Human Perception of Weight in Networked Virtual Environment with Haptic Sense—Influence of Network Delay

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Abstract ² In this paper, we investigate the influence of network delay on weight perception in networked virtual environment by experiment. In the experiment, each of two users manipulates a haptic interface device, and the users collaboratively lift up a stick by holding two ends of the stick in a 3D virtual space. A weighted ball is placed on the stick, if one end of the stick is lower than the other end, the ball moves to the lower end. The users try to keep the ball at the center of the stick while lifting up the stick. We also implement the local lag control as Quality of Service (QoS) control and compare results with the control and those without it. Experiment results demonstrate that the local lag control is effective, and it is possible to keep the ball around at the center when the network delay is smaller than about 50 ms.

Index Terms² Haptic sense, network delay, weight perception, QoS

I. INTRODUCTION

Recently, a number of studies focus on networked virtual environments with haptic sense [1], [2]. By using haptic sense, we can largely improve the efficiency of collaborative work in networked virtual environments where it is necessary for multiple users to do collaborative work while watching the same displayed images simultaneously. However, when the information is transmitted over a Quality of Service (QoS) [3] non-guaranteed network like the Internet, the receiving times at different terminals may be different from each other owing to network delays and delay jitters. This means that some terminals may have already received information while the other terminals may have not received the information. Then, users at different terminals may watch different displayed images at the same time, and the efficiency of collaborative work may deteriorate.

In order to solve the problem, QoS control such as simultaneous output-timing control [4] is needed to absorb delay differences among different terminals. Several types of simultaneous output-timing control such as local lag control [5], group (or inter-destination) synchronization control [6], and adaptive û-causality control [7] have been proposed. In the local lag control, each source terminal buffers local information for a constant time called the local lag, which is denoted by û (1 0) and equal to the network delay. Therefore, all the terminals output the information simultaneously. There are mainly three schemes (master-slave destination scheme [6], synchronization maestro scheme [8], and distributed control scheme [9]) for group synchronization control. In the master-slave destination scheme, the terminals are grouped into a master terminal and slave terminals. The master terminal determines the target output time [10], which denotes an instant at which each terminal should output information for the group synchronization, and notifies all the slave terminals. Each slave terminal gradually adjusts its output timing to the output timing of the master terminal. In the synchronization maestro scheme, a synchronization maestro determines the reference output timing [8] based on information about the output timings from all the terminals and multicasts the reference output timing to all the terminals. The main difference between the distributed control scheme and the synchronization maestro scheme is in how to determine the reference output timing. In the distributed control scheme, each destination determines the reference output timing based on information about the output timings from the other terminals. In the û-causality control [8], each packet has a time limit which is equal to the generation time of the packet plus û seconds for preservation of the real-time property, and the packet is output at the time limit. The adaptive û-causality control [7] dynamically adjusts the value of û among all the terminals according to the network delay.

To absorb delay differences among different terminals, we can use either of the three types of the control. In this paper, we can employ the local lag control since the control is the most simple.

On the other hand, it is important to transmit information about weights and shapes of objects, and R E M H F W ¶ V P R Y H P H Q W in collaborative work using haptic sense [11], [12]. In [11], the authors handle collaborative work in which two users move an object together to eliminate a target in a 3-D virtual space. In the work, the users transmit their wills about

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movement direction of the object to each other by haptic sense and by haptic and visual senses. They investigate the influence of network delay on will (object's movement direction) transmission. In [12], the authors deal with collaborative haptic play with building blocks. In the play, by manipulating haptic interface devices, two users pile up building blocks collaboratively to build a dollhouse in a 3-D virtual space. In order to do the collaborative haptic play precisely, they proposed a group synchronization control scheme with prediction and investigate the effects by experiment. However, the influences of network delay on human perception of weight are not clarified sufficiently. Furthermore, the effect of the local lag control in human perception of weight has not been investigated.

In this paper, we deal with collaborative work called a networked balance system with haptic sense in which two users collaboratively lift a weighted ball, and we investigate the influence of network delay (including symmetric and asymmetric network delay). We also examine the effect of local lag control by experiment. In order to clarify how efficiently the work can be done only by weight perception, we deal with three cases of collaborative work and compare results among the cases. In one case, users do the collaborative work while watching the virtual space and perceiving the weight of the ball. In another case, the users do collaborative work while perceiving the weight of the ball, but cannot watch the virtual space. In the other case, they do collaborative work while watching the virtual space but cannot perceive the weight of the ball.

The remainder of this paper is organized as follows. Section II describes the networked balance system with haptic sense. Section III explains the experiment method, and Section IV presents experimental results. Finally, Section V concludes the paper.

II. NETWORKED BALANCE SYSTEM WITH HAPTIC SENSE

Fig. 1 shows the system configuration of the networked balance system and a displayed image of the virtual space. The system consists of two PCs (PCs 1 and 2), and a haptic interface device (Geomagic Touch [13]) is connected to each PC.

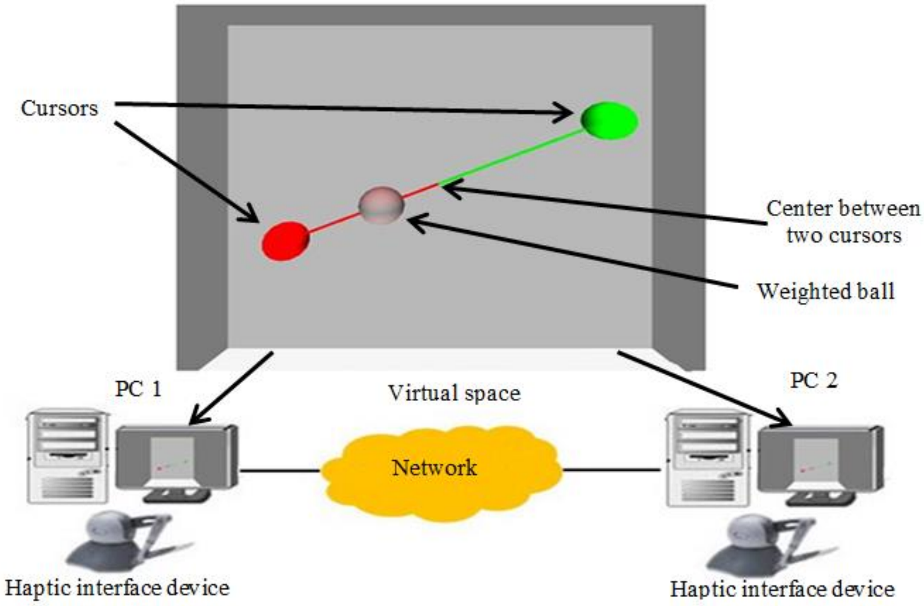

Fig. 1. System configuration of networked balance system with haptic sense.

By manipulating the haptic interface device, each of two users can operate a cursor (denotes the position of Geomagic Touch stylus's tip) in the virtual space which is surrounded by a floor, a ceiling, and walls. The cursors are connected to two ends of a stick (weight: 0 gf) which can be stretched or shrunk freely between the two ends. Between the two cursors (i.e., the two ends of the stick), the ball (weight: 270 gf) is placed on the stick. The feedback force applied to a user is proportional to the distance from the user's cursor to the ball. Fig. 2 shows the calculation method of reaction force. In Fig. 2, the proportion of the distance from the red cursor to the weighted ball to the distance from the green cursor to the weighted ball is k : (1.0 $-k$); m is the mass of the weighted ball, and g (9.8 m/s^2) is the gravitational acceleration. The feedback force applied to the red cursor's user is calculated by (1.0 $-k$) F, and that applied to the green cursor's user is calculated by k F. The ball moves to the side of lower cursor (end) along the stick if there exists altitude difference between the two cursors. The users try to keep the ball at the center of the stick (as shown in Fig. 1, the right side of the center is green, and the left side of the center is red) while piling up the stick.

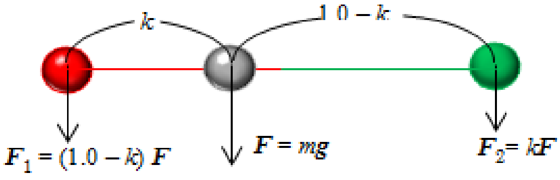

Fig. 2. Calculation method of reaction force.

III. EXPERIMENT METHOD

In our experiment system, we employ a network emulator (NIST Net [14]) instead of the network of Fig. 1. The network emulator generates a constant delay (called the additional network delay in this paper) for each packet transmitted between the two PCs. The users start to do collaborative work from the initial state in which the weighted ball is placed at the center of the stick and two cursors are placed on the floor (see Fig. 3). They are asked to lift the ball to a height of 16.7 (we here assume that the diameter of cursor is 1) collaboratively while trying to keep the ball at the center of the stick and to move at a constant speed (see Fig. 4). The movement distance of 16.7 corresponds to 10 cm in the real space when they lift the stylus of the haptic interface device vertically.

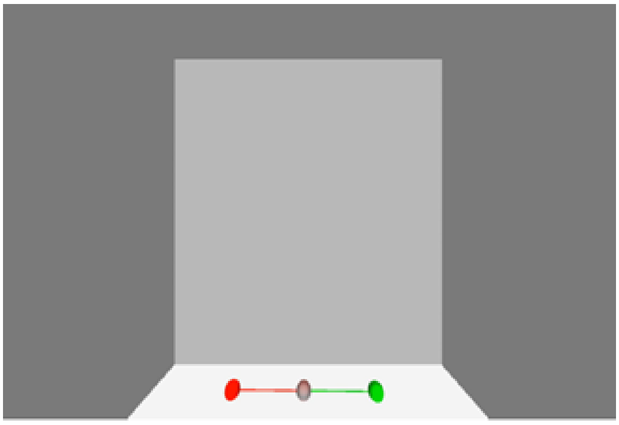

Fig. 3. Displayed image of initial state

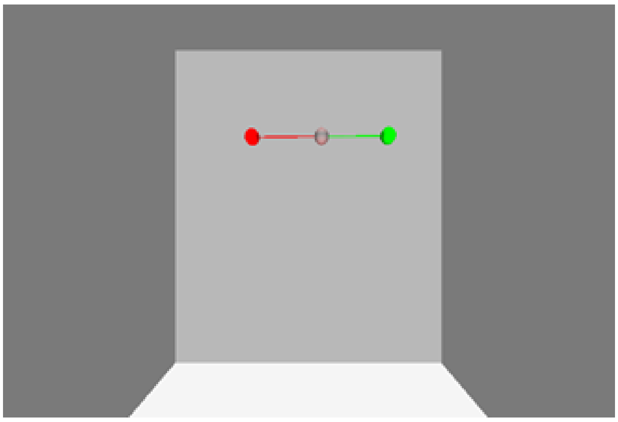

Fig. 4. Displayed image of end state

If the ball is not located at the center, each user tries to adjust the place of the ball by moving up his/her cursor c stop moving. In the experiment, we handle three mode (modes 1, 2, and 3). In mode 1, the users do collaborative work while watching the virtual space and perceiving the weight of the ball. In mode 2, they do collaborative work while perceiving the weight of the ball but cannot watch the virtual space. In this mode, after displaying the initia image of virtual space, the virtual space becomes blac.. and they cannot watch the virtual space. In mode 3, they do collaborative work while watching the virtual space but cannot perceive the weight of the ball. Then, we compare results with the local lag control and those without the control in the three modes.

We carried out the experiment in the cases of symmetric and asymmetric network delays. In the case of symmetric network delay, the round-trip delay is changed from 0 ms to 300 ms; in the case of asymmetric network delay, that is changed from 0 ms to 600 ms.

We measured the position of the ball and operation time in the experiment. The position of ball is defined as the distance between the ball and the center of the stick, and positions on the right side of the center are denoted by plus values and those on the left side are done by minus ones.

In the experiment, the mode was selected in random order for each pair of users; in each selected mode, the conditions (with/without the local lag control) and additional network delays were also selected in random order for each pair of users.

IV. EXPERIMENT RESULTS

We show experiment results from Figs. 5 through 12. Fig. 5 and Fig. 6 plot the average of average position, and Fig. 7 and Fig. 8 do the average of standard deviation of position versus the round-trip network delay between the two terminals. The reason why we select the round-trip network delay as the abscissa axis is because we carried out regression analysis and found that the experiment results hardly depend on the delay difference between the two terminals and depend on the round-trip network delay. Figures 9 and 10 show the average operation time and the standard deviation of operation time versus the round-trip network delay are shown in Fig. 11 and Fig. 12. The experiment results of symmetric network delay are shown in Fig. 5, Fig. 7, Fig. 9, and Fig. 11, and those of asymmetric network delay are shown in Fig. 6, Fig. 8, Fig. 10 and Fig. 12. Since it is hard to see these figures clearly if we plot the 95% confidence intervals, we plot the intervals only in Fig. 5

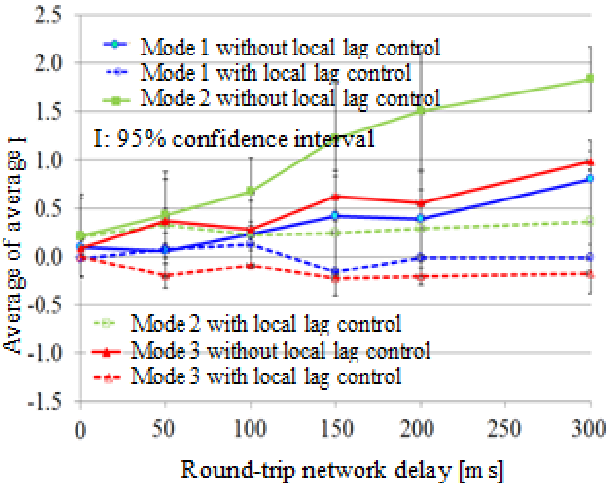

Fig. 5. Average of average position versus round-trip network delay in case of symmetric network delay.

From Fig. 5 and Fig. 6, we find that in the modes without the local lag control, the averages of average position increases as the round-trip network dela becomes larger. On the other hand, the averages a hardly affected by the round-trip network delay, and the averages are small. This means that the local lag contr is effective for the work.

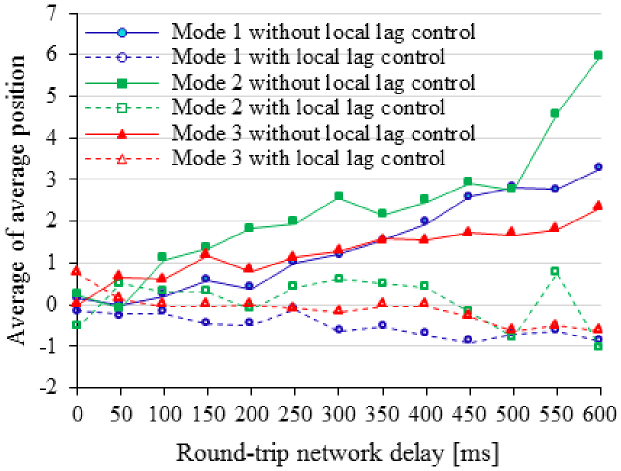

Fig. 6. Average of average position versus round-trip network delay in case of asymmetric network delay.

From Fig. 5, we notice that the averages in mode 1 a similar to those in mode 3. This means that in mode (users do collaborative work while watching virtual space and perceiving the weight of the ball), the visual sense i mainly used in the collaborative work. Additionally, from Fig. 5, we see that the averages hardly depend on t round-trip network delay in the three modes with the local lag control. We also find that the averages of mod 2 are slightly larger than those of modes 1 and 3. This because the users cannot watch the virtual space in mode 2. However, even though the users cannot watch the virtual space, it is possible to do the collaborative work with certain accuracy. On the other hand, from Fig. 5, we find that the averages in the case without the local la control are larger than those with the local control. This is because in the case without the local lag control, the consistency of weight perception becomes worse as th round-trip network delay increases. Furthermore, from Fig. 5, we notice that the average in mode 2 without the local lag control is the largest. Especially when the round-trip network delay is larger than about 50 ms, the average rises largely. However, when the round-trip network delay is smaller than approximately 50 ms, the averages are smaller than about 0.5; therefore, it i possible to keep the ball around at the center by usin only weight perception in this range. We can also find similar tendency in Fig. 6.

From Fig. 7 and Fig. 8, we find that the average of standard deviation of position is smaller than about 1.5 in modes 1 and 3 with the local lag control. This means that the ball is almost fixed at the center. Considering the results shown in Fig. 5 and Fig. 6, we can say that in modes 1 and 3 with the local lag control, the ball is almost always kept at the center of the stick while lifting up.

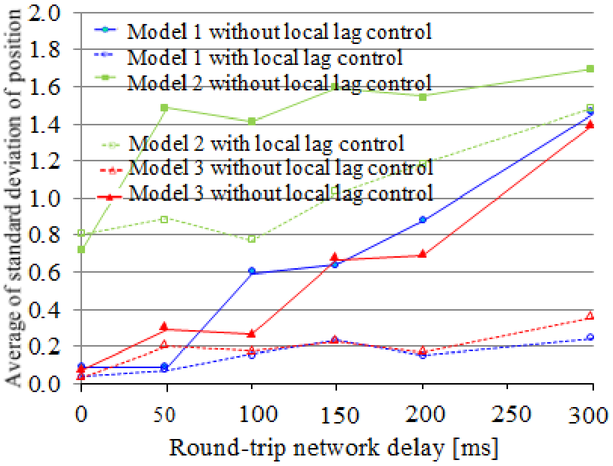

Fig. 7. Average of standard deviation of position versus round-trip network delay in case of symmetric network delay.

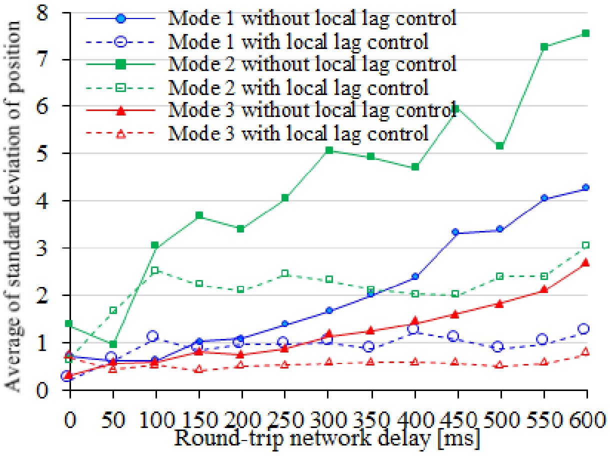

Fig. 8. Average of standard deviation of position versus round-trip network delay in case of asymmetric network delay.

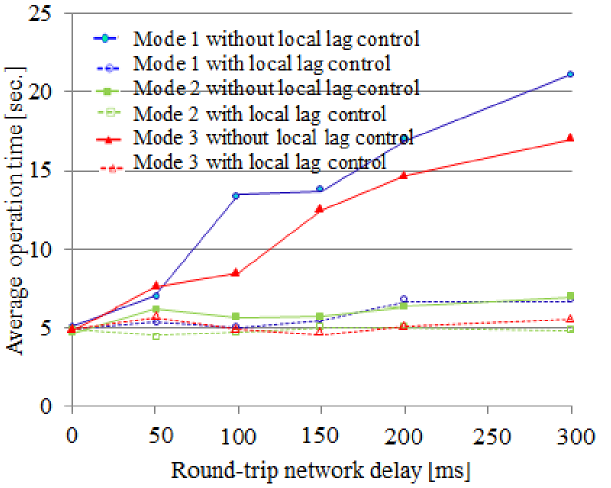

Fig. 9. Average operation time versus round-trip network delay in case of symmetric network delay.

From Fig. 9 and Fig. 10, we notice that in modes 1 and 3 without the local lag control, the average operation time increases as the round-trip network delay becomes larger. This is because the users cannot get consistency of the position from vision in order to keep the ball at the center of the stick, and they try to adjust the ball many times. We also notice in the figure that the average operation time in mode 2 without the local lag control is almost the same as that in mode 2 with the local lag control.

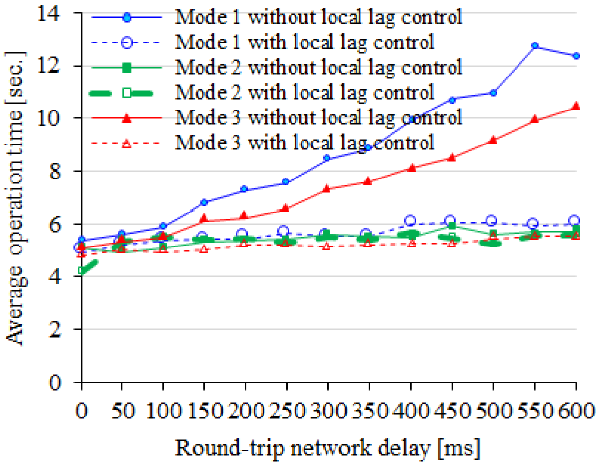

Fig. 10. Average operation time versus round-trip network delay in case of asymmetric network delay.

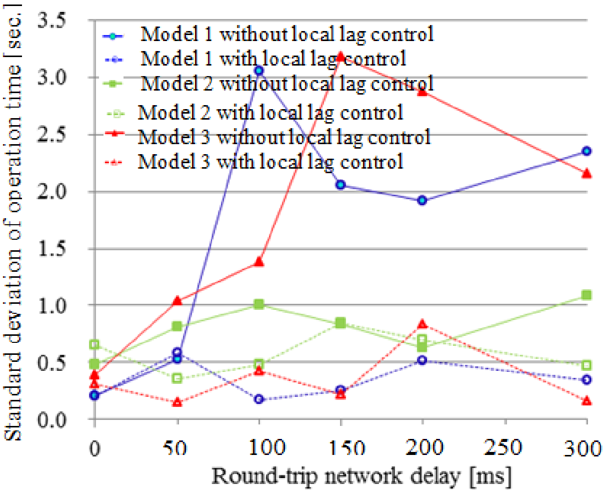

Fig. 11. Standard deviation of operation time versus round-trip network delay in case of symmetric network delay.

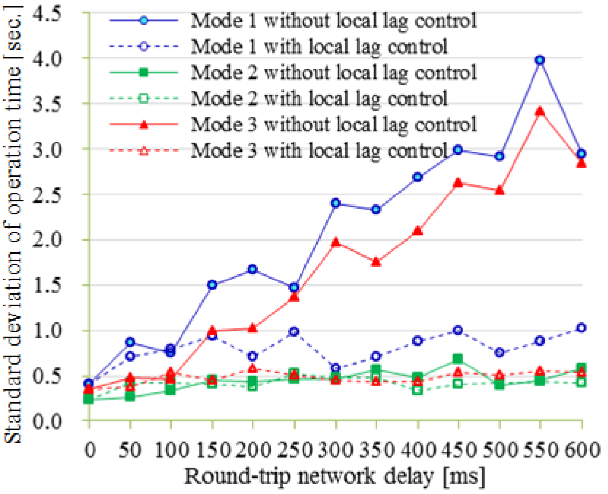

Fig. 12. Standard deviation of operation time versus round-trip network delay in case of asymmetric network delay.

In Fig. 11 and Fig. 12, we notice that the standard deviations of operation time become larger as the round-trip network delay becomes larger than about 100 ms in modes 1 and 3 without local lag control. This also means that the local lag control is needed.

V. CONCLUSIONS

In this paper, we investigated the influences of network delay on human perception of weight in a networked balance game where two users collaboratively lift a weighted ball in virtual environment. We dealt with three modes of collaborative work (mode 1: users do the collaborative work while watching the virtual space and perceiving the weight of the ball; mode 2: the users do collaborative work while perceiving the weight of ball but cannot watch the virtual space; mode 3: they do collaborative work while watching the virtual space but cannot perceive the weight of the ball), and we handled two cases of symmetric and asymmetric network delays in the three modes. As a result, we found that the local lag control can improve the efficiency of the collaborative work. Also, without carrying out the local lag control, it is difficult to keep the ball placing at the center of stick as the network delay increases. However, when the network delay is smaller than approximately 50 ms, it is possible to keep the ball around at the center.

As the next step of our research, we need to carry out the experiment with different weights and movement speeds of the ball when the stick is lifted.

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REFERENCES

[1] E. Steinbach, S. Hirche, M. Emst, F. Brandi, R. Chaudhari, J. Kammerl DQG , 9LWWRULDV ³+DSWLF Communications´ IEEE Journals & Magazines, vol. 100, no. 4, pp. 937-945, Apr. 2012.

[2] 3 +XDQJ DQG < ,VKLEDVKL ³4R6 FR assessment in multi-VHQVRU\ FRPPXQLFDWLRQV IEICE Trans. Commun., Special Section on Quality of Communication Services Improving Quality of Life, vol. E96-B, no. 2, pp. 392-403, Feb. 2013.

[3] ITU-7 5HF , ³*HQHUDO DVSHFWV RI and networkSHUIRUPDQFH LQ GLJLWDO QHWZ

[4] P. Huang, Y. Ishibashi, and M. Sithu, ³Enhancement of simultaneous output-timing control with human perception of synchronizatLRQ HUURUV DPRQJ PXOWLSOH Proc. The 2nd IEEE International Conference on Computer and Communications, Oct. 2016, pp. 2099-2103.

[5] 0 0DXYH - 9RJHO DQG : (IIHOVEHUJ timewrap: Providing consistency for replicated continuous DSSOLFDWLRQV´ IEEE Trans. on Multimedia, vol. 6, no. 1, pp. 47-57, Feb. 2004.

[6] Y. Ishibashi, A. Tsuji, and S. Tasaka, "A group synchronization mechanism for stored media in multicast communications," in Proc. IEEE International Conference on Computer Communications, April 1997, pp. 693-701.

[7] Y. Ishibashi, S. Tasaka, and Y. Tachibana, "Adaptive causality and media synchronization control for networked multimedia applications," in Proc. Conf. Rec. the IEEE International Conference on Communications, June 2001, pp. 952-958.

[8] Y. Ishibashi and S. Tasaka, "A group synchronization mechanism for live media in multicast communications," in Proc. Conf. Rec. IEEE Global Telecommunications Conference, Nov. 1997, pp. 746-752.

[9] Y. Ishibashi and S. Tasaka, "A distributed control scheme for group synchronization in multicast communications," in Proc. International Symposium on Communications (ISCOM), Nov. 1999, pp. 317-323.

[10] Y. Ishibashi and S. Tasaka, "A synchronization mechanism for continuous media in multimedia communications," in Proc. IEEE International Conference on Computer Communications, April 1995, pp. 1010-1019.

[11] P. Huang and Y. Ishibashi, "QoE assessment of will transmission using vision and haptics in networked virtual environment," International Journal of Communications, Network and System Sciences, vol. 7, no. 8, pp. 265-278, Aug. 2014.

[12] P. Huang, Y. Ishibashi, N. Fukushima, and S. Sugawara, "Interactivity improvement of group synchronization control in collaborative haptic play with building blocks," in Proc. The 9th Annual Workshop on Network and Systems Support for Games, Nov. 2010.

[13] [Online]. Available: http://geomagic.com/en/products/phantom-omni/ overview

[14] M. Carson and D. Santay, "NIST Net: A Linux-based network emulation tool," ACM SIGCOMM Computer Communication Review, vol. 33, no. 3, pp. 111-126, July 2003.

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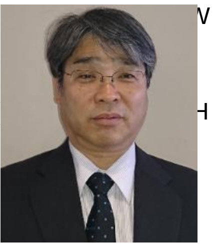

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