Proceedings of the Third IASTED International Conference
Human-Computer Interaction
March 17-19, 2008 Innsbruck, Austria
ISBN Hardcopy: 978-0-88986-725-3 / CD: 978-0-88986-726-0

"LAZY SUSAN" CHAIR COMMUNICATION SYSTEM FOR REMOTE WHOLE-BODY INTERACTION AND CONNECTEDNESS

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ABSTRACT
A few communication systems that support a sense of connectedness among people who are physically separated recently have received attention. Our previous research has shown that bodily interactions enhance this sense of connectedness. In the current work, we designed two "Lazy Susan" Chair communication systems that can communicate bodily actions between physically separated people by way of rotations of the chairs on which they are sitting. One system is based on rotating a disk by hand, and the other is based on rotating the chair itself. The characteristics of these two systems are described, and the communication experiments to determine the relative effectiveness of the two systems are discussed.

KEY WORDS
Whole-body interaction, connectedness, communication, timing, and Lazy Susan

1. Introduction

Remote communication utilizing mobile phones and e-mail messages has become an integral part of daily life in the modern world. However, creating a sense of trust and a feeling of security require face-to-face contact [1]; therefore, bodily presence is the most important issue for creating a sense of connectedness among remote users of computer-assisted communication technology [2][3]. A few communication systems have been proposed that support a sense of connectedness among family members living apart from each other, especially younger members who want to watch over an elderly person living alone, and long-term experiments utilizing those communication systems have demonstrated their validity [4][5]. In spite of these systems, there has been insufficient research into a communication system that creates a real sense of bodily connectedness among people physically separated from one another.

Our goal, then, was the design of a communication system that allows people who are separated physically from each other to feel as if they were together in the same place. To reach this goal, we devised a "Lazy Susan" communication system to support bodily interaction among remote people by representing bodily actions visually through video images and by providing a tool that can be operated by remote people at their actual physical sites[6][7]. Use of this system demonstrated that interacting via a virtually-shared physical tool enhances the sense of connectedness among remote people.

To further develop this communication system, the following specific questions needed to be addressed: What kinds of motions should be conveyed? Should bodily interactions consistently take place? What effects does a time lag have on creating the sense of connectedness? We decided that all these questions could be addressed if we focused on the significance of "a holistic sense of embodied interaction" [2], and if we designed a communication system to support it – examples of embodied interaction are a mother cradling a baby in her arms and people playing on the same swing or seesaw.

The communication system we designed allows remote people to communicate bodily actions by way of rotations of the stools or chairs on which they are sitting, as illustrated in Figure 1. In the following sections, we describe the design and implementation of this system and, based on experiments we conducted, discuss its characteristics for creating a sense of connectedness.

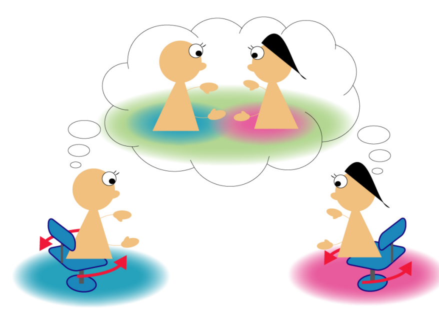


Figure 1: Concept of whole-body interaction with "Lazy Susan" Chair communication system

2. Design

2.1 Related work

There are several communication systems that support remote bodily interactions with physical contact, such as shaking hands. These systems can be classified into two types from the point of view how bodily action is represented.

The first way is to represent the motions of the human hand and arm directly by a robot hand and arm. In Telephonic Arm Wrestling [8], people can arm-wrestle with a remote partner; and in Tele-handshake Interface [9], they can shake hands with a remote partner. Moreover, other tele-operated robots for interpersonal communication, such as Tele-existence[10], PRoP[11], and Gestureman[12] , are also positioned in this category.

The second way is to represent the bodily actions of humans implicitly by movements of a physical object manipulated by a remote partner. Our previous "Lazy Susan" communication systems are positioned in this category [6][7], as is our "Interactive Spatial Copy Wall" system, in which remote partners can interact with each other by moving hundreds of moveable pipes [13]. Also in this category are inTouch [14], in which rotations of three wooden rollers are synchronized with those of remote rollers, and RobotPHONE [15], in which the head, arms, and legs of a stuffed toy are synchronized with those of remote toy; both these systems are used for remote haptic interaction. In addition, general-purpose VR haptic displays including PHANToM [16] are also available. Finally, LUMEN [17] is a palm-size deformable surface display that can be used for remote interaction.

All the systems above are intended to represent actions of just one body part such as a hand or arm. There are a few systems that represent whole-body actions, but only between people in the same place. One such system, which is called a motion platform or motion bench, is based on a large actuator that simulates the motions of an airplane and an automobile [18]. Another such system involves two rocking chairs that swing in sync with one another [19]. As far as we know, however, there are no communication systems that support whole-body interactions between people located in places remote from one another.

2.2 Mock-up

Our idea was to design a system of two, identical rotatable stools that were connected and synchronized with one another. We chose stools because it is reasonable that they can be utilized in any house. To investigate how this rotating stool system affected interpersonal communication, we developed a few mock-up stools for use in face-to-face situations (see Figure 2). When a

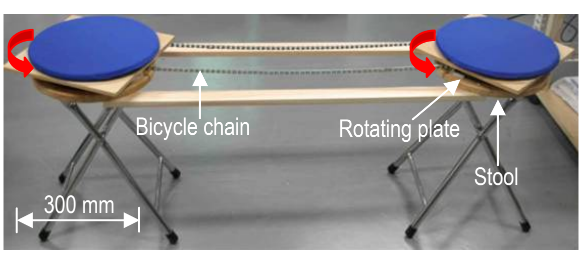


Figure 2: Mechanical mock-up of "Lazy Susan" Chair

person rotates the stool on which he is sitting, the other stool rotates in a corresponding way. Several subjects held conversations while sitting on the interconnected stools, and reported that they felt an enhanced sense of connectedness with their partner.

2.3 Requirements

We have proposed two ways to operate the motions of remote chairs so that they create a sense of whole-body interaction and connectedness. The first way involves a person who rotates his own local disk by hand in order to rotate a remote chair. We assume that the hand and arm motions of this one person convey a sense of whole-body action to the other person, like the sense that is conveyed when a mother cradles a baby in her arms. For this way, we utilized a "Lazy Susan" communication system that we previously developed in which the rotations of two remote disks are synchronized with one another. However, the disk can be rotated only by hand, and people cannot sit on it.

The second way involves a person who rotates his own local chair that he is sitting on, in order to rotate a remote chair on which another person is sitting, so that the rotations of the two chairs are in sync with one another. We assume that the whole-body movements conveyed between these two people are similar to those conveyed between two people playing on the same swing.

It was for developing the stool that rotates a person sitting on it that we decided to consider system requirements. The maximum rotating speed of the chair was calculated to be 50 [rpm], based on analyzing the movements of a person sitting on a rotatable stool with a marker on his back. The rated torque that a chair needs to produce to rotate a person sitting on it is approximately 4.7[Nm], which was calculated from the following conditions: a human subject who weighed 80[kg] and a 150 [mm] radius cylinder that rotated at 50 [rpm]. Finally, it was decided that the data transmission function required to operate the system should be developed for use over the Internet and should be easy to use, so that an ordinary person just could connect it to a power source and switch it on.

3. Implementation

3.1 Drive mechanism

The drive mechanism rotates a chair that a standard-size adult sits on. Our initial drive mechanism (max torque: 8 [Nm], max rotating speed: 47 [rpm]) is composed of a DC motor and a gear box. This drive mechanism did rotate the person sitting on it; however, a loud noise generated from its gear box prevented conversation while the chair was rotating. To reduce the noise, we used a geared motor with a rated torque of 15.6[Nm] and a rated rotating speed of 50[rpm].

We constructed our "Lazy Susan" chair system by combining the less noisy drive mechanism with a

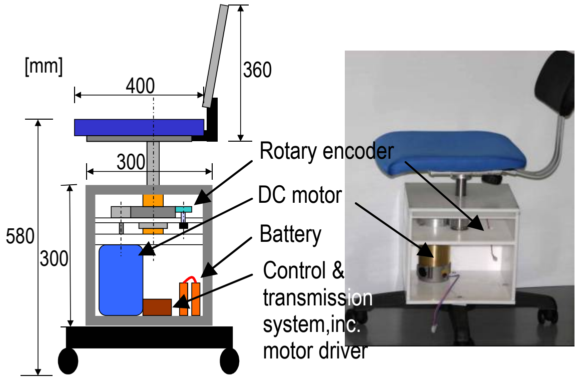


Figure 3: Drive mechanism of “Lazy Susan” Chair

commercially produced office chair. Figure 3 illustrates the “Lazy Susan” chair and the structure of its drive mechanism. The casters shown are attached to the chair only to make moving it easy; they are detached from the chair when the system is being used. A performance test demonstrated that the chair-drive mechanism operates with a time constant of 310 [msec].

3.2 Control and transmission

The control and transmission unit controls the chair drive-mechanism and communicates with a remote corresponding unit via the Internet. The unit includes a motor controller composed of a motor controller board (iXs Research, iMCs01) and a motor driver board (iXs Research, iMDs03, 24[V], 7[A]). The motor controller board receives rotational position data from a rotary encoder (NEMICON, OME-360-2MC) in the drive mechanism and outputs PWM signals to a motor driver board. The motor controller board also communicates with a data communication controller via a USB connection. The data communication controller, which contains a one-board microcomputer (AKI-H8/3069F), transmits rotational position data to a remote data communication controller via an IP network. Consequently, the rotational position of controlled chair corresponds to the rotations of a remote chair or disk. When only the control and transmission unit is utilized, the “Lazy Susan” chair communication system can be operated without a computer. However, when the rotational positions of the chairs are measured and recorded, it is necessary to use a Windows PC instead of the data communication controller to run the controller software we developed. Figure 4 shows the casing of the data communication controller.

3.3 Communication system

3.3.1 Disk-Chair communication system

A “Lazy Susan” Disk-Chair communication system was first developed based on the rotations of a remote disk operating a remote chair. Figures 5 and 6 illustrate the system.

The rotational position of the rotatable disk is measured by a rotary encoder embedded in the disk drive-

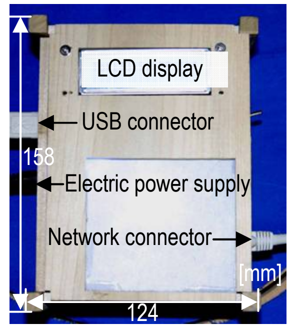


Figure 4: Data communication controller

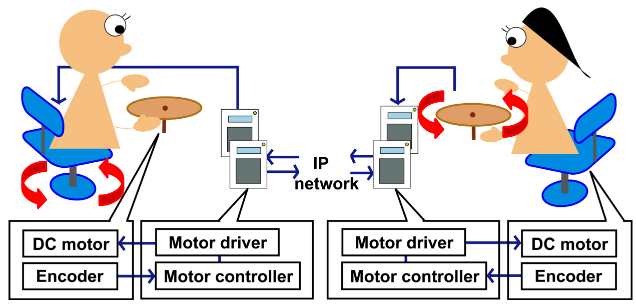


Figure 5: Schematic diagram of “Lazy Susan” Disk-Chair communication system

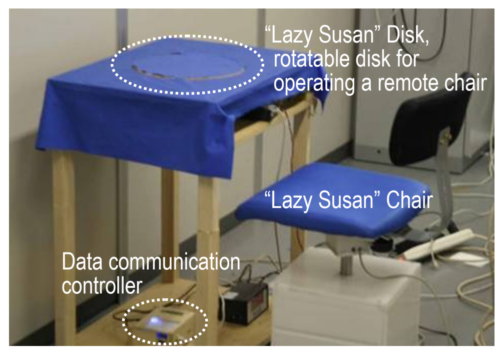


Figure 6: “Lazy Susan” Disk-Chair communication system

mechanism with a DC motor (Japan Servo Co.,Ltd., DME34S36G10B), and transmitted to a data communication controller via a motor controller board. Subsequently, the data is transmitted to a remote data communication controller via an IP network, and then the remote motor controller controls the rotational position of the chair according to the received data as a target value. Consequently, the rotations of each chair are synchronized with those of each disk.

When people interact with this system, the disk and chair will behave as if they were coupled by a spring coil. When one rotating disk is stopped, the other chair stops at the same time and in the same position. If there is a conflict – if, for example, one person attempts to rotate the disk clockwise while the other person attempts to rotate the chair counterclockwise – then each person will feel torque in the opposite direction.

3.3.2 Chair-Chair communication system

In addition, a “Lazy Susan” Chair-Chair communication system was developed based on the rotations of a chair

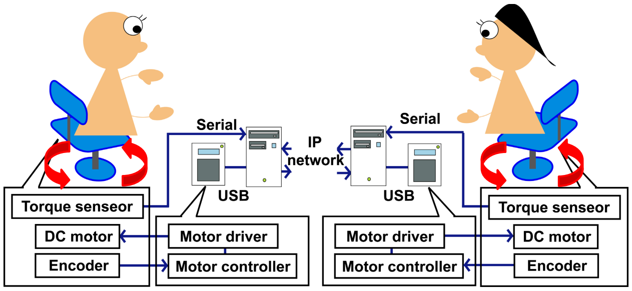


Figure 7: Schematic diagram of "Lazy Susan" Chair-Chair communication system

being synchronized with those of a remote chair. Figure 7 illustrates the system.

This Chair-Chair system is based on a torque control method, whereas the Disk-Chair system discussed above is based on a position control method. In the Chair-Chair system, a torque sensor (Takasu-Giken, SHLW-10M) is installed between the seat of the chair and the shaft of the drive mechanism. Torque data is transmitted to a control computer via serial communication. Subsequently, it is transmitted to a remote control computer via an IP network. The control computer calculates the difference between the torque values of the two chairs and adjusts the motion resistance of the chairs accordingly – the greater the difference in torque, the greater the resistance to motion (a zero difference in torque is considered ideal). For example, when one person attempts to rotate his chair clockwise while the other person attempts to rotate his chair counterclockwise, then each person rotates more slowly and feels resistance in his rotating direction.

4. Communication Experiment

4.1 Disk-Chair communication system

To investigate how the Disk-Chair communication system is used during conversation and what effects the system has on interpersonal communication between remote people, an experiment was conducted with three pairs of adult students. Before the experiment, all the subjects were given explanations about the purpose and the procedures of the experiment and how to utilize the communication system. Each subject was placed in a room that was physically separated from the room of his partner, and each pair of subjects had a conversation about college life over the telephone for 4 minutes. They were asked to rotate their disk however they chose. Figure 8 shows one pair of subjects utilizing the system. After the experiment, they were asked to write down their comments about the impressions they had of the conversation and of the bodily interactions they experienced. These comments are summarized in Table 1.

During the experiment, rotational position data of the chairs were recorded in a control computer. Figure 9 shows the temporal response of the rotations of two chairs. Three patterns of temporal response were found. The first pattern shows that the rotations of both of or either of the two chairs remained almost stable, as illustrated in Figure

Figure 8: "Lazy Susan" Disk-Chair communication system in use. Rotating your own disk operates a remote chair.

Table 1: Summarized comments from users of Disk-Chair communication system

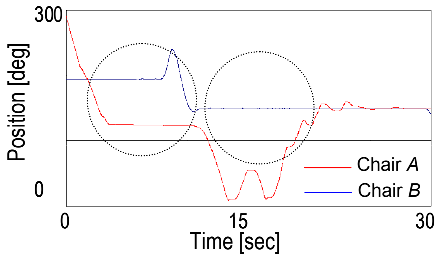
•They understood they were connecting with a remote communication partner.
•They felt they rotated the disk consciously.
•They could have a delightful conversation with their remote partner once there was correct timing between rotations of the disk and rotations of the chair.
•They sensed an uncomfortable feeling when rotations of their own disk were different from those of their own chair.
•They sometimes rotated the disk too much when they were not engaged in conversation.
•They sometimes were surprised by the sudden rotations of their own chair when they were not engaged in conversation.

9(a). The second pattern shows that the rotations of the chairs were different from one another, as shown in Figure 9(b). And, the third pattern shows that the rotations of the chairs were almost in phase, as illustrated in Figure 9(c).

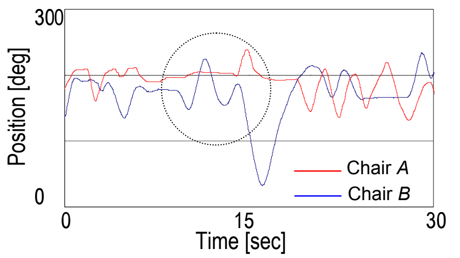
4.2 Chair-Chair communication system

To investigate how the Chair-Chair communication system is used during conversation and what effects the system has on interpersonal communication between remote people, another experiment was conducted with the same three pairs of subjects following the same procedure for 4 minutes, except this time they were asked to rotate their chair however they chose. After the experiment, they again were asked to write down their comments about the effects of the system. Figure 10 shows one pair of subjects utilizing this system, and Table 2 shows their summarized comments.

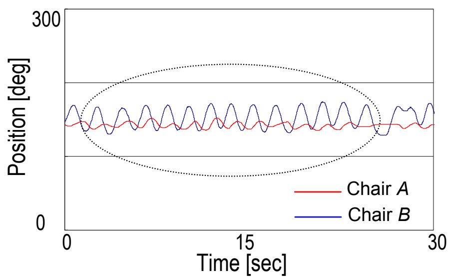
Once again, rotational position data of the chairs were recorded in a control computer during the experiment. Figure 11 shows the temporal response of the rotations of two chairs. Two patterns of temporal response were found. The first pattern shows that the phase of rotation of the two chairs almost corresponds, although the amount of displacement is different, as shown in Figure 11 (a).The second pattern shows that both amplitude and phase of



(a) The first pattern of temporal response



(b) The second pattern of temporal response



(c) The third pattern of temporal response

Figure 9: Temporal responses of rotations of two remote chairs during use of "Lazy Susan" Disk-Chair communication system.

Figure 10: "Lazy Susan" Chair-Chair communication system in use

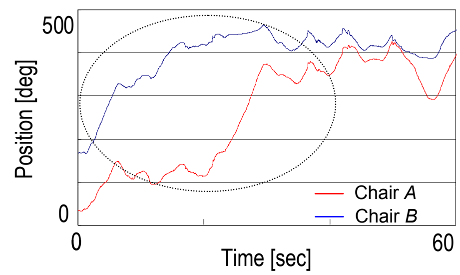
rotations of the two chairs correspond – it should be noted that some subjects commented on synchronous rotations.

5. Discussion

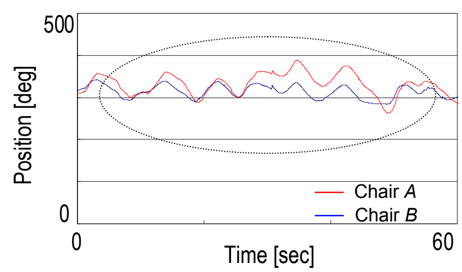
Experiments were conducted on two communication systems: Disk - Chair and Chair - Chair. Table 3

Table 2: Summarized comments from users of Chair-Chair communication system

- They felt a sense of connectedness with a remote communication partner through whole-body interaction much more strongly than they did with the Disk-Chair communication system.
- They felt that the timing was automatically correct between rotations of their own chair and those of the remote chair another communication partner was operating.
- They sensed the response of a remote communication partner much more easily than they did with the Disk-Chair communication system.
- They felt it was easy to talk to a remote communication partner.



(a) The first pattern of temporal response



(b) The second pattern of temporal response

Figure 11: Temporal responses of rotations of remote interconnected chairs during conversation in utilizing "Lazy Susan" Chair-Chair communication system

summarizes the features of the two systems. In both experiments, most of the subjects commented on the timing of interactions of the two systems and on the effect on interpersonal communication caused by the difference in the timing of interactions while using the two systems. Therefore, we will focus on the timing of interactions, or the temporal responses of movements, of the two chairs.

In the Disk-Chair communication system, which applies the position control method, to synchronize the rotations of his own chair with those of the other chair, each person consciously rotated his own disk based on recognizing the position of his own chair. This means that each subject alternately adjusts the rotations of his own disk according to the rotations of his own chair, which are being controlled by the other subject. Consequently, it is difficult for the subjects to keep the rotations of their chairs in phase with one another.

In the Chair-Chair communication system, which applies the torque control method, to synchronize the rotations of his own chair with those of the other chair, each person

Table 3: Characteristics of two communication systems as to bodily interactions

System	Control method	How to operate for synchronization of movement between two remote chairs	Timing of interaction between two remote people
Disk-Chair	Position control: controlling rotational position according to target value of remote corresponding position	Each person rotates his own disk based on recognizing the position of his own chair.	Relatively difficult to adjust
Chair-Chair	Torque control: controlling rotational velocity to reduce difference between the torque produced in the two chairs	Each person rotates his own chair to reduce resistance.	Relatively easy to adjust

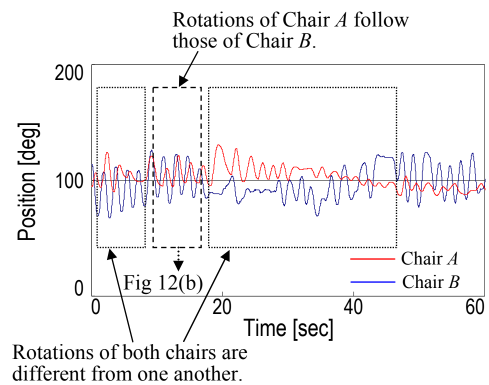
consciously rotated his own chair toward reducing the resistance, which is caused by the difference between the torque (represented as a velocity component) produced by each chair. This means that each person is able to adjust the rotations of his own chair at any time when he feels resistance as a changing velocity. Consequently, it is easier in the Chair-Chair system than in the Disk-Chair system for people to adjust the rotations of their own chair so that they are in phase with those of the other chair.

Moreover, to further investigate these temporal features, a cross-correlation analysis was performed between the rotations of the two chairs in each communication system. Figures 12 and 13 show one typical example of our finding that rotations of the two chairs are obviously in sync. Furthermore, in the Chair-Chair communication system, the cross-correlation coefficient is higher and the time lag is smaller than they are in the Disk-Chair communication system.

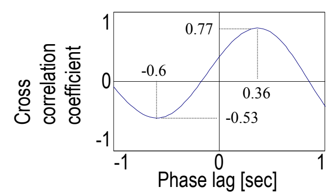
This result demonstrates that it is easier for people to synchronize the rotations of their own chair with those of the other chair while using the Chair-Chair communication system than it is while using the Disk-Chair communication system. And, this finding corresponds with some of the comments made by the subjects. For example, they said that when using the Disk-Chair communication system that “they sensed an uncomfortable feeling when the rotations of their own disk were different from those of their own chair.” They also said that while utilizing the Chair-Chair communication system that “they felt a sense of connectedness with their remote communication partner through whole-body interaction much more strongly than when using the Disk-Chair communication system.” It is clear from all of this that the timing of interactions between remote people greatly influences the sense of connectedness they experience.

6. Conclusion

The significance of a sense of co-existence and connectedness has increased among people engaged in computer-mediated communication. Therefore, a method that creates such a sense is desirable. Based on our previous study, we devised two communication systems to support the sense of whole-body interaction and ,

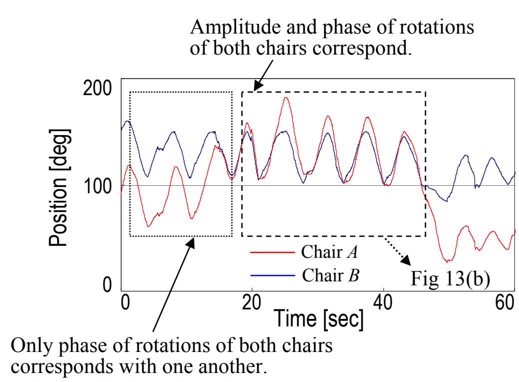


(a) Rotational position of the two chairs

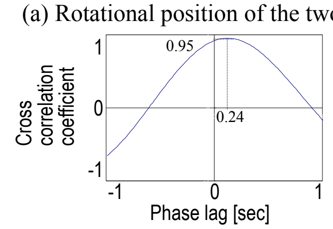


(b) Cross correlation of the two chairs

Figure 12: Disk-Chair communication system



(a) Rotational position of the two chairs



(b) Cross correlation of the two chairs

Figure 13: Chair-Chair communication system

therefore, enhance the sense of connectedness between people who are physically separated. First, we developed a Disk-Chair communication system, in which rotations of a chair are synchronized with those of a corresponding remote disk based on a position control method. Second, we developed a Chair-Chair communication system, in which rotations of a chair are synchronized with those of a corresponding remote chair based on a torque control method. Experiments with these two systems demonstrated that it is easier for people to synchronize the rotations of their own chair with those of a remote chair while utilizing the Chair-Chair communication system than it is while using the Disk-Chair communication system. We believe that our systems, from the viewpoint of the timing of interactions, show promise in regard to creating a sense of bodily interaction and connectedness (being together in or sharing the same space at the same time) among physically separated people. However, as the experiments we conducted were only small-scale, further study is required to test validate the usefulness of our systems. Additionally, we specifically plan to investigate the differences between the position control method and the torque control method, as well as the use of video images for enhancing the sense of connectedness.

Acknowledgements

This research is supported partially by a Grant-in-Aid for the WABOT-HOUSE Project by Gifu Prefecture. The authors would like to thank Masaaki Iyoda and Kouichi Uno for their help. We would also like to thank Prof. Robert DiGiovanni for editing the final version of this paper.

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