Proc. of IEEE Int. Conf. on Systems, Man and Cybernetics (SMC2012), (2012.10), pp.2121 - 2126

Basic Study on Bilateral Swinging Interaction by Moving a Chair Together

Akira KASHIWAGI and Tomo HASEGAWA
Graduate School of Creative Science and Engineering, Waseda University
Department of Modern Mechanical Engineering
59-308, 3-4-1, Okubo, Shinjuku, Tokyo, Japan

Shigeru WESUGI
Faculty of Science and Engineering, Waseda University
Department of Modern Mechanical Engineering
59-308, 3-4-1, Okubo, Shinjuku, Tokyo, Japan
wesugi@waseda.jp

Abstract— **Several researches focused on haptic interactions have advanced so far. Many of such communication tools were designed for actions of specific body part such as upper arm. Therefore in the current work, authors devised a novel interaction system in which people can interact with each other by swinging their whole bodies such as using a rocking chair. The swinging interaction system is constructed based on trapezoidal-shape linkage mechanism embedding direct drive motor inside, and the system can drive based on various control methods. Then authors investigated and discussed the feature of behaviors dependent on control methods.**

Keywords- bilateral interaction; haptic interaction; whole-body swinging; compliance control; rocking chair

I. INTRODUCTION

Various remote communication tools such as telephone, video meeting, e-mail and micro-blog are often seen in our daily lives. Most of these much-used tools mainly handle sound, video or text, but don't support physical interactions such as shaking hands and linking arms. Meanwhile, several communication tools supporting remote haptic interactions have been devised and proposed in the laboratory stage.

For instance, in ComTouch, the pressure that is generated when one person strongly holds the device is transmitted to another remote person as vibrating stimulation [1]. In Telephonic Arm Wrestling [2], a user can arm-wrestle with other user by using a robot arm; and in Tele-handshake Interface [3], a user can shake hands with another remote user. Moreover, other tele-operated robots for interpersonal communication such as PRoP [4], Gestureman [5] and telenoid [6], are also positioned in the line. These tools are designed based on the way to represent the motions of the human hand and arm directly by a robot hand and arm. Another way of remote haptic interaction is to represent the physical actions of human by movements of a physical object manipulated by a remote person. Positioned in this category are InTouch [7], in which rotations of three wooden rollers are synchronized with those of remote rollers, RobotPHONE [8], in which the head, arms, and legs of a stuffed toy are synchronized with those of remote toy, and motions of straw manipulated with a tongue are synchronized with those of remote straw [9]; these systems are also used for remote haptic interaction. In addition, general-purpose VR haptic displays including PHANToM [10] are also available. Furthermore, a control method for remote haptic interaction when there is time delay [3], or an impression on manipulating the device depending on controlling condition [11] have also been investigated.

Most of communication tools above mentioned intend to represent actions of only a single part of body such as a hand, arm and mouth. However, there are several physical interactions with whole body including hugging, lifting up and cradling, in face-to-face communication especially between close friends or families. Thus, in order to support rich and variable communication between people who are physically separated, instead of ways that authors have been proposing to support remote physical interactions with a sense of co-presence in previous researches [12][13], authors focus more on interacting with whole body, especially a "swinging" movement that we can observe when sitting down on the rocking chair and playing on the swing, to support remote physical interactions with whole body in this current research. This paper describes our idea on whole-body swinging interaction by moving a chair with each other, design approach of an interaction system and its implementation of the system. Additionally, the paper discusses feature and utilization of our swinging interaction system and its significance.

II. DESIGN OF INTERACTION

A. Whole-body interaction

In order to design supporting system of remote physical interactions with whole body, authors referred to several interactions with whole body in face-to-face situation. Physical interactions with direct touch are hugging and cradling. On the other hand the interactions through tools and play equipments without mutual direct touch are playing on a seesaw, playing on a swing and playing on a spring rider. Authors focus on the latter interactions with tools because by use of these tools, it would not only intimate people but also various users including young and old can interact with each other, and also not only two but also three or four users can utilize such tools at the same time.

Based on such design approach, authors previously developed a "Lazy Susan" Chair communication system, that is, the rotations of a chair are synchronized with those of a corresponding remote chair, to support physical interaction with remote partner [14]. In this system, like other interaction tools mentioned above, in order to interact with remote partner, one person has to move his/her chair by kicking the floor or by twisting upper body. This means that each and/or both users need to keep on moving the tool to interact with each other and when both users stop moving the tool, no physical interaction occurs between them. This is a common principle that most of haptic interaction systems above mentioned are designed. Though haptic interactions with a hand or an arm require fairly low loads to users, physical interactions with whole body would require a lot of work to the user. Therefore a remote interaction system for supporting such interactions should reduce physical loads of users and easily keep on dynamic interaction with whole body, just by, for instance, adjusting timing of moving so that users would not have to move the tool intensively for the whole time. Based on this guideline, playing on a seesaw is excluded because each communication partner should move alternately for continuous interaction, thus playing on a swing or a spring rider are considered to be an appropriate interaction model, because the motion of those tools continues for a while after users stop moving once they move them, and additionally because users can easily adjust their motions by moving not just leg but also various parts of body such as head, arm and other upper body.

B. *Swinging whole-body together*

By examining features of playing on a swing or a spring rider, authors design an interaction system that people can interact with each other by swinging and that keeps on interacting once the system starts.

Firstly, a swing is composed of a seat, long chains and sturdy frame. Considering that the system is installed indoors, the frame suspending long chains is too obstructive. Also, swinging the seat requires relatively high torque because the seat is located some distant from rotation center. At the same time, it is difficult to synchronize motions of one seat with that of remote another one, because the chain suspending the seat is too flexible in order to control its motion precisely. That's why authors consider playing a swing is not appropriate for structural model.

Secondly, in a spring rider, a board or a seat is attached to compression springs, and the board swings in the roll, yaw and pitch direction. In order to control swinging of each board or a seat precisely, the interaction system might require complicated mechanism and control method. Therefore authors focus on sitting in a rocking chair, which only swings in pitching direction, to decrease the degree of freedom of swinging. Then authors searched several existing systems to design such rocking-chair interaction system

One large-scaled system, which is called a motion platform or motion bench that is used to simulate the motions of an airplane and an automobile [15], might be available to construct such a rocking chair system. However, authors consider that such system is unsuitable for swinging interaction between two users, because such system has a low backdrivability, or it is difficult for a user to swing the seat, because its mechanism is based on multiple linear actuators. Another such system that may also be available is a system that involves two rocking chairs which swing in sync with one [16]. In this system it is difficult to control the motions of each chair precisely because the chair is moved by the pendulum attached beneath the seat.

Consequently, authors should design and construct a new interaction system, and so we measured features on swinging of a commercial rocking chair. It showed that the maximum inclination angle of the seat is ±5 [deg], and the maximum angular rate is 40 [deg/sec]. Based on such data, authors designed a swinging interaction system as showed in Figure 1, and also designed specification of swinging interaction system as illustrated in table1.

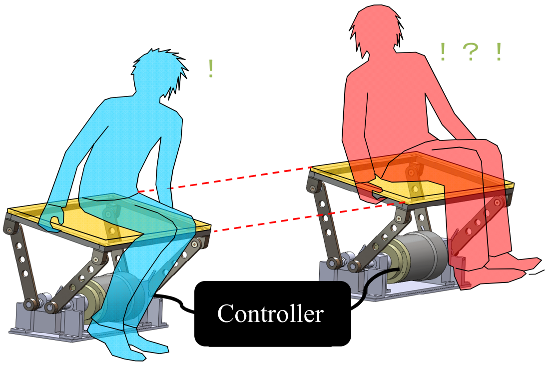


Figure 1. Concept of "Synchronized Swinging Interaction" by moving a chair

Table 1. Supposed specification of interaction system

size	width: 700, depth: 600, height: 400 [mm]
maximum inclination angle of the seat	±15 [deg]
maximum angular rate	40 [deg/sec]
available user	maximum weight 80 [kg] (100[kg] with seat)

III. INTERACTION SYSTEM

A. *Swinging mechanism*

Authors design a rocking-chair-like interaction system, in which movements of one seat are synchronized with those of another one, supporting for swinging interaction between two users who are physically separated.

Such interaction system requires mechanism that controls a seat that a user is sitting on periodically and precisely. Authors consider that it is difficult to control the inclination of a rocking chair seat precisely because such usual rocking chair is simply placed on the floor without any restraint which can easily slip. As a matter of fact, authors are only interested in the swinging motion of rocking chair seat that moves back and forward like a rocking-chair seat swings and not the mechanism of it, so authors used trapezoidal-shape linkage mechanism to construct the system. The most important thing about this mechanism is that such motion can be controlled precisely by rotating the shaft at one node. Additionally, authors devise to attach a torsional spring (7.24 [Nm/deg]) around the shaft as counterbalance as illustrated in Figure 2. This counterbalance spring supports output of actuator to move the seat and a user which therefore the actuator can be downsized. Additionally because of such spring, the seat can swing as damped oscillation without any control as a rocking chair swings. And, a seat unit is interchangeable depending on use application or on physical size of user because the upper unit is constructed from frame bar. Then, this mechanism is all covered around for a safety reason.

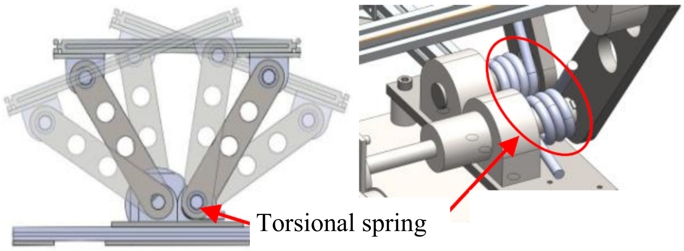


Figure 2. Tracks of a trapezoidal linkage and attached torsional springs

B. *Actuator and sensors*

A high-power drive mechanism should not only swing the seat while user's sitting on but also move forcefully against action of the user. Then, the drive mechanism requires high backdrivability for a user to be able to move the seat connecting to the actuator. Additionally, the mechanism should drive variously based on position of seat and on torque to seat for achieving precise control. In order to meet these requirements, direct drive motor is employed. This motor outputs very high torque (max.130[Nm]) and rotates slowly (max. rotational rate 1.2 [rps]) compared to general DC motor. The motor has advantages in compact size, no gearbox and no backlash, and can sufficiently move a user and the seat frame that are approximate 100 [kg]. Considering stiffness of the structure, authors design and construct a drive mechanism embedding the direct drive motor in, in which a long shaft is installed through the motor and the shaft connects to two side plates.

Rotational angle of the shaft is measured by a high-resolution rotary encoder (1228800 [ppr]) embedded in the direct drive motor. And toque transmitted to the shaft is measured by use of strain gauge attached on each side of the shaft. And relation between strain and torque was measured beforehand based on calibration experiment. Additionally, movement of a user's swinging the seat is measured by 6 DOF force sensor (LFX-A-3KN, Kyowa Electronic Instruments) embedded in the seat. These sensors are to measure moment rotating around the shaft that occurs when a user moves whole body in the pitch direction, horizontal force that occurs when a user moves the seat back and forward by kicking the floor, and perpendicular force supporting a user on the seat. When the user who weighs over 80 kg swinging the seat, force and torque applied to the sensor exceed allowable load, therefore protection mechanism is installed to the sensor.

C. *Control flow*

Process of controlling position and torque of each seat is described as follows. Firstly, data of each sensor is collected to a control computer. Data of strain gauge is amplified and transmitted to the control computer via 16bit I/O board. Data of rotary encoder is transmitted to the control computer through motor driver (DrvGIII, Yokogawa Electric Corporation) and through motion control board (CONTEC, SMC-4DL-PCI). Additionally data of 6 DOF force sensor is read in the computer through 16bit I/O board. In the control computer, target values for torque control based on strain gauge data and for position control based on rotary encoder data are calculated using data coming from both seats. Then, the signal related to torque control is transmitted to motor driver via I/O board, and the signal related to position control is also transmitted to motor driver via motion control board. Finally, the motor driver controls position and torque of direct drive motor. Figure 3 illustrates schematic diagram of the interaction system.

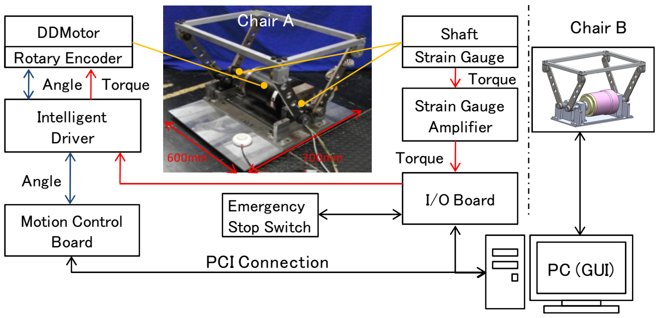


Figure 3. Schematic diagram of the basic swinging interaction system (not including 6 DOF sensor in this figure)

For safety sake, both users can easily and immediately stop swinging when they feel nauseous or scared by pushing a switch located on the floor, or when an operator finds unusual phenomena, he will push the switch in his hand.

Although in the current interaction system, motions of two chairs are controlled in a single control computer to simplify the interaction system, each chair can be controlled two or more computers by transmitting control data via the internet.

D. *Control method.*

The motion of chair can be controlled based on various control methods by changing combination of sensor data and signals controlling torque and/or position of motor. In the current basic research, only three control methods are installed.

Firstly, in position control method as illustrated in Figure 4, motor driver controls angular position of direct drive motor by only use of rotary encoder data in order to synchronize positions of one seat with that of another one. Each motor can be controlled at the same instant for angular position of one motor to correspond to that of another one, therefore, once the difference between angular positions of two motors is generated, each motor rotates in a way to reduce the difference.

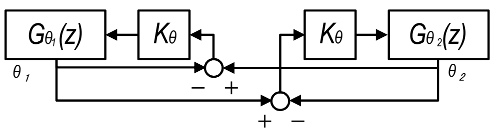


Figure 4. Block diagram of position control method

However, while there is no difference between both motors, both motors are still. This position control is a simple method because only positional data is used and other torque data is ignored.

Secondly, another simple method is torque control that motor driver controls torque of motor by using data from strain gauge concerning torque different from two motors. In this control method, the motor rotates toward the direction in which each of users generates bigger torque. While there is balance between torques in both seats, each motor is still. However this control method is not available in this swinging interaction system, because the motor can rotate only in the limited area which would easily be exceeded in this system.

Finally, hybrid control method and compliance control method are described with consideration for position and torque. Hybrid control is a method that is combination of position control and torque control that motor driver controls position of the motor based on position and torque data. It measures the difference in angle and torque between two seats and multiplies and adds them with weighing factor to calculate the target angle as illustrated in Figure 5. It can easily change the effect of position control method or of torque control method simply by changing the weighting factor.

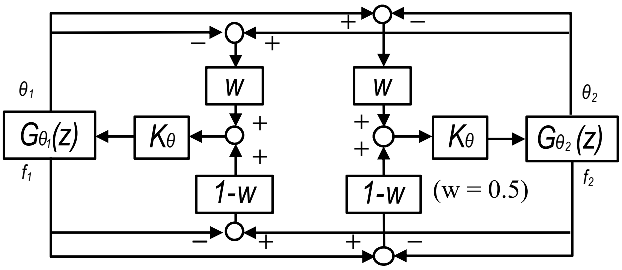


Figure 5. Block diagram of hybrid control method

Compliance control is also a method combining position control and torque control that motor driver controls torque of the motor based on position and torque data as illustrated in Figure 6. This compliance control method is often applied to robot hand control, in which stiffness is adjusted when external force acts on the hand. In this system, amount of values to control the torque of the motor is calculated by the formula below;

$$F_c = M\ddot{\theta} + D\dot{\theta} + K\theta \qquad (1)$$

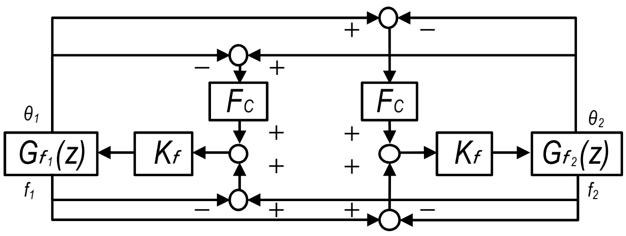


Figure 6. Block diagram of compliance control method

IV. Performance Test

A. Procedure

In order to investigate the difference of motions of two seats depending on three control methods; position control, hybrid control and compliance control, authors conducted performance test. Two experimenters sit on each seat in the interaction system, and swing the seat freely at both sides as illustrated in Figure 7. They can swing the seat by moving upper body or by kicking the base on the floor. They are asked to wear headphone playing white-noise while swinging the seat to avoid hearing other sounds such as rotating motor and another experimenter kicking the floor so that they can focus on only the movement of the seat. Then movements of an experimenter cannot be observed by another because of partitioning each site with a curtain. During experiments data of rotary encoder, strain gauge and 6DOF sensor is sent to the control computer.

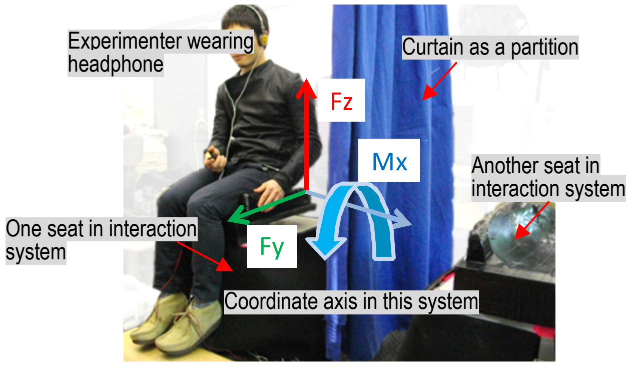
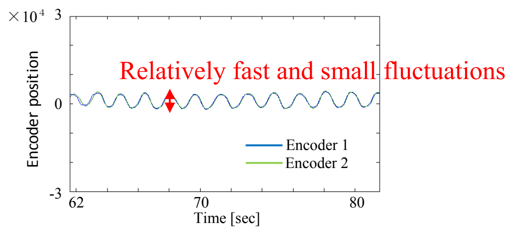


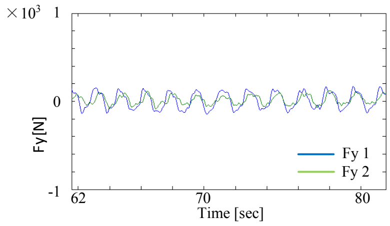
Figure 7. A scene of performance test that two experimenters swing each seat (only one person appears in this figure)

B. Result

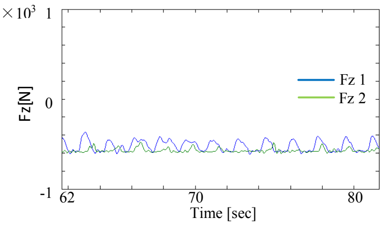
In this paper authors especially focus on a phenomenon of synchronization that position of one seat almost corresponds to that of another one, because it is difficult to consider the difference between each control method while variously fluctuating of seats. And authors also pick up in this paper M_x: moment rotating the seat in the pitch direction, F_y: force of a user's moving the seat back and forward, and F_z: force supporting a user on the seat. Then, authors show characteristic behaviors in each control method. Figure 8 shows behaviors in the position control, Figure 9 shows behaviors in the hybrid control, and Figure 10 shows them in the compliance control.



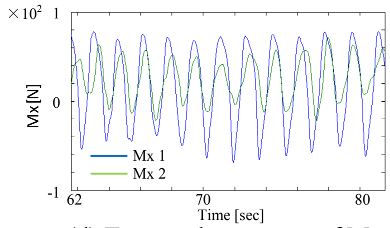
(a) Temporal responses of angular position



(b) Temporal responses of F_y

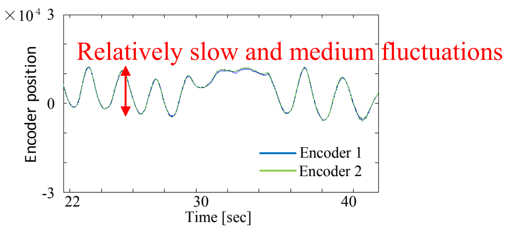


(c) Temporal responses of F_z

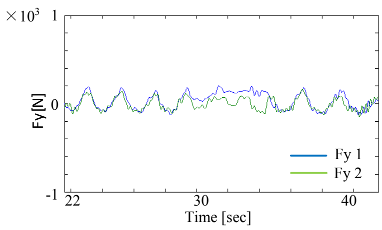


(d) Temporal responses of M_x

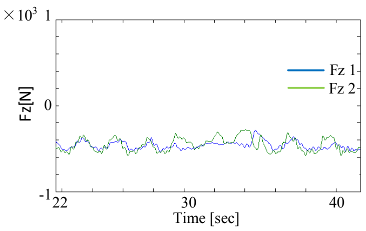
Figure 8. Temporal responses of motions of two chairs and movements of two users in position control method



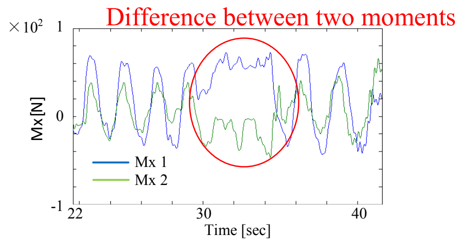
(a) Temporal responses of angular position



(b) Temporal responses of F_y

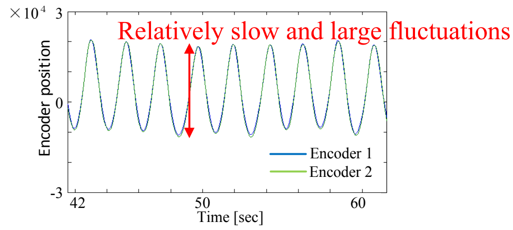


(c) Temporal responses of F_z

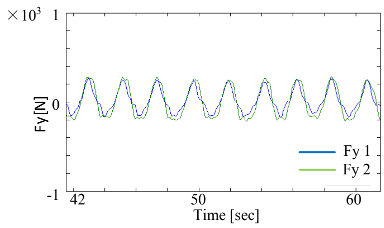


(d) Temporal responses of M_x

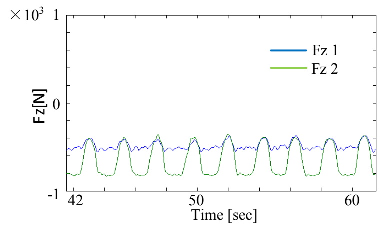
Figure 9. Temporal responses of motions of two chairs and movements of two users in hybrid control method



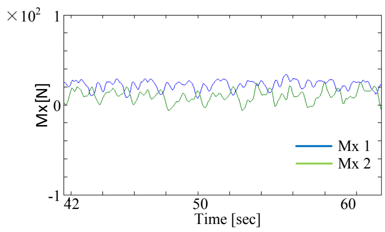
(a) Temporal responses of angular position



(b) Temporal responses of F_y



(c) Temporal responses of F_z



(d) Temporal responses of M_x

Figure 10. Temporal responses of motions of two chairs and movements of two users in compliance control method

V. Discussion

Firstly authors consider features of motions of seats by observing Figure 8, 9 and 10. Amplitude of synchronized swinging increases in following order; position control, hybrid control and compliance control. The amplitude in compliance control is approximately 4 to 5 or times larger than in the position control, and the amplitude in hybrid control is approximately 2 to 3 or times larger than in position control. Then authors apply frequency analysis in such synchronized swinging, and results indicate that the peak appears in about 0.45－0.7[Hz] in position control method, about 0.4－0.45[Hz] in hybrid control method and in compliance control method.

Secondly, authors consider features of fluctuation of moment M_x that shows how the user trying to move the seat. In position control, amplitude of fluctuation of M_x is much larger compared to in other two control methods and the rhythm of fluctuation is similar to the rhythm of motion of the seat. In hybrid control, the fluctuation is fairly close to motions of seat, though it includes high-frequency fluctuation. A unique phenomenon that is not observed in position control is that synchronization of motions of the seats is observed even when moments that two people generate fluctuate in opposite phase. In compliance control, fluctuation of moments is not similar to motions of seat, and the fluctuation seems to be variable compared to in other two control methods.

Finally, in F_y and F_z authors have not found any specific features dependent on each control method at this point.

Authors summarize features in synchronized swinging above mentioned. In position control method, both seats move relatively shortly and fast, and people move whole body widely in the pitch direction. Meanwhile, in hybrid control method and in compliance control method, both seats move relatively long and slowly, and people move their bodies variously. This indicates that difference of control method makes great effect on motions of two seats, which therefore changes how users move their bodies for swinging the seat. Authors consider such change is significant to support various physical interactions between two people who are separated.

Additionally, effects of swinging whole body from the point of relaxation when sitting in a rocking chair have been researched [17]. Authors expect that it points out physical interaction with whole body should generate unique effect that is ignored in much-used communication tools. As the performance test authors conducted were only in small-scale, further study is required to investigate features dependent on each control method and to validate the usefulness of our systems.

VI. Conclusion

Though a lot of communication tools for remote haptic interactions have been devised and proposed, there are few interaction systems supporting physical interactions with whole body that are seen in actions such as hugging and cradling. In order to support various physical interactions, authors devise an interaction system in which people can interact with each other by swinging their whole bodies by using tools such as a rocking chair. The swinging interaction system is constructed based on trapezoidal-shape linkage mechanism embedding direct drive motor inside, and the system can drive based on various control methods. Results from performance test indicate that the control method makes great effect on motions of two seats, which therefore influence how users move their bodies to swing the seat. Further study will demonstrate features of unique effect of such physical interaction system with whole body.

Acknowledgments

This paper is a part of the outcome of research performed under a Waseda University Grant for Special Research Projects (Project number: 2008B-160, 2009B-156, 2010A-504). The authors would like to thank Yoshinori Hayashi for his help. We would also like to thank Junpei Nakamoto for editing the final version of this paper.

References

[1] A. Chang, E. Gunther, H. Ishii, “ComTouch: Design of a Vibrotactile Communication Device”, DIS2002, pp.312-320, 2002.

[2] N.White, D.Back, “Telephonic Arm Wrestling”, http://www.normill.ca/artpage.html, 1986.

[3] S.Manorotkul, Y.Kunii, H.Hashimoto, “Tele-handshake Interface Based on Teleoperation with Time Delay”, Proc. 7th Int’l Power Electronics & Motion Control Conf., pp.337-341, 1996.

[4] E.Paulos, J.Canny, “PRoP: Personal Roving Presence”, Proc. ACM SIGCHI Conf. on Human Factors in Computing Systems, pp.296-303, 1998.

[5] H.Kuzuoka, S.Oyama, K.Yamazaki, K.Suzuki,& M.Mitsuishi, “GestureMan: A Mobile Robot that Embodies a Remote Instructor’s Actions”, Proc. ACM Conf. on Computer Supported Cooperative Work, pp. 155-162, 2000.

[6] http://hil.atr.jp/projects/kibans/res/Telenoid-resources.html, 2010.

[7] S. Brave, A. Dahley, “inTouch:A a medium for haptic interpersonal communication”, CHI EA’97, pp363-364, 1997.

[8] D.Sekiguchi, M.Inami, N.Kawakami, T.Maeda, Y.Yanagida, & S.Tachi, “RobotPHONE: RUI for Interpersonal Communication”, ACM SIGGRAPH 2000 Conference Abstracts and Applications, 134, 2000.

[9] N.Takahashi, Y.Kuniyasu, M.Sato, S.Fukushima, M.Furukawa, Y. Hashimoto and H. Kajimoto, “Kiss Interface for Intimate Communications”, Journal of Human Interface Society, Vol.13 No.4, pp.335-343, 2011.

[10] T.H.Massie, J.K.Salisbury, “The phantom haptic interface: A device for probing virtual objects”, Proc. the ASME Winter Annual Meeting, Sympo. on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp.295-299, 1994.

[11] M.Hara, Y.Jung, J.Huang and T.Yabuta, “Basic Study on Sensory Aspects of a Master/Slave System for Force Telecommunication”, Proc. of 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.5112-5117, 2006.

[12] S.Wesugi, Y.Miwa, “Overlaying a virtual and a real table to create inter-real virtual space”, Proc. 3rd Annual SIGCHI-NZ Sympo. on Computer-Human Interaction, pp.37-42, 2002.

[13] S.Wesugi, Y.Miwa, “Facilitating interconnectedness between body and space for full-bodied presence - Utilization of Video projection “Lazy Susan” communication system –“, Proc. 7th Annual Int’l. Workshop on Presence, pp.208-215, 2004.

[14] Wesugi.S., and Miwa,Y. ,“Lazy Susan” Chair Communication System for Remote Whole-Body Interaction and Connectedness, Proceedings of the Third IASTED International Conference Human-Computer Interaction, pp.93-99, 2008.

[15] G.C.Burdea, P.Coiffet, Virtual Reality Technology (Wiley-IEEE Press, 2 edition, 2003).

[16] N.Fujimura, “Remote Furniture”, http://www.andrew.cmu.edu/user/noriyuki/artworks/remotefurniture/index.html, 1999.

[17] J. V. Deusen, J. Kiernat, “An Exploration of the Rocking Chair as a Means of Relaxation”, Journal of Physical & Occupational Therapy in Geriatrics, Vol. 4(2), pp.31-38, 1985.