Adaptive Delta-Causality Control Scheme with Dynamic Control of Prediction Time in Networked Haptic Game

Yusuke Hara, Yutaka Ishibashi, Norishige Fukushima, and Shinji Sugawara

Nagoya Institute of Technology
Nagoya, Japan

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Outline

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Many researchers have focused on networked real-time games so far. Using haptic media in networked real-time games gives players a higher sense of immersion.

**Background**

Network delay, delay jitter, and packet loss may lead to non-guaranteed QoS, affecting the consistency and causality among terminals and the QoE (Quality of Experience) may be seriously damaged.

**Problems**

- The consistency and causality among terminals may be disturbed.
- QoE (Quality of Experience) may be seriously damaged.
The interactivity deteriorates because the scheme buffers not only information received from the other terminals but also information of the local terminal before output.

To solve the problems, the authors proposed the adaptive $\Delta$-causality control scheme$^1$.

To improve the interactivity, the authors proposed the adaptive $\Delta$-causality control scheme with prediction$^2$.

- We found that there exists the optimal prediction time according to the network delay.

It is worth changing the prediction time dynamically according to the network delay.

Such a study has not been done so far.

This work

- We enhance the adaptive Δ-causality control scheme with prediction by changing the prediction time dynamically according to the network delay.
- We also investigate the effect of the scheme subjectively by QoE assessment for the networked air hockey game using haptic media.
Networked Air Hockey Game
Using Haptic Media (1/4)
The game is based on a peer-to-peer (P2P) model.

Each terminal refreshes a screen at 60 Hz.

Each terminal sends MUs to the other terminal at 60 Hz.

Only the owner of the puck, who has hit the puck last, calculates the position and velocity of the puck and sends MUs of the puck to the other terminal at 60 Hz.

A terminal which is not the owner of the puck outputs the puck at a position which has been received from the owner.

A player of the mallet feels force feedback when the mallet hits the puck or a wall.
Networked Air Hockey Game Using Haptic Media (3/4)

Reaction force between mallet and puck

\[ F = K_s \cdot K_{mp} (V_p - V_m) \]

- \( V_p \): Velocity of puck toward mallet
- \( V_m \): Velocity of mallet toward puck
- \( K_s \): Spring constant
- \( K_{mp} \): Reflection coefficient between mallet and puck
Networked Air Hockey Game Using Haptic Media (4/4)

Reaction force between mallet and wall

\[ P_w \text{ (Position vector of contact point of wall)} \]

\[ P_m \text{ (Position vector of center point of mallet)} \]

\[ F = K_s \cdot K_{mw}(P_m - P_w) \]

\( K_s \): Spring constant
\( K_{mw} \): Reflection coefficient between mallet and wall
Adaptive Δ-causality control scheme

• If an MU is received within the time limit (its generation time + Δ) of the MU, the MU is saved in the buffer until the time limit, and then it is output.
• Otherwise, the MU can be used only to predict the future position without output.
• The value of Δ is dynamically changed according to the network delay, and it is shared between the terminals.
• Δ is set to a value between the minimum value Δ_L and the maximum value Δ_H. (Δ_H ≥ Δ_L ≥ 0)
The scheme outputs each received MU by predicting the future position later than the output time of the MU by the prediction time $T_{\text{predict}} \geq 0$ to keep the interactivity high.

$T_{\text{predict}}$ is shown on the frame time scale (one frame means the refresh interval of the screen and is 16.7 ms).

For simplicity, the first-order prediction is used.

The scheme also advances the output time of each MU at the local terminal by $T_{\text{predict}}$ frames.

However, if there does not exist an MU which should be output after $T_{\text{predict}}$ frames, the MU is output by prediction.
Adaptive $\Delta$-Causality Control Scheme with Dynamic Control of Prediction Time (3/3)

Adaptive $\Delta$-causality control scheme with dynamic control of prediction time

- $T_{\text{predict}}$ is changed dynamically according to the network delay.
- We dynamically change the value of $T_{\text{predict}}$ according to the value of $\Delta$ because the interactivity depends on the time interval from the moment an MU is generated until the instant the MU is output.
- From results of a preliminary experiment, we found that $\hat{T}_{\text{predict}}$ (optimal value of $T_{\text{predict}}$) and $\Delta$ have a linear relationship as follows:
  \[ \hat{T}_{\text{predict}} = 0.05\Delta - 2.00 \]
- We determine the value of $T_{\text{predict}}$ by rounding the value of $\hat{T}_{\text{predict}}$ off to the closest whole number so that it becomes an integer larger than or equal to 0.
NIST Net generates an additional delay for each packet transmitted between the terminals according to the Pareto-normal distribution.

Network emulator

Terminal

(NIST Net)

Terminal

100BASE-TX cable

MUs are transferred by User Datagram Protocol (UDP).
The QoE assessment was carried out for each pair of subjects.

We set $\Delta_L = 10$ ms and $\Delta_H = 200$ ms.

The average additional delay is set to 50 ms, 100 ms, and 150 ms, and the standard deviation is set to 10 ms.

The value of $T_{\text{predict}}$ is selected from 0 frame to 12 frames.

The average additional delay and the value of $T_{\text{predict}}$ were presented in random order for each pair.

Subjects: 10 persons (ages: between 21 and 23)
Results of Preliminary Experiment (1/3)

MOS of comprehensive quality

- Optimal value

Average additional delay
- 50 ms
- 80 ms
- 100 ms
- 130 ms
- 150 ms

I 95% confidence interval

Prediction time [frame]
Results of Preliminary Experiment (2/3)

Average of $\Delta$

- About 26 ms
The correlation coefficient between measured and calculated values was 0.99.
QoE Assessment Method (1/2)

- The QoE assessment was carried out for each pair of subjects.
- We made a comparison of the adaptive $\Delta$-causality control scheme with dynamic control of prediction time and that with prediction, in which $T_{\text{predict}}$ is fixed.
- We set $\Delta_L = 10$ ms and $\Delta_H = 200$ ms.
- The average additional delay is changed from 0 ms to 150 ms, and the standard deviation is set to 10 ms. (When the average is 0 ms, the standard deviation is set to 0 ms.)
- In the scheme where $T_{\text{predict}}$ is fixed, the value of $T_{\text{predict}}$ is changed from 0 frame to 7 frames.
- The average additional delay and the two schemes were presented in random order for each pair; the prediction time was also done in random order in the scheme where $T_{\text{predict}}$ is fixed.
Each subject was asked to base his/her judgment about the following assessment items in terms of the five-grade impairment scale.

- Interactivity of local mallet (time difference between movement of PHANToM and that of local mallet)
- Interactivity of puck
- Output quality of local mallet (smoothness of movement of local mallet)
- Output quality of opponent’s mallet
- Output quality of puck
- Comprehensive quality (most important)

We obtained mean opinion score (MOS).

Subjects: 30 persons
(ages: between 21 and 23)
Assessment Results (1/6)

MOS of interactivity of local mallet

I 95% confidence interval

- $T_{\text{predict}} = 0$
- $T_{\text{predict}} = 2$
- $T_{\text{predict}} = 3$
- $T_{\text{predict}} = 5$
- $T_{\text{predict}} = 6$
- $T_{\text{predict}} = 7$
- Dynamic control

Average additional delay [ms]
Assessment Results (2/6)

MOS of interactivity of puck

I 95% confidence interval

Average additional delay [ms]
Assessment Results (3/6)

MOS of output quality of local mallet

I 95% confidence interval

MOS of output quality of local mallet

Average additional delay [ms]

- $T_{\text{predict}} = 0$
- $T_{\text{predict}} = 2$
- $T_{\text{predict}} = 3$
- $T_{\text{predict}} = 5$
- $T_{\text{predict}} = 6$
- $T_{\text{predict}} = 7$

Dynamic control
Assessment Results (4/6)

MOS of output quality of opponent’s mallet

MOS vs. Average additional delay [ms]

- $T_{\text{predict}} = 0$
- $T_{\text{predict}} = 2$
- $T_{\text{predict}} = 3$
- $T_{\text{predict}} = 5$
- $T_{\text{predict}} = 6$
- $T_{\text{predict}} = 7$

Dynamic control

I 95% confidence interval
Assessment Results (5/6)

MOS of output quality of puck

I 95% confidence interval

Average additional delay [ms]
Assessment Results (6/6)

MOS of comprehensive quality

I 95% confidence interval

Average additional delay [ms]
Conclusions

- We enhanced the adaptive $\Delta$-causality control scheme with prediction by changing the prediction time dynamically according to the network delay in order to keep both interactivity and media output quality high.
- We also investigated the effect of the enhanced scheme by QoE assessment for a networked air hockey game using haptic media.

- The dynamic control of the prediction time is effective.
Future Work

- Investigate the dynamic behavior of the enhanced scheme by carrying out the experiment when the network delay changes largely.
- Study how to employ the enhanced scheme together with the adaptive dead-reckoning and examine its effect.
- Enhance the game to play doubles and study QoS control when a pair of users fight against the other pair while cooperating in the pair.