those previous "Interactive Spatial Copy Wall" can represent appearance of remote person within face-sized region and remote people can interact with this display with each other as depicted in Figure 3.

3. Advanced “Interactive Spatial Copy Wall” representing for upper body

We focused on the aforementioned display mode and further developed “Interactive Spatial Copy Wall” display system in order to represent bodily actions of upper body. Therefore, we implemented the “Interactive Spatial Copy Wall” display system composed of a display system of multiple modules twice as much as in the previous system, and three-dimensional appearance measuring system by utilizing infrared camera based on stereo vision.

3.1 Display system composed of multiple modules

In order to represent bodily actions of upper body, area of display requires twice as much as area of previous systems. Accordingly, we constructed a display system of 192 modules twice as much as 96 modules in the previous system. At the beginning, we implemented 192 modules, which we developed so far, on trial based on the architecture of previous system, and tested whether all 192 modules could operate concurrently. We found that several cylinder drives operated slowly, data communication among modules and host computer were unstable, and whole system frequently broke down all at once. In order to solve these hardware problems, we designed system architecture anew by focusing on power source for cylinder actuator, data communication between cylinder modules and between cylinder module and host computer.

3.1.1 Power source

Capacity of power source is one of the crucial problems concerning controlling all of 192 cylinder modules concurrently. In the previous system, a situation of controlling all modules concurrently was not supposed, and power source system was designed by calculating sum of rated current consumed in each drive mechanism. Therefore, the power source system should be designed considering fluctuations and the maximum current in start-up. Each DC motor (Mabuchi motor, RE-260) in drive mechanism requires 1.8 [A] at the maximum in 5[V]. Controlling 192 modules all at once requires 345.6 [A] (=1.8[A]×192) at the maximum. It is difficult to utilize switching power source supplying such current capacity in general power supply facility. Hence, a vehicle battery (Japan storage battery co., ltd., SEB130) is chosen for a power source. The power source system is composed of 48 regulator units, each of which can drop from 12[V] to 5[V] through 9[V], and supply 7[A] for 4 cylinder modules at the maximum.

3.1.2 Data communication

Data communication is another significant problem because data of cylinder position and load of data communication processing increase with an increase in number of cylinder modules. In order to overcome this problem, we designed a hierarchical communication structure, in which host computer can communicate with intermediate controller units, and then the intermediate controller unit can communicate with each cylinder module. When we applied this architecture to new display system composed of 192 cylinder modules, we found that data communication frequently broke down among an intermediate controller unit and cylinder modules.

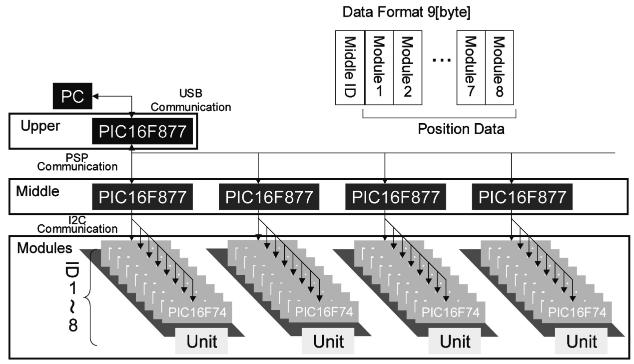


Figure 4. Data communication architecture of “Interactive Spatial Copy Wall” display system

The protocol in the data communication between an intermediate controller unit and a cylinder module is based on I2C. We checked I2C specification by Philips [9], and found the limitation of a maximum bus capacitance of 400 [pF]. Therefore, in order to reduce bus capacitance, we shortened interconnection between an intermediate controller unit and a cylinder module, and reduced the number of cylinder module per intermediate controller unit from 16 modules to 8 modules. Figure 4 illustrates new data communication architecture of 4 units, each of which includes one upper controller unit and 6 middle controller units communicating 8 modules respectively. Consequently, all 192 cylinder modules can communicate with the host computer.

We explain data communication among host computer and each cylinder module. Data transmitted from the host computer is composed of 9 [byte]; 1[byte] for ID of the middle controller unit and 8 [byte] for targeted position of cylinder in 8 modules. The host computer transmits the data to an upper controller unit via USB. The upper controller unit checks the ID of the middle controller unit, and transmits the data to the specific middle controller unit via PSP (Parallel Slave Port). At that time, other middle controller units receive BUSY signals and wait the processing. And then, the middle controller unit receiving the data transmits 1-byte cylinder position to each cylinder module via I2C. The middle controller unit can recognize each cylinder module because a cylinder module can have one of eight IDs by setting dip switch. Consequently, each cylinder module can receive the targeted position and control the position of cylinder. Simultaneously, in up-stream from cylinder module to the host computer, each middle controller unit packages the controller ID and 8 position data of cylinder within one packet, and sends to the host computer through the upper controller unit.

Based on the aforementioned architecture, we implemented a display system composed of 192 cylinder modules as demonstrated in Figure 5.

3.1.3 GUI for controlling cylinder module

We completed the GUI (Graphical User Interface) in order to control directly each cylinder module through the host computer. The GUI shows processing of data

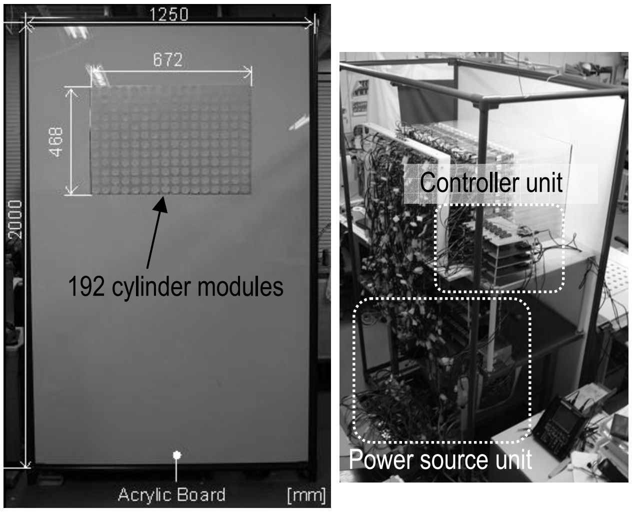


Figure 5. Appearance of a display system

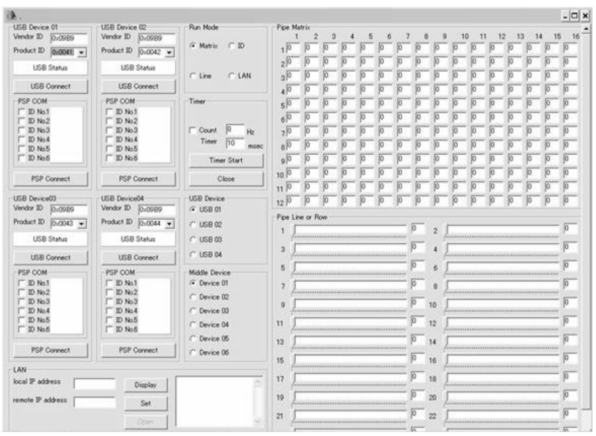


Figure 6. GUI to motior and control every cylinder module and control units

communication of upper controller units and middle controller units, and positions of 192 cylinders simultaneously as seen in Figure 6. We can also control positions of all cylinder modules by each cylinder and by each control unit through inputting data and by operating a slider with mouse. Additionally, an automatic control can be also possible by inputting shape and position of any object as well as manual controlling.

3.2 Three-dimensional appearance measuring system

The method measuring three-dimensional appearance of a remote communication partner performed by the previous system had a few problems such that it is difficult to detect only a person, and it can only measure convex surface not concave surface. In order to solve these issues, we design and develop a measuring system to satisfy the following requirements.

- It should detect only person not including other objects.
- It should measure a person in any background.
- It should update the data approximately 5 [Hz] at least for detecting bodily action during general conversation.
- It should measure bodily action including leaning and rotating by 45 [deg] at the maximum.
- It should measure concave surface as well as convex surface.

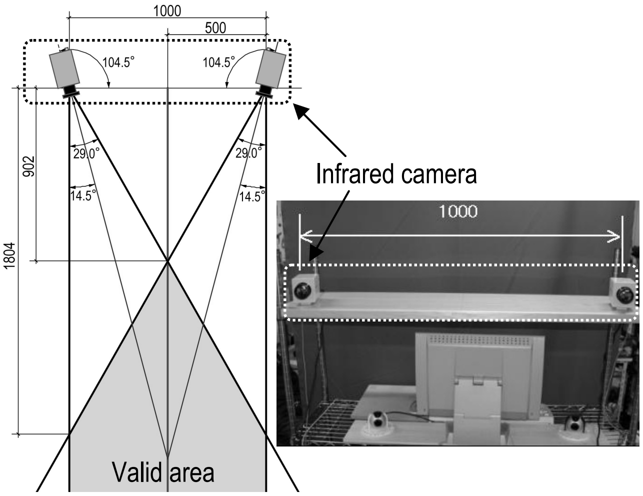


Figure 7. Two infrared camers installed on the steel rack and its valid area

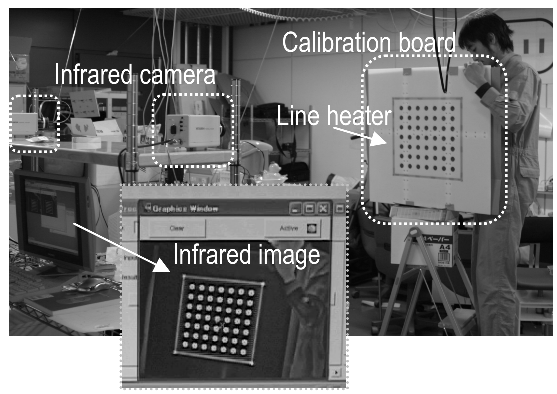


Figure 8. A scene in calibrating infrared camera

- It should obtain an accuracy of resolution of display system, in which the sectional shape of each cylinder is a circle (Φ30[mm]), cylinders are aligned by approximately 40[mm], and the cylinder can move from 0 to 250[mm].

Therefore, we propose three-dimensional measuring system based on stereo vision by utilizing infrared camera and by using virtual human model.

3.2.1 Calibration for infrared camera

Stereo vision method requires calibration of camera before measuring. General CCD camera can be calibrated by taking a printed calibration table, however, an infrared camera cannot take a printed image. We devise a calibration board for infrared camera. The calibration board (712.5×712.5[mm]) is made of ABS resin and a line heater in square groove (400×400[mm]) was embedded therein. The board also has 49 circular holes (Φ25[mm]) within the square.

Moreover, two infrared cameras (Mitsubishi Electric, IR-SC1) are installed on the steel rack and can take the area as shown in Figure 7. We calibrate this stereo vision system when we have a calibration board in the valid area and place an electric heater behind the calibration board. Figure 8 demonstrates a scene in calibration and the infrared image.

3.2.2 Calculating 192 specific points

We explain our method based on stereo vision utilizing virtual human model in this section. Although we have tried to employ stereo vision method by only utilizing infrared camera based on a fundamental idea, it was difficult to detect specific points in the infrared image stably though it was easy to select an image of a person's body. Therefore, we employed heat-source markers used in calibration board as well as head and hand as specific points. We conformed those specific points in the infrared image to those of a virtual human model, which is constructed and stored in the computer in advance. Then this system produces 192 points in three dimensions at the maximum by calculating the position and posture of the virtual human model. We explain this flow in detail as follows.

(i) Constructing a virtual human model

Before measuring the appearance of a person in three dimensions, the virtual human model of the person's upper body was created. A primary model of trunk of the body is composed of ellipses sliced by every 10 [cm], a primary model of head is composed of disks by every 5 [cm], and a primary model of arm is composed of sliced disks by every 5 [cm] as shown in Figure 9. Vertices are set along each outline of sliced disk by 30 [deg], and triangles are created by connecting those vertices between next disks. The final virtual human model is composed of hundreds of triangles. At the present moment, the size of body for primary model is measured manually.

(ii) Detecting the specific points

In order to detect specific points of the person's body stably in infrared image, the person attaches four small heat-source markers on the front trunk, and two armband heat-source markers on each elbow as shown in Figure 10. Then, eight specific points of four small markers, two armband markers and both hands can be detected and identified in the infrared image in consideration of three factors of greyscale, area and roundness (see Figure 10).

(iii) Conforming specific points to virtual model

We calculate the amount of position and posture of the person by utilizing eight specific points based on general stereo view method, and we apply the amount to the virtual human model. Consequently, the virtual model can be re-created in the computer, corresponding to the position and posture of the real person. We explain the calculation in detail in Figure 11.

Position of the person can be calculated from the position of the center of gravity of four heat-source markers, and the center of gravity in the virtual human model is transformed according the amount in Figure 11(a). Then, posture of the person is calculated from the scalar product between present tangent vector and initial tangent vector connecting two of four heat-source markers, and from the scalar product between present normal vector and initial normal vector of the trunk in Figure 11(b). The normal vector is calculated from vector product between two tangent vectors of the trunk connecting two of four heat-source markers. Position and posture of arm is calculated from two vectors, connecting

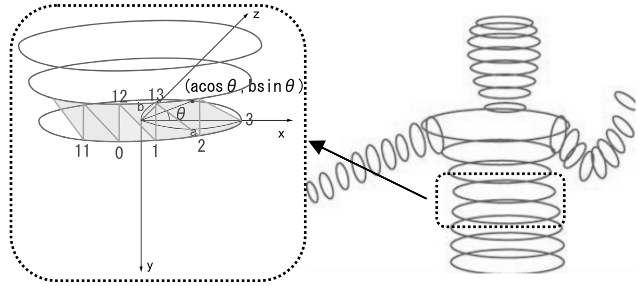


Figure 9. A virtual human model

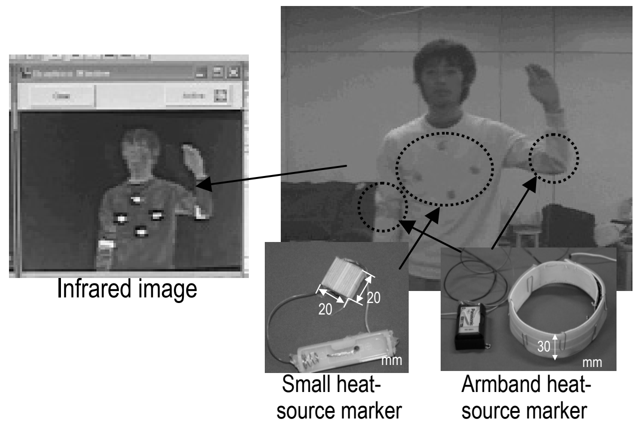
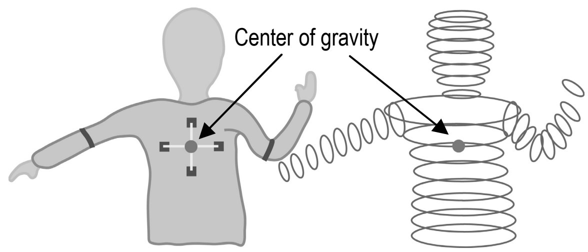
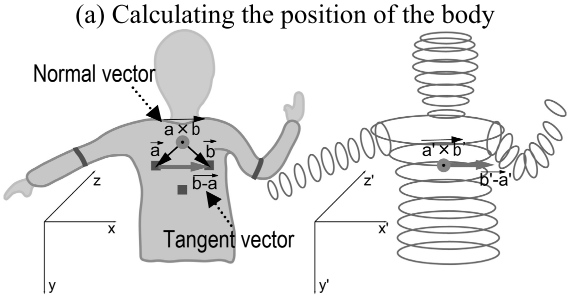


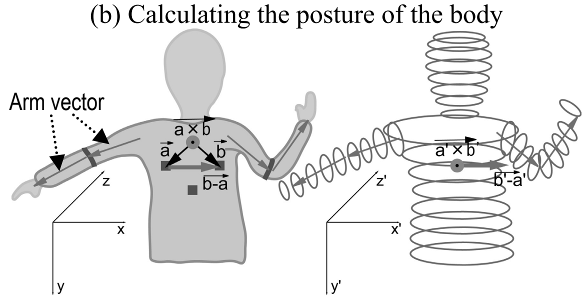
Figure 10. Detecting specific points in infrared image



(a) Calculating the position of the body



(b) Calculating the posture of the body



(c) Calculating the positon and psoture of the arm

Figure 11. Conforming specific points to virtual model

from the point of shoulder, which is calculated from the virtual body, to the center of armband heat-source markers, and between the center of armband heat-source

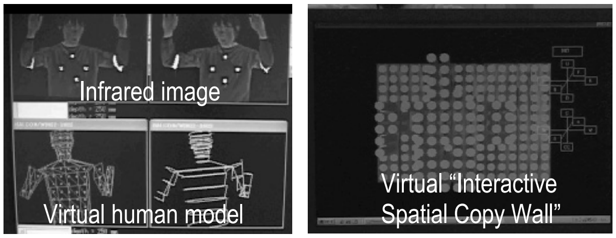


Figure 12. Virtual “Interactive Spatial Copy Wall” to visualize a depth map

markers and center of hand in Figure 11(c). At the present moment, a head movement is not calculated.

(iv) Producing depth map

At the last, a depth map expressing three-dimensional appearance of the person in front of the camera is produced by conforming the virtual coordinates where the virtual human is present to the real coordinates where the physical person is present. In order to detect triangle polygons constituting virtual human body facing to the virtual camera, scalar product is calculated between a normal vector of each triangle polygon and a vector of light axis of the virtual camera. Then, the distance is calculated between the center of gravity of the chosen triangle polygon and the reference plane on 192 lattice points corresponding to 192 modules in the display. The matrix composed of 192 distance values is the depth map for controlling each cylinder module.

Additionally, we developed a virtual “Interactive Spatial Copy Wall” to visualize such a depth map by utilizing World Tool kit library (Sense 8) as shown in Figure 12.

3.3 Construction of “Interactive Spatial Copy Wall”

We completed the “Interactive Spatial Copy Wall” display system by integrating display system composed of 192 cylinder modules and three-dimensional appearance measuring system as shown in Figure 13. The depth map of 192 distance values is transmitted from the remote computer to the local host computer via LAN. Then, the depth map is transformed into the 16×12 matrix data corresponding to alignment of 192 cylinder modules.

Each 8 byte in the matrix, for example from 1st to 8th row in the first line, from 9th to 16th row in the first line, and so on, and 1 byte of the middle controller unit ID are combined into a 9-byte packet. Those packets are transmitted to each cylinder module as explained in the previous section. Consequently, the display represents pseudo three-dimensional appearance of a remote person by transforming each cylinder module.

Video of the remote person with remote background is cast over the surface of the modules and the acrylic screen around the modules by the video projector.

4. Representing a remote person

We have evaluated the performance of our “Interactive Spatial Copy Wall” display system.

First, we control the “Interactive Spatial Copy Wall” display system by inputting several commands through GUI. The results were promising and encouraging,

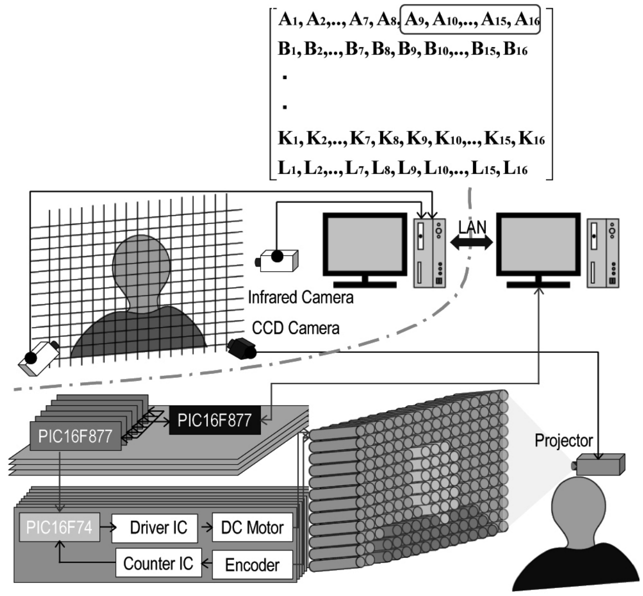
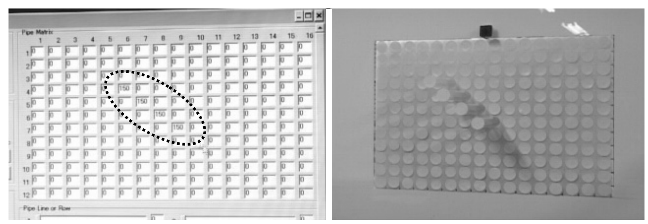
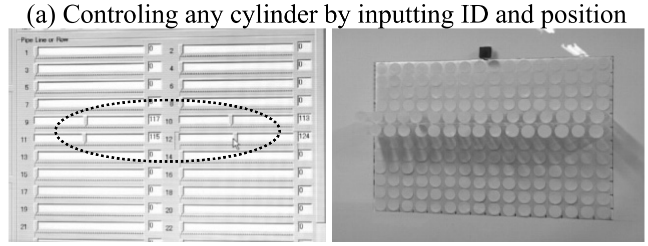


Figure 13. Schematic diagram of “Interactive Spatial Copy Wall” display system



(a) Controling any cylinder by inputting ID and position



(b) Controling group of cylinders by operating slider

Figure 14. A scene of controling cylinder modules

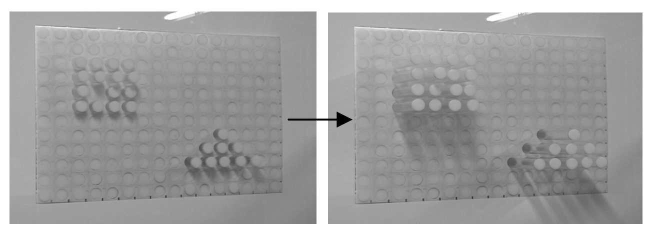


Figure 15. A scene of displaying various figures

indicating that each cylinder module can obtain the targeted position data by approximately 10 [Hz]. We can choose and control any cylinder module by inputting ID and the position of cylinder numerically in the GUI as shown in Figure 14(a). We can also control a group of cylinder modules under one middle controller unit in a similar mode by operating the slider as shown in Figure 14(b). Then, the “Interactive Spatial Copy Wall” display can represent and transform various figures simultaneously by inputting the data created manually in advance as shown in Figure 15.

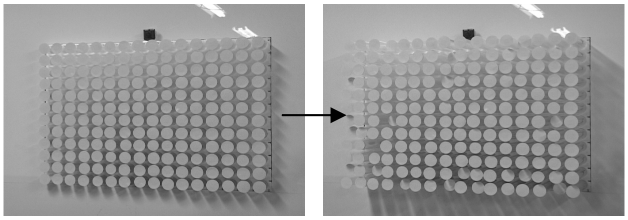


Figure 16. A scene of controling all of 192 modules

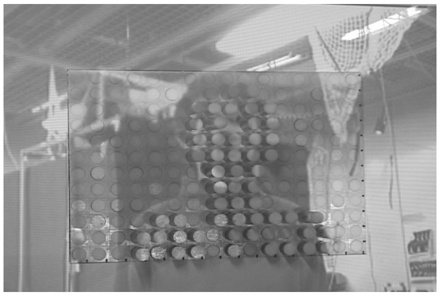


Figure 17. Displaying a three-dimensional appearance of a person with video projection

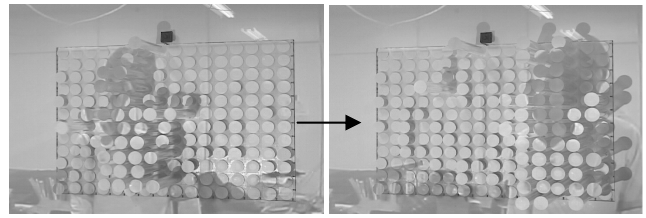
We also confirmed that all of 192 cylinder modules work all at once as shown in Figure 16. This indicates the problem of capacity of power source has been solved at the present system.

Additionally, we create a three-dimensional appearance data manually from the photo, and then we control the display system based on the data with video projection of the person as shown in Figure 17. The representation indicates that we can understand the outline of the person on the display.

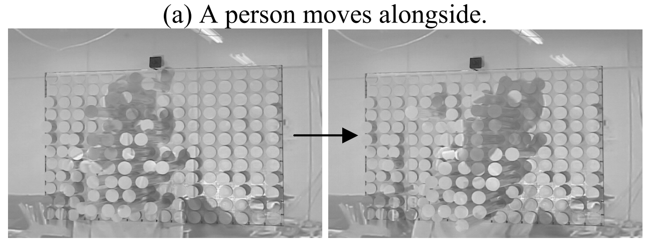
Second, we had conducted a performance test of "Interactive Spatial Copy Wall" display system as follows. A person attached heat-source markers on his clothes, and we investigated frame rate of producing the depth map. It was 5-6[Hz], indicating that our system satisfies the requirement as to updating the data for detecting bodily action during general conversation. Then, instead of investigating the accuracy of three-dimensional appearance of real person's body, we examined the position and posture of the specific points of heat-source markers. Each marker is detected within an accuracy of 2[cm] at the maximum in the valid area as illustrated in Figure 7.

Regarding the posture of the person, yaw of the body (rotating around the vertical axis) can be detected in 50[deg] at the maximum. If the body moves over the value, heat-source markers on the body trunk cannot be detected. Roll of the body (rotating around the normal vector of the body) can be detected in 45[deg] at the maximum. If the body moves over the value, each of heat-source markers on the body trunk cannot be distinguished.

Figure 18 depicts scenes that "Interactive Spatial Copy Wall" display system represents pseudo three-dimensional appearance according to bodily actions of a remote person with video projection. We found that cylinders moves according to the movements of bodily actions back and forth and around approximately in real time.



(a) A person moves alongside.



(b) A person inclines his body.

Figure 18. Scenes of displaying bodily actions of a remote person in three dimensions with video projection

5. Discussion

Several display systems have been proposed based on moving multiple pins and cylinders so far. Feelex [10] can represent a virtual object on the screen (240×240 [mm]) which can be moved vertically by 36 cylinders (Φ40[mm], stroke 80[mm]) and on which the virtual image can be projected. Popup [11] can also express three-dimensional object in the areas of two hands by controlling 256 pins (stroke 30[mm]) with shape memory alloy coil actuator. These display systems represent a three-dimensional object within the area of both hands at best in comparison to that of our system representing upper body.

Interactive Kinetic Façade [12] can move 50 pipes more than distance in our display system, however, it is inappropriate to represent a person's body because interspace between each pipe is wider than that in our display system.

As for the rest, a few display systems have been proposed to deform the surface of the display although those displays cannot represent an object in three dimensions. Super Cilia Skin [13] possesses dozens of felt-coating pins with a magnet thereunder, and the directions of pins can be controlled by an electromagnet behind the display. Additionally, Wooden Mirror [14] can represent bodily action of people in the 35×29[inch] area by controlling the tilt of 830 wooden plates with servo motor.

As stated above, our "Interactive Spatial Copy Wall" display system is the first display to represent three-dimensional appearance of remote person's upper body based on the method of moving hundreds of cylinders.

We still have improvements to represent three-dimensional bodily actions of a remote person precisely, because outline of the body is obscure as we observed the appearance on the display in Figure 18. We consider two factors to be improved; difference in features of each cylinder module and measuring a three-dimensional appearance of a remote person.

At the present moment, the same software and parameters are installed in the cylinder position controller of each cylinder module. However, features of motor and drive mechanism are different from each other slightly. Consequently, even when each module receives the cylinder position data simultaneously, the present position of cylinder is different from the ideal position, respectively, at the moment. When the person moves continuously, those differences appear more prominently. We consider this problem can be solved by adjusting control parameters optimally in every cylinder module and by controlling position of each cylinder faster.

Secondly, three-dimensional appearances of a remote person should be measured more precisely. If we employ the method utilizing virtual human model, the difference between a virtual human model and the real person should be reduced primarily by constructing the virtual model with 3D scanner automatically and precisely, and by registering the virtual human model to the real person's body accurately. The method of stereo vision in real time without virtual human model should be also investigated.

6. Conclusion

A communication technology creating a sense of bodily presence of a remote person and a feeling as if remote people were bodily-present at the same place as you are have received attention these days and a requirement of developing such technology will increase more than ever. However, such communication technology has underdeveloped so far. In order to create a sense of sharing the common presence with a remote communicator, we have paid a special attention on issues of physical presence of a remote communication partner and bodily interaction with each other, and have proposed two methods to integrate a video avatar and a robot avatar, and to integrate a video avatar and movements of physical object which is operated by the remote person.

In order to create a sense as if a remote communication partner were bodily-present at the same place, we proposed an idea of a novel "Interactive Spatial Copy Wall" display system so far based on features of two methods, which represents a pseudo three-dimensional shape of a remote communication partner with movable cylinders. In this paper, we describe our advanced "Interactive Spatial Copy Wall" display system to represent bodily actions of remote person's upper body in real time. Therefore, we design system architecture anew by focusing on power source for cylinder actuator, data communication and measuring three-dimensional appearance of a remote person. Consequently, our "Interactive Spatial Copy Wall" display system achieves to represent three-dimensional appearance of remote person's upper body based on the method of moving hundreds of cylinders.

As further development of our systems, the system needs to be modified to represent three-dimensional bodily actions of a remote person precisely, by adjusting cylinder module optimally and by measuring three dimensional appearance of a remote person much more accurately.

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