QoE Assessment of Operability and Fairness for Soft Objects in Networked Real-Time Game with Haptic Sense

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***Abstract*—In this paper, we carry out QoE (Quality of Experience) assessment of operability of haptic interface device for each player and fairness between players for soft objects in a networked real-time game. We handle a balloon bursting game in which two players burst balloons (i.e., soft objects) in a 3D virtual space by using haptic interface devices. Assessment results show that the operability depends on the network delay, and the fairness is mainly dependent on the difference in network delay between the players' terminals.**

***Keywords*—networked real-time game; virtual environment; soft objects; balloon bursting game; haptic sense; network delay; quality of experience**

I. Introduction

Recently, a number of researchers have been directing their attention to networked real-time games with haptic sense [1]-[5]. When such games are played over a network like the Internet, the consistency (e.g., the positions of an object at terminals are the same) may be disturbed owing to the network delay, delay jitter, and packet loss. For example, when players play a networked real-time game by using haptic interface devices, positions of virtual styli (i.e., CG images of haptic interface devices) and positions of shared objects in a 3D virtual space may be different from terminal to terminal. Not only the consistency among the terminals, but also the fairness among the players may be damaged when the network delays among the players' terminals are different from each other. In [6], Brun *et al.* describe that the fairness is high when the same condition is provided to all the players.

In order to keep the consistency high at the players' terminals, we can employ the local lag control, which buffers the local information for a constant time called the local lag according to the network delay from the local terminal to the other terminal [7]. Thus, the interactivity may be degraded. The local lag control keeps the consistency high, but it does not maintain the fairness among the players when the network delays among the players' terminals are different from each other. Therefore, to maintain the fairness high, we can use the adaptive Δ-causality control [8], which also employs the local lag control. The adaptive Δ-causality control sets the local lag to the maximum network delay among the terminals. When the maximum network delay is large, the interactivity may seriously be degraded under the adaptive Δ-causality control. This leads to the severe degradation of the operability of haptic interface device. To keep both operability and fairness high, there is a trade-off relationship between them. Therefore, it is important to investigate the relationship between the operability and the fairness.

In [3], a networked real-time game in which each of two players try to contain a target (a sphere) competitively with his/her object (a rigid cube) by manipulating his/her haptic interface device is dealt with in a 3D virtual space. The influence of the network delay on the fairness is investigated by QoE (Quality of Experience) [9] assessment. Assessment results show that the players feel unfairness when the difference in network delay between them is larger than about 30 ms. Also, in [4], the influence of the time it takes for a smell to reach a player on the fairness is investigated in a fruit harvesting game where two players play in a 3D virtual space. In the game, all the fruit objects in the 3D virtual space are hard ones. As a result, it is illustrated that the fairness is hardly damaged when the time is smaller than about 500 ms. However, to the best of our knowledge, there is no previous work which investigates the influence of network delay on the operability of haptic interface device and the fairness among players for soft objects in virtual environments. In the case of hard objects, it is found that the objects become heavier as the network delay increases [5]; that is, their characteristics change owing to network delay. The characteristics of soft objects may change in the same way as hard objects; for example, they become harder and/or heavier as the network delay increases. However, it is not clear how the characteristics change. Therefore, we need to investigate the influence of network delay on QoE for soft objects.

In this paper, we deal with a networked balloon bursting game in which two players burst balloons (i.e., soft objects) using haptic interface devices in a 3D virtual space and the players compete with each other for the number of burst balloons. Each player who bursts more balloons than the other player wins the game. We also carry out QoE assessment subjectively and objectively for the balloon bursting game. We investigate the influence of network delay on the operability of haptic interface device and the fairness between the players.

The remainder of this paper is organized as follows. Section II describes the balloon bursting game. Assessment environment is explained in Section III. Assessment results are presented in Section IV, and Section V concludes the paper.

II. BALLOON BURSTING GAME

The system configuration of the balloon bursting game is shown in Fig. 1, where each of two players (*players 1* and *2*) bursts balloons with his/her haptic interface device in a 3D virtual space. The two players compete with each other for the number of burst balloons. As shown in Fig. 1, we employ four balloons for simplicity in the virtual space. The system consists of two terminals (*terminals 1* and *2*), each of which has a PC with a display, a haptic interface device (Geometric Touch [10]), and a headset. Each player employs his/her haptic interface device to move the virtual stylus in the 3D virtual space. When the player touches the balloon with the tip of the stylus, the reaction force is perceived through the haptic interface device; he/she can feel the softness of the balloon. The balloon is distorted when the player pushes the balloon with the stylus. If he/she pushes it strongly, the balloon is largely distorted, and it is burst and disappeared. Then, he/she hears a sound of bursting it via the headset.

In this paper, player 1 bursts two blue balloons alternately on the left side of the virtual space, and player 2 bursts two pink balloons on the right side. This purpose is to avoid the situation of trying to burst the same balloon simultaneously at the two terminals for simplicity. To solve the problem and determine which player bursts the balloon earlier than the other player, we can use AtoZ [11] and Count Down Protocol [12] as in [13].

Before the start of the game, the players stand ready by placing their styli at their respective initial positions (see the virtual space in Fig. 1). The players start to burst the balloons when "START" message is displayed on the screen and a buzzer sound is output. During the game, the numbers of balloons burst by the two players are displayed on the screen. The players stop the game when "GAME OVER" message appears on the screen 30 seconds after the beginning of the game. The buzzer sound also alerts the players to stop the game at that time. A player who bursts more balloons than the other player wins the game. When a balloon is burst and disappeared, a new balloon automatically appears at the location of the burst balloon. Both players try to burst their respective balloons from the front side of the balloon as fast as they can.

The reaction force applied to the haptic interface device is generated by the haptic rendering engine [14], which uses the object shape and material properties such as stiffness and friction for calculation of the reaction force. The force applied to a balloon when the player pushes the balloon with the stylus is equal to the reaction force against the player. The player feels larger reaction force as the penetration depth of the stylus becomes larger; the volume of the balloon decreases in this paper. The penetration depth of the stylus is the distance from the surface of the balloon to the tip of the stylus. There may be several methods of judgment of bursting a balloon. In this paper, we use a method in which a balloon is burst when the volume of a balloon reaches a threshold value. We set the threshold value to 90% of the initial volume of the balloon in our assessment.

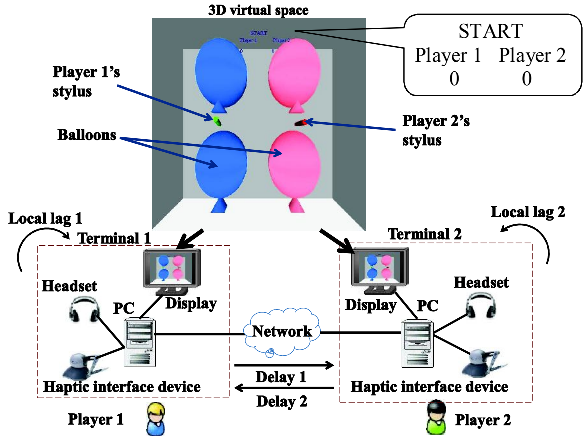

Fig. 1. System configuration of balloon bursting game.

In order to clarify the relations between the reaction force and penetration depth, we explain four cases (the *standard balloon case*, *small balloon case*, *hard balloon case*, and *soft balloon case*) in this paper. In the standard balloon case, the radii of three dimensional axes (x, y, and z) of the balloon are 1.1, 1.5 and 1.1, respectively (see the virtual space in Fig. 1), where we assume that the length of the stylus is 1.0. In the small balloon case, we use a small balloon which has the radii of 0.35, 0.48, and 0.35, respectively. Balloons in the hard and soft balloon cases are two times harder and softer, respectively, than those in the standard balloon case; the sizes of the balloons are the same as those in the standard balloon case.

III. ASSESSMENT ENVIRONMENT

A. Assessment System

In our assessment system, the two terminals are connected to each other via a network emulator (NIST Net [15]) which is used instead of the network shown in Fig. 1. The network emulator generates an additional constant delay for each packet transmitted between the terminals. Note that the network delay jitter can be absorbed by buffering under media synchronization control such as the Virtual-Time Rendering (VTR) [16]; we here take account of the jitter by including the buffering time in the constant delay as in [17]. We call the constant delay from terminal 1 to terminal 2 *delay 1*, and that from terminal 2 to terminal 1 *delay 2* (see Fig. 1). We call the local lag at terminal 1 *local lag 1* and that at terminal 2 *local lag 2*. Local lags 1 and 2 are set to the same values as delays 1 and 2, respectively. We carried out QoE assessment with 16 subjects (males and females) whose ages were between 20 and 30.

In QoE assessment of operability, we use only terminal 1 for simplicity. This is to focus only on the relation between the local lag control and the operability of the haptic interface device. In this case, local lag 1 is generated at terminal 1; note that local lag 1 is set to the same value as delay 1. We carry out the assessment for all the four cases described in Section 2 to investigate the influences of size and hardness of balloons on the operability. Each subject bursts the two blue balloons alternately on the left side of the virtual space. When a balloon is burst, a new balloon automatically appears at the location of the burst balloon. The subject tries to burst his/her balloon from the front side of the balloon as fast as he/she can.

In QoE assessment of fairness, we handle only the standard balloon and the small balloon cases. This is because we found that results of the other cases had similar tendencies to those of the standard balloon and small balloon cases in our preliminary experiment. In the assessment, each pair of subjects play the balloon bursting game and compete with each other for the number of burst balloons. A subject bursts two blue balloons alternately on the left side of the virtual space, and the other subject bursts two pink balloons on the right side.

B. Assessment Methods

1) Operablity

Each subject practiced about two minutes under the condition that delay 1 was set to 0 ms before the assessment for each case. In each case, we changed delay 1 in random order from 0 ms to 500 ms at intervals of 50 ms for each subject. The order of cases was also selected in random order for each subject. The subject burst the balloons with the stylus continuously for 30 seconds. After each stimulus, he/she was asked to base his/her judgment about the operability of haptic interface device when he/she bursts a balloon (i.e., the easiness of bursting) based on the five-grade impairment scales (5: Imperceptible, 4: Perceptible, but not annoying, 3: Slightly annoying, 2: Annoying, 1: Very annoying) [18]. By averaging the scores of all subjects, we obtained *Mean Opinion Score* (*MOS*) [18]. As objective assessment measure, we adopted the number of burst balloons. The total assessment time for each case was about twenty minutes per subject.

2) Fairness

Before the assessment, each pair of subjects played the balloon bursting game for three times to get used to the game on the condition that delays 1 and 2 are set to 0 ms; that is, the same condition is provided to the pair. Note that the fairness in the game means that the same condition is provided to all the players [6]. By practicing, each subject knows how to burst a balloon by using a haptic interface device. In each of the standard balloon and small balloon cases, we carried out the assessment by changing delay 1 from 0 ms to 500 ms and setting delay 2 to 0 ms, 100 ms, 300 ms, or 500 ms.

Assessments in which delay 2 is set to 0 ms, 100 ms, 300 ms, and 500 ms are referred to as *assessments 1* through *4*, respectively. The order of combinations of delays was changed in random order for each pair of subjects. It took 30 seconds for each stimulus. After each stimulus, each subject was asked to base his/her judgment about the fairness in terms of wording used to define the five-grade quality scale (5: Fair, 4: Rather fair, 3: Neither fair nor unfair, 2: Rather unfair, 1: Unfair) [18]. In each stimulus, if the pair obtained almost the same results about victory or defeat as those in the practice, where the fairness was high, the pair regarded the fairness as high and valued the score at 5. The subject gave a score from 1 through 5 for each stimulus. By averaging scores of all the subjects, we obtained MOS. We also adopted the number of burst balloons as an objective assessment measure. The total assessment time in each case was about two hours for each pair of subjects.

IV. Assessment Results

A. Operability

1) Subjective and objective assessment results

We show MOS of operability versus delay 1 for the four cases in Fig. 2. We also show the average number of burst balloons in Fig. 3. In the figures, the 95% confidence intervals are also plotted.

In Fig. 2, we see that the MOS values of all the cases decrease as delay 1 becomes larger. This is because the local information at terminal 1 is buffered for a time of delay 1; thus, since the interactivity is degraded, each subject feels that the balloon becomes harder and more slippery, and it is difficult to burst the balloon. From the figure, we also find that the MOS value of the small balloon case is smaller than those of the other cases when delay 1 is larger than or equal to about 100 ms. The reason is that it is more difficult to operate a virtual stylus so as not to slip from the small balloon when the delay 1 is large. Moreover, we observe in the figure that when delay 1 is smaller than or equal to about 150 ms, the MOS value is higher than 3.5; this means that the deterioration in QoE is allowable for network delays smaller than or equal to about 150 ms [19].

Figure 3 reveals that the average numbers of burst balloons in all the cases become smaller as delay 1 increases. We also observe that the average number of burst balloons in the soft balloon case is the highest. The average number of burst balloons in the hard balloon case is the smallest when delay 1 is smaller than or equal to around 250 ms. When delay 1 is larger than about 300 ms, the number of burst balloons in the small balloon case is the smallest.

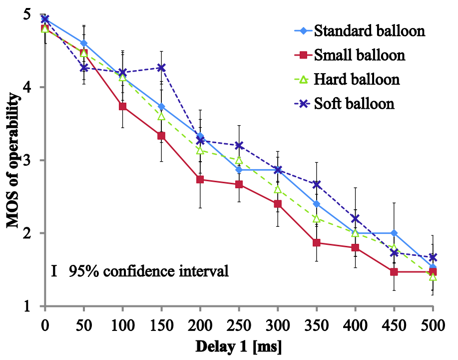

Fig. 2. MOS of operability versus delay 1.

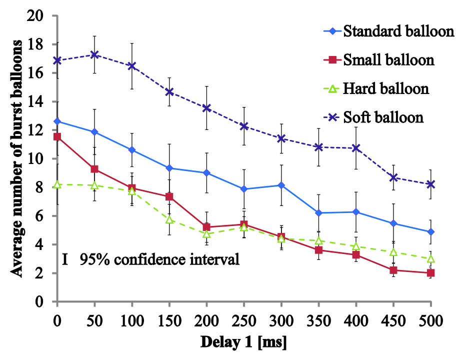

Fig. 3. Average number of burst balloons versus delay 1.

2) Relations between objective and subjective results

In order to investigate the relationship between the average number of burst balloons (or the local lag) and MOS of operability, we carried out the regression analysis [20]. As a result, we obtained estimated equations shown in Table I, where O_{MOS} denotes the estimated value of MOS of operability, N_{burst} is the average number of burst balloons, Δ is the local lag, and R^2 is the contribution rate adjusted for degrees of freedom [20], which shows goodness of fit with the estimated equation. Since the contribution rates are very high in Table I, we can say that MOS of operability can be estimated with a high degree of accuracy from the average number of burst balloons or the local lag.

We also carried out the regression analysis to investigate the relationship between the average number of burst balloons and the local lag. We found that the average number of burst balloons can be estimated from the local lag accurately to a great extent since the contribution rates shown in Table II are very high.

TABLE I. ESTIMATED EQUATIONS FOR MOS OF OPERABILITY.

Case	Equation	R^2
Standard balloon	$O_{\mathrm{MOS}} = 0.431N_{\mathrm{burst}} - 0.497$	0.988
	$O_{\mathrm{MOS}} = -0.007\Delta + 4.812$	0.982
Small balloon	$O_{\mathrm{MOS}} = 0.378N_{\mathrm{burst}} + 0.653$	0.981
	$O_{\mathrm{MOS}} = -0.007\Delta + 4.526$	0.959
Hard balloon	$O_{\mathrm{MOS}} = 0.601N_{\mathrm{burst}} - 0.195$	0.952
	$O_{\mathrm{MOS}} = -0.007\Delta + 4.708$	0.991
Soft balloon	$O_{\mathrm{MOS}} = 0.339N_{\mathrm{burst}} - 1.154$	0.949
	$O_{\mathrm{MOS}} = -0.007\Delta + 4.857$	0.974

TABLE II. ESTIMATED EQUATIONS FOR NUMBER OF BURST BALLOONS.

Case	Equation	R^2
Standard balloon	$N_{\mathrm{burst}} = -0.015\Delta + 12.260$	0.969
Small balloon	$N_{\mathrm{burst}} = -0.018\Delta + 10.169$	0.945
Hard balloon	$N_{\mathrm{burst}} = -0.011\Delta + 7.978$	0.916
Soft balloon	$N_{\mathrm{burst}} = -0.019\Delta + 17.598$	0.976

B. Fairness

1) Subjective and objective assessment results

We show QoE assessment results for assessment 2 in Fig. 4, where the 95% confidence intervals are also plotted. The figure shows the average difference in the number of burst balloons and MOS of fairness versus the delay difference (defined as delay 1 minus delay 2) in the small balloon case. We do not show results of assessments 1, 3 and 4 in the small balloon case and those of all the assessments in the standard balloon case since they have similar tendencies to those in Fig. 4.

In Fig. 4, we see that the average difference in the number of burst balloons becomes smaller as the delay difference increases. The average difference is positive when the delay difference is up to around 0 ms. This is because when delay 1 is smaller than delay 2, subjects at terminal 1 can burst more balloons than subjects at terminal 2. The average difference is negative when the delay difference is larger than about 0 ms. At that time, the subjects at terminal 2 can burst more balloons than the subjects at terminal 1. From Fig. 4, we also observe that the MOS value is larger than 3.5 and the average difference is close to zero when the delay difference is larger than or equal to –100 ms and smaller than or equal to around 75 ms. Thus, the allowable range is between –100 ms and 75 ms according to [19]. We also found that assessment 2 in the standard balloon case has almost the same allowable range as that in the small balloon case. Moreover, we noticed that the MOS value is larger than 3.5 in the following ranges: around 0 ms to 100 ms in assessment 1 of the standard and small balloon cases, around –75 ms to 75 ms in assessment 3 of the standard balloon case, around –75 ms to 100 ms in assessment 3 of the small balloon case, around –100 ms to 0 ms in assessment 4 of the standard balloon case, and around –75 ms to 0 ms in the assessment 4 of the small balloon case.

Based on the above considerations, we can roughly say that the allowable range of absolute difference in network delay is less than or equal to around 75 ms. Note that in assessments 1 and 4, the delay difference cannot be negative and positive values, respectively.

2) Relations between objective and subjective results

In order to investigate the relationship between MOS of fairness and the average difference in the number of burst balloons, and that between MOS of fairness and the absolute value of delay difference (also, difference of local lag), we carried out the regression analysis. As a result, we obtained equations shown in Table III for all the assessments of both standard and small balloon cases. In Table III, F_{MOS} is the estimated value of MOS of fairness, $D_{N_{\mathrm{burst}}}$ is the average difference in the number of burst balloons, and D_{Δ} is the difference of local lag. From Table III, we find that the contribution rates are high. Thus, we can say that MOS of fairness can be estimated with a high degree of accuracy from the absolute value of average difference in the number of burst balloons or the absolute value of the difference of local lag.

C. Relation between operability and fairness

We also investigated the relationship between MOS of fairness and the difference in MOS of operability between terminals 1 and 2. The reason is as follows. First, we illustrated that MOS of operability can be estimated from the average number of burst balloons or the local lag with a high level of accuracy in Subsection IV. A. Second, we found that MOS of fairness can be estimated from the average difference in the number of burst balloons or the difference of local lag accurately to a large extent in Subsection IV. B. Therefore, we guess that there may be a close relationship between MOS of fairness and the difference in MOS of operability.

As a result of the investigation by the regression analysis, we obtained the equation shown in Table IV for all the assessments of both standard and small balloon cases. In Table IV, $D_{O_{\mathrm{MOS}}}$ is the difference in MOS of operability between terminals 1 and 2. The contribution rate is high as shown in Table IV. Thus, we can say that MOS of fairness can be estimated from the difference in MOS of operability between terminals 1 and 2 accurately to a large extent.

TABLE III. ESTIMATED EQUATIONS FOR MOS OF FAIRNESS.

Equations	R^2
$F_{\mathrm{MOS}} = -0.233\lvert D_{N_{\mathrm{burst}}}\rvert + 4.019$	0.910
$F_{\mathrm{MOS}} = -0.006\lvert D_{\Delta}\rvert + 3.976$	0.822

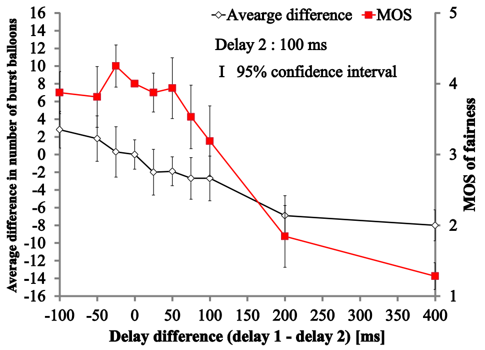

Fig. 4. Average difference in number of burst balloons and MOS of fairness in assessment 2.

TABLE IV. ESTIMATED EQUATION FOR MOS OF FAIRNESS FROM DIFFERENCE IN MOS OF OPERABILITY.

Equations	R^2
$F_{\mathrm{MOS}} = -0.903 D_{O_{\mathrm{MOS}}} + 3.932$	0.795

V. CONCLUSIONS

In this paper, we carried out QoE assessment of operability and fairness for a balloon bursting game in a networked virtual environment with haptic sense. As a result, we found that the operability strongly depends on the number of burst balloons or local lag. We also observed that the allowable range of local lag is around 150 ms and that of absolute difference in network delay between players is within around 75 ms.

We further examined the relationships between subjective and objective assessment results. We found that MOS of operability can be estimated from the average number of burst balloons or local lag with a high degree of accuracy. Moreover, we illustrated that MOS of fairness can roughly be estimated from the average difference in the number of burst balloons or the absolute value of local lag difference. Furthermore, we carried out the regression analysis to investigate the relationship between MOS of fairness and the difference in MOS of operability between players. We found that MOS of fairness can be estimated from the difference in MOS of operability between two players almost accurately.

As our future work, we will carry out QoE assessments with other judgments of bursting balloons in the balloon bursting game; for example, a balloon can be burst when the force applied to the balloon reaches a threshold. In order to improve the easiness of bursting and fairness, we will also enhance the adaptive Δ-causality control so that we do not need to set the local lags at all the terminals to the maximum network delay by taking account of the allowable range of local lag and the network delay difference.

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