FAIRNESS AMONG GAME PLAYERS IN NETWORKED HAPTIC ENVIRONMENTS: INFLUENCE OF NETWORK LATENCY

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ABSTRACT

By experiment, this paper examines the influence of network latency on the fairness among players in a networked real-time game where we use haptic interface devices. In the experiment, we subjectively and objectively clarify the influence by changing the difference in network latency between two players. Experimental results show that the difference which leads to unfairness depends on the network latency. We also demonstrate that the differences larger than 30 ms or 40 ms lead to unfairness in the experimental system. Furthermore, we hardly perceive unfairness when the network latency of the two players is less than around 30 ms in the experiment.

1. INTRODUCTION

By using haptic interface devices in networked virtual environments, we can largely improve the efficiency of work in a 3-D virtual space [1]. However, the network latency may seriously degrade the efficiency of work. This is because haptic media have severe constraints on the network latency. The maximum allowable latency is about 30 to 60 ms [2].

In [3], Hikichi *et al.* handle collaborative work in which two users lift and move a computer graphics (CG) object by manipulating haptic interface devices (PHANToM [4]). They investigate the influence of the difference in network latency between the two users on the efficiency of the work. As a result, they show that a user with smaller network latency can help the other user. On the other hand, in competitive work such as networked real-time games, the difference in network latency between two players leads to unfairness between them. However, to the best of the authors' knowledge, there is no paper that addresses the fairness issue among players for haptic media.

This paper deals with a networked real-time game in which two players do work competitively by using haptic interface devices. We examine the influence of the network latency on the fairness between the two players subjectively and objectively.

The rest of this paper is organized as follows. Section 2 outlines a networked real-time game which is handled in the paper. Section 3 describes a system model for haptic media in the game. Section 4 explains the method of the experiment, and experimental results are presented in Section 5. Section 6 concludes the paper.

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2. NETWORKED REAL-TIME GAME

In this paper, we handle a networked real-time game in which two players lift and move their own CG objects competitively by manipulating haptic interface devices. We here employ the PHANToM DESKTOP as a haptic interface device.

Each player lifts and moves his/her object (a rigid cube) so that the object contains the target (a sphere) in a 3-D virtual space (height: 89.7 mm, width: 129.7 mm, depth: 89.7 mm) as shown in Fig. 1. The mass of the object is 0.5 kg, and the acceleration of gravity is 2.0 m/s^2. When the target is contained by either of the two objects, it disappears and then appears at a randomly-selected position in the space. The two players compete on the number of eliminated targets with each other for 30 seconds from 5 seconds after beginning of each experimental run[1]. Each side of the cube is a quarter of the virtual space's height, and the radius of the sphere is half of the cube's side. The objects and target do not collide with each other, and the PHANToM cursors (i.e., the positions or contact points of the PHANToM) do not collide with the target.

3. SYSTEM MODEL

Here we adopt a client-server model for the networked real-time game as shown in Fig. 2. Each client inputs/outputs a *media unit* (*MU*), which is an information unit for media synchronization, at a rate of 1 kHz. MUs input at each client are transmitted to a single server.

The server carries out causality (i.e., ordinal relation) control over received MUs. The causality control is required to maintain the temporal order of manipulation events. Then, the server calculates the force against the CG objects and obtains the positions of the CG objects. The server also

[1]We lifted and moved the cube from the floor to the target within the 5 seconds

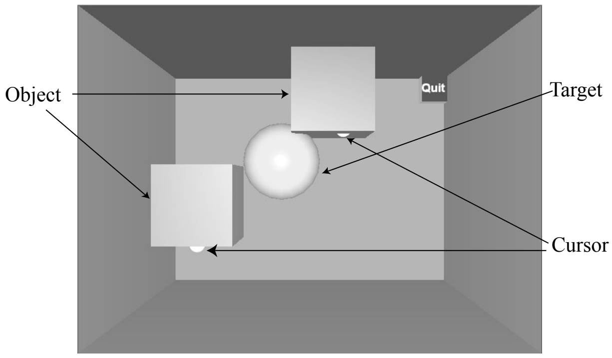

Fig. 1. A displayed image of the virtual space.

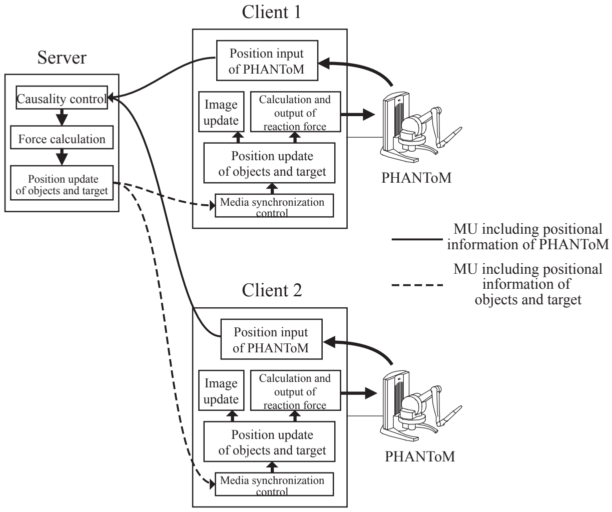

Fig. 2. A system model.

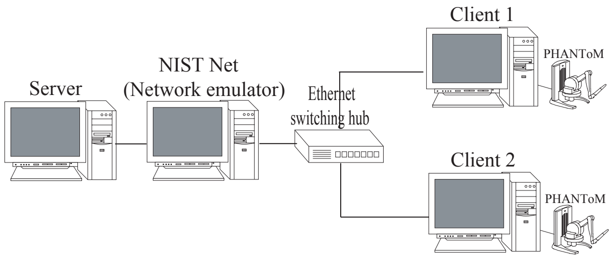

Fig. 3. Configuration of the experimental system.

judges which object contains the target. If the distance between the center of the object and that of the target is less than 4 mm, the server judges that the object contains the target and updates the position of the target. Then, the server transmits the positional information as an MU to the clients. The information is also included in the succeeding MUs.

When each client receives an MU, it updates the positions of the CG objects after carrying out media synchronization control and calculates the reaction force applied to the player. If the positional information of the target in the MU is different from that in the previous MU, the client deletes the target at the old position and displays the target at a new position based on the information. The rendering rate of the virtual space is 30 Hz at the client.

For the media synchronization control, we adopt *Skipping* [5]. Skipping outputs only the latest arrived MU at each point of output time (i.e., every millisecond). It skips obsolete MUs. Since we handle constant network latency in this paper (see Section 4), we do not need to absorb network delay jitter. Thus, we employ Skipping in this paper[2].

4. METHOD OF THE EXPERIMENT

As shown in Fig. 3, the experimental system consists of the server (CPU: Pentium4 processor at 2.26 GHz, OS: FreeBSD 4.7), clients 1 and 2 (CPU: Pentium4 processor at 2.80 GHz, OS: WindowsXP), and a network emulator (NIST Net [6]). The two clients are connected to the server through an Ethernet switching hub and NIST Net. As described earlier, each client has the PHANToM DESKTOP as a haptic interface device.

By using NIST Net, we here generate an additional constant delay for each MU transmitted from the server to each client. We select the additional constant delay from the server to client 1 (referred to as *additional delay 1*) from among 0, 20, 40, 50, and 60 ms. The additional constant delay from the server to client 2 (*additional delay 2*) is set to values larger than or equal to that from the server to client 1.

First, fifteen subjects used client 2 and played with one expert who used client 1. We assessed the fairness objectively and subjectively at the same time. In this case, we can clarify how much the subjects are in disadvantageous places in terms of the fairness; note that the network latency of client 2 is longer than or equal to that of client 1. Next, in order to clarify how much they are in advantageous positions for the fairness, they used client 1, and the expert client 2.

To assess the fairness objectively, we have measured the *elimination rate of the targets*. This measure is defined as the ratio of the number of eliminated targets at each client to the total number of appeared targets.

For subjective assessment, we have enhanced the single stimulus method in ITU-R BT.500-5 [7], which is a recommendation for subjective assessment of television pictures; this is because there is no standard for subjective assessment of haptic media. Before the assessment, each subject practiced manipulation of the PHANToM three or four times on the condition that there was no additional delay. Then, the

[2] We also used the virtual-time rendering (VTR) algorithm [5] instead of Skipping. The VTR algorithm compensates for the network delay jitter by changing the buffering time of MUs dynamically according to the network delay jitter. As a result, we obtained almost the same results as those in this paper.

Table 1. Three-grade scale.

score	description
3	fair
2	neither fair nor unfair
1	unfair

test samples (i.e., the additional delays) were presented in random order in each session, which lasted around 15 minutes. The duration of each test sample was set to 30 seconds as described earlier. The fifteen subjects, whose ages were between 21 and 24, were asked to base their judgments in terms of the wording used to define the subjective scale (Table 1). Each subject gave a score from 1 through 3 to each test. The reason why we use the three-grade scale is that it seems to be difficult for us to assess the fairness by using the five-grade scale[3], which is commonly used to obtain MOS (mean opinion score) [7].

5. EXPERIMENTAL RESULTS

We first discuss the case in which the network latency of the subjects is longer than or equal to that of the expert. Next, we deal with the case in which the subjects have shorter latency than the expert.

5.1. Case of Longer Latency

We show the elimination rate of the targets at client 2 and MOS as a function of additional delay 2 in Figs. 4 and 5, respectively. In the figures, we also display the 95 % confidence intervals; however, when the interval is smaller than the size of the corresponding symbol representing the experimental result, we do not plot it in the figures.

In Figs. 4 and 5, we first find almost the same tendencies excluding when additional delays 1 and 2 are 50 ms and 60 ms, respectively. By the regression analysis, we quantitatively examined the relations between the objective and subjective assessment results. As a result, we have obtained $V_{\mathrm{MOS}} = 4.947 - 4.253R_{\mathrm{e}}$, where V_{MOS} is an estimated value of MOS, and R_{e} denotes the elimination rate. The contribution rate adjusted for degrees of freedom is 0.929. Therefore, we can roughly predict MOS by using the elimination rate.

Next, in Fig. 4, we see that when additional delay 1 is 0 ms and additional delay 2 is smaller than around 40 ms, the elimination rate of approximately 0.5 is achieved. This means that the subjects and the expert are even since the elimination rate is around 0.5 when additional delays 1 and 2 are zero; we can confirm this in Fig. 5. However, in the figures, when additional delay 1 is 0 ms and additional delay 2 exceeds around 40 ms, the elimination rate and MOS start to decrease largely. Therefore, the differences larger than or equal to about 40 ms between additional delays 1 and 2 lead to unfairness when additional delay 1 is 0 ms.

[3] We will try to use the five-grade scale in the near future.

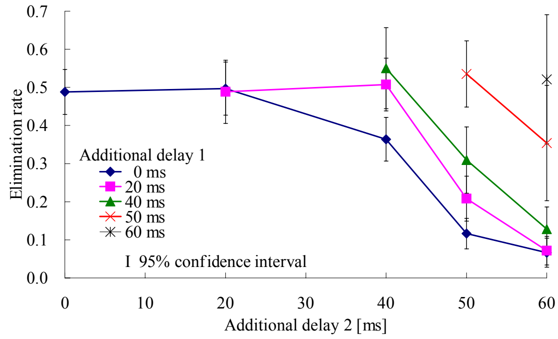

Fig. 4. Elimination rate of the targets at client 2 versus additional delay 2 in the case of longer latency.

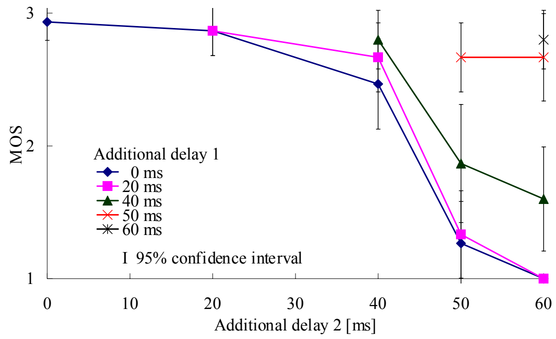

Fig. 5. MOS versus additional delay 2 in the case of longer latency.

We also notice in the figures that when additional delay 1 is 20 ms and additional delay 2 is smaller than or equal to around 40 ms, the elimination rate is approximately 0.5 and the MOS is around 3 (i.e., fair). When additional delay 1 is 20 ms and additional delay 2 becomes larger than or equal to around 50 ms, the elimination rate and MOS become smaller seriously. Thus, in this case, the differences larger than or equal to around 30 ms lead to unfairness. In the figures, when additional delay 1 is 40, 50, or 60 ms, additional delay 2 of the same value as additional delay 1 produces the elimination rate of around 0.5 and MOS of about 3.

As described earlier, when additional delays 1 and 2 are 50 ms and 60 ms, respectively, the elimination rate has a different tendency from MOS. That is, although the elimination rate at additional delay 2 of 60 ms is largely different from that at additional delay 2 of 50 ms, MOS at additional delay 2 of 60 ms is almost the same as that at additional delay 2 of 50 ms. When additional delay 2 was 50 ms or 60 ms, it was very difficult for the subjects to do the work. In the figures, when additional delays 1 and 2 are larger than or equal to around 50 ms, the 95 % confidence intervals are long. Therefore, we are now increasing the number of players in order to derive firmer conclusions.

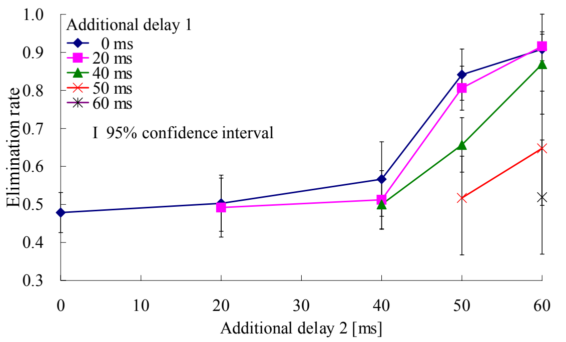

Fig. 6. Elimination rate of the targets at client 1 versus additional delay 2 in the case of shorter latency.

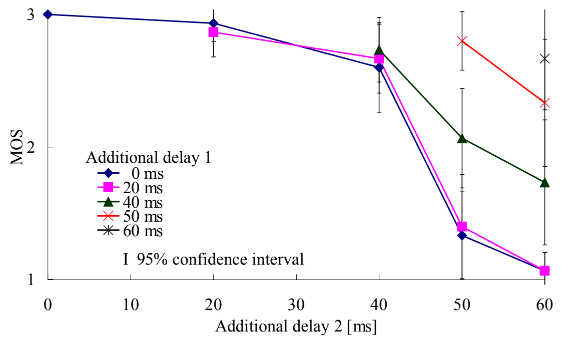

Fig. 7. MOS versus additional delay 2 in the case of shorter latency.

From the above observations, we can say that the difference which leads to unfairness depends on the network latency. The differences larger than 30 ms or 40 ms lead to unfairness in the experimental system. When the network latency of the two players is shorter than around 30 ms, we hardly perceive unfairness.

5.2. Case of Shorter Latency

Figures 6 and 7 plot the elimination rate of the target at client 1 and MOS, respectively, versus additional delay 2. From the figures, we can derive almost the same conclusions as those in the previous subsection. That is, the results in Fig. 6 and those in Fig. 4 are almost symmetric with respect to the line of the elimination rate of around 0.5. Also, the results in Fig. 7 is almost the same as those in Fig. 5.

As a result of the regression analysis, we have obtained $V_{\rm MOS} = 0.931 + 3.709R_{\rm e}$. The contribution rate adjusted for degrees of freedom is 0.912. Thus, we can approximate MOS by using the elimination rate.

To keep the fairness between the two clients, we need to carry out *group* (or *inter-destination*) *synchronization control* [8], which adjusts the output timing among multiple clients. We have demonstrated the effectiveness of the control by experiment; this will be reported in another paper.

6. CONCLUSIONS

This paper investigated the influence of network latency on the fairness between two players in a networked real-time game where the players use haptic interface devices by experiment. As a result, we found that the difference which leads to unfairness depends on the network latency. The differences larger than 30 ms or 40 ms lead to unfairness in the experimental system. When the network latency of the two players is shorter than around 30 ms, we hardly perceive unfairness.

As the next step of our research, we will investigate the influence of the network delay jitter on the fairness. We also plan to handle the case in which there exist three or more clients. Furthermore, we need to deal with other kinds of networked real-time games.

7. REFERENCES

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