Influence of Network Delay on QoE for Soft Objects in Networked Haptic Virtual Environment

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Outline

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• Judgment of bursting
• Assessment system and methods
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• Conclusions and future work
Background

A number of papers about the influences of network delay on QoE (Quality of Experience) in networked haptic virtual environments have been published so far.

However, there is no previous work which investigates the influence of network delay on QoE such as fairness and easiness of operability for soft objects.

To investigate the influence of network delay on QoE for soft objects, we deal with a networked balloon bursting game.
In a networked real-time game, the consistency (e.g., the positions of objects are the same in a virtual space) and causality (i.e., temporal anteroposterior relation) between terminals can be damaged owing to the network delay.

The difference in network delay between the terminals may lead to unfairness between the players.

We need to carry out QoS (Quality of Service) control such as the adaptive $\Delta$-causality control*1 in order to maintain the fairness between players high.

If the adaptive $\Delta$-causality control is used in the game, the interactivity may be deteriorated.

The control buffers local information for a time equal to the larger network delay between two terminals under the local lag control\(^*2,3\).

- The local lag control buffers local information for a time called the local lag equal to the network delay from the local terminal to the other terminal.
- When the network delay from the local terminal to the other terminal is equal to that in the opposite direction, only the local lag control may maintain the fairness between the players high.
- When the network delay is different from that in the opposite direction, the fairness may be deteriorated under only the local lag control.

We implement a balloon bursting game. We investigate the influence of network delay on the easiness of bursting for each player as the first step of our work in the networked balloon bursting game. We carry out subjective and objective QoE assessments.

The easiness of bursting may be deteriorated since the interactivity is degraded.

It is important to investigate human perceptible range of the easiness of bursting owing to local lag.

This work

We implement a balloon bursting game.

We investigate the influence of network delay on the easiness of bursting for each player as the first step of our work in the networked balloon bursting game.

We carry out subjective and objective QoE assessments.
Balloon bursting game (1/5)

3D virtual space

Player 1’s stylus

Balloons

Player 2’s stylus

Terminal 1

Headset

PC

Display

Haptic interface device

Player 1

Terminal 2

Headset

PC

Display

Haptic interface device

Player 2

Network
The reaction force applied to the haptic interface device is generated by the haptic rendering engine\(^1\), 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 penetration depth of the stylus is the distance from the surface of the balloon to the tip of the stylus.

When the balloon is distorted by the stylus, its volume is varied.

We can obtain the volume by using Bullet Physics Library *2.

Balloon bursting game (4/5)

To clarify the relations among the reaction force, penetration depth, and the volume of a balloon, we explain four cases (cases 1 through 4). In all cases, we assume that the length of the stylus is 1.0.

Case 1
- The radii of three dimensional axes (x, y, and z) of the balloon are 1.1, 1.5 and 1.1, respectively.

Case 2
- A small balloon is used which has the radii of 0.35, 0.48, and 0.35, respectively.
Balloon bursting game (5/5)

Case 3

- A balloon which is two times harder than that in case 1 is used.

Case 4

- A balloon which is two times softer than that in case 1 is used.

The sizes of the balloons in cases 3 and 4 are the same as that in case 1.
Reaction force versus elapsed time

Elapsed time: the time interval from the moment the surface of a balloon is touched with the stylus until the instant the balloon is burst.
Penetration depth versus elapsed time

- Case 1 (normal balloon)
- Case 2 (small balloon)
- Case 3 (hard balloon)
- Case 4 (soft balloon)
The balloon is burst when the volume of the balloon is smaller than a threshold value. We set the threshold value to 90% of the initial volume of the balloon in our assessment.
For simplicity, we use only terminal 1.

Note that local lag 1 is equal to constant delay 2 if we use the two terminals.
Each subject bursts the two blue balloons alternately which are located on the left side of the virtual space.

When a balloon is burst, a new balloon always automatically appears for the burst balloon.

Each subject tries to burst his/her balloon from the front side of the balloon as fast as he/she can.

We handle cases 1 through 4 in the assessment to investigate the influences of different size and hardness of a balloon on the easiness of bursting.
Assessment methods (1/2)

- Local lag 1 is changed 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.
Assessment methods (2/2)
Subjective QoE Assessment

Each subject was asked to base his/her judgment on the easiness of bursting.

Five-grade impairment scale

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Imperceptible</td>
</tr>
<tr>
<td>4</td>
<td>Perceptible, but not annoying</td>
</tr>
<tr>
<td>3</td>
<td>Slightly annoying</td>
</tr>
<tr>
<td>2</td>
<td>Annoying</td>
</tr>
<tr>
<td>1</td>
<td>Very annoying</td>
</tr>
</tbody>
</table>

Subjects
Number of subjects: 16
Age: Between 20 and 28
Gender: Male and female

We obtain Mean Opinion Score (MOS).

Total assessment time: One and half hours

As **objective assessment measure**, we adopted the number of burst balloons.
Subjective assessment results

MOS of easiness of bursting vs. Local lag 1 (ms)

- Case 1 (normal balloon)
- Case 2 (small balloon)
- Case 3 (hard balloon)
- Case 4 (soft balloon)

95% confidence interval
Objective assessment results

Average number of burst balloons vs. Local lag 1 (ms)

- Case 1 (normal balloon)
- Case 2 (small balloon)
- Case 3 (hard balloon)
- Case 4 (soft balloon)

95% confidence interval
Mapping from Objective assessment measure to subjective assessment measure

<table>
<thead>
<tr>
<th>Case</th>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>$E_{MOS} = 2.291N_{burst} + 1.239$</td>
<td>0.988</td>
</tr>
<tr>
<td></td>
<td>$E_{MOS} = -146.000\Delta + 706.950$</td>
<td>0.982</td>
</tr>
<tr>
<td>Case 2</td>
<td>$E_{MOS} = 2.596N_{burst} + 1.589$</td>
<td>0.981</td>
</tr>
<tr>
<td></td>
<td>$E_{MOS} = -138.770\Delta + 638.370$</td>
<td>0.959</td>
</tr>
<tr>
<td>Case 3</td>
<td>$E_{MOS} = 1.583N_{burst} + 0.565$</td>
<td>0.952</td>
</tr>
<tr>
<td></td>
<td>$E_{MOS} = -146.760\Delta + 693.150$</td>
<td>0.991</td>
</tr>
<tr>
<td>Case 4</td>
<td>$E_{MOS} = 2.798N_{burst} + 3.881$</td>
<td>0.949</td>
</tr>
<tr>
<td></td>
<td>$E_{MOS} = -145.450\Delta + 712.810$</td>
<td>0.974</td>
</tr>
</tbody>
</table>

$E_{MOS}$: the estimated value of MOS of easiness of bursting

$N_{burst}$: the number of burst balloons

$\Delta$: local lag

$R^2$: the contribution rate adjusted for degrees of freedom
Conclusions

- We investigated the influence of network delay on QoE for a balloon bursting game in a networked haptic virtual environment.
- We carried out subjective and objective QoE assessments for the easiness of bursting of each player.
- We also examined the relationship between the MOS value of the easiness of bursting and the objective assessment measure by regression analysis.
- We found that the easiness of bursting strongly depends on the number of burst balloons or local lag.
Future Work

- We will investigate the influence of network delay on fairness between players in the balloon bursting game.
- We will also carry out the assessment using the other values of softness and size of a balloon, and other judgments of bursting in the game.