Interactivity Improvement of Group Synchronization Control in Collaborative Haptic Play with Building Blocks

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Outline

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- Play with Building Blocks
- System Model
- Group Synchronization Control Scheme with Prediction
- Experimental Method
- Experimental Results
- Conclusions and Future work

Background

In networked haptic environments

Users can touch and move objects by manipulating haptic interface devices.

We can largely improve the efficiency of collaborative work.

Network delay,
delay jitter, etc.

- The output quality of a haptic media stream may seriously deteriorate.
- The terminals may not output ***media units*** (***MU***s, each of which is the information unit for media synchronization) simultaneously.

Problem

Owing to the network delay, delay jitter, and other network problems, terminals may not output MUs simultaneously

The users of different terminals may watch different screens from each other, and they may not be able to do the collaborative haptic work precisely.

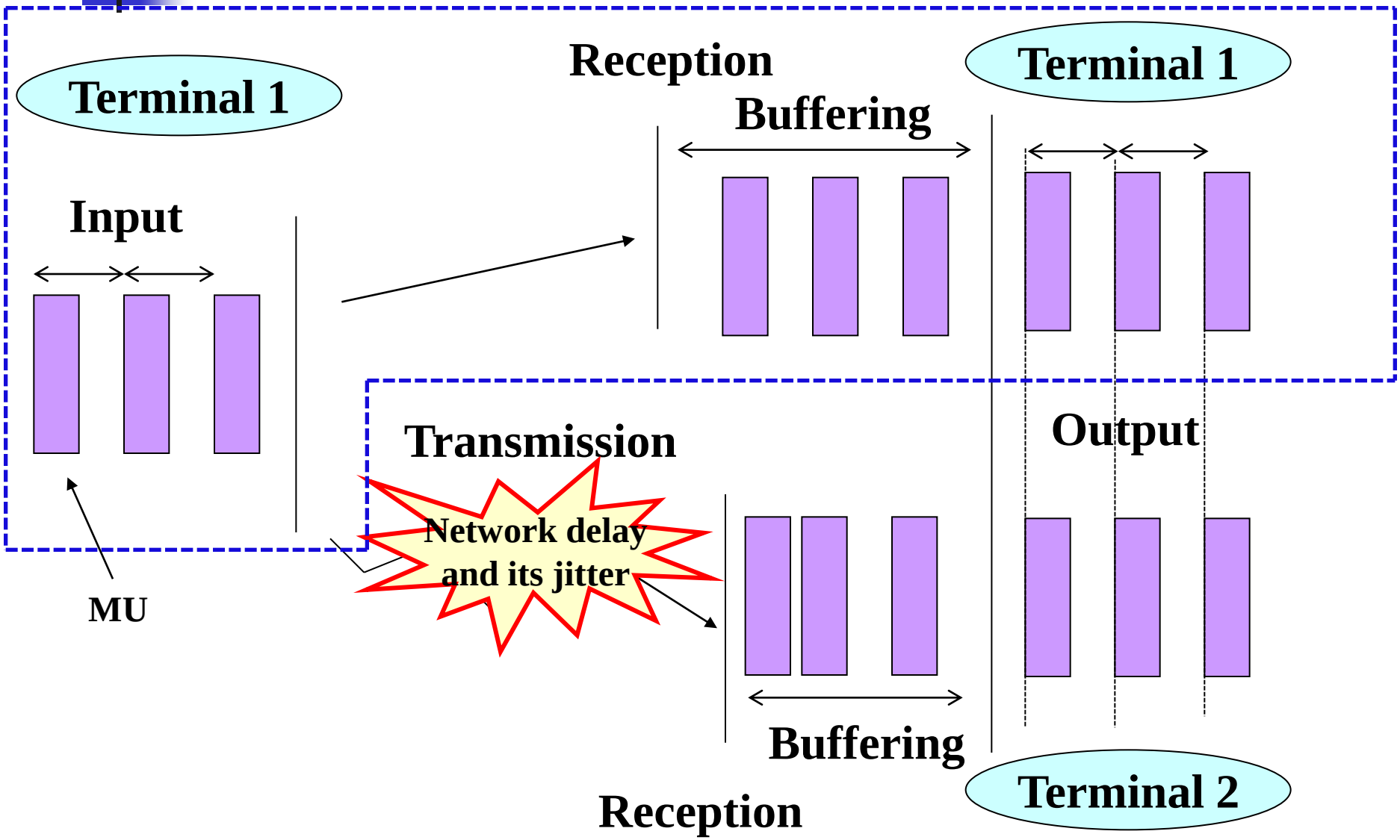
It is necessary to carry out ***group* (or *inter-destination*) *synchronization control***

Adjust the output timing of MUs among multiple terminals

Degrades the interactivity slightly

Improvement of interactivity of the group synchronization control is needed.

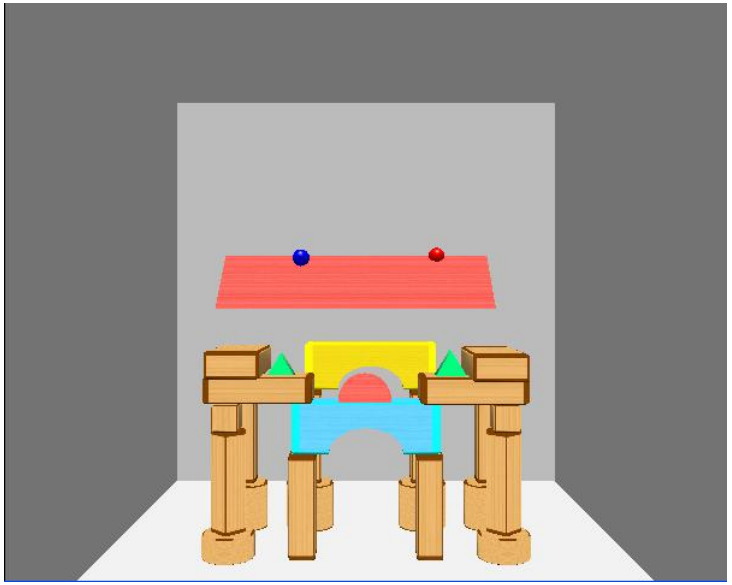
Group Synchronization Control



Purpose

Previous work

- We developed collaborative haptic play with building blocks which deals with 26 objects in a 3-D virtual space.
- Investigate the influences of network delay and delay jitter on collaborative haptic play.



⇨ The positions of blocks may be different among multiple terminals, and the users may not be able to do the collaborative haptic play precisely.

This study

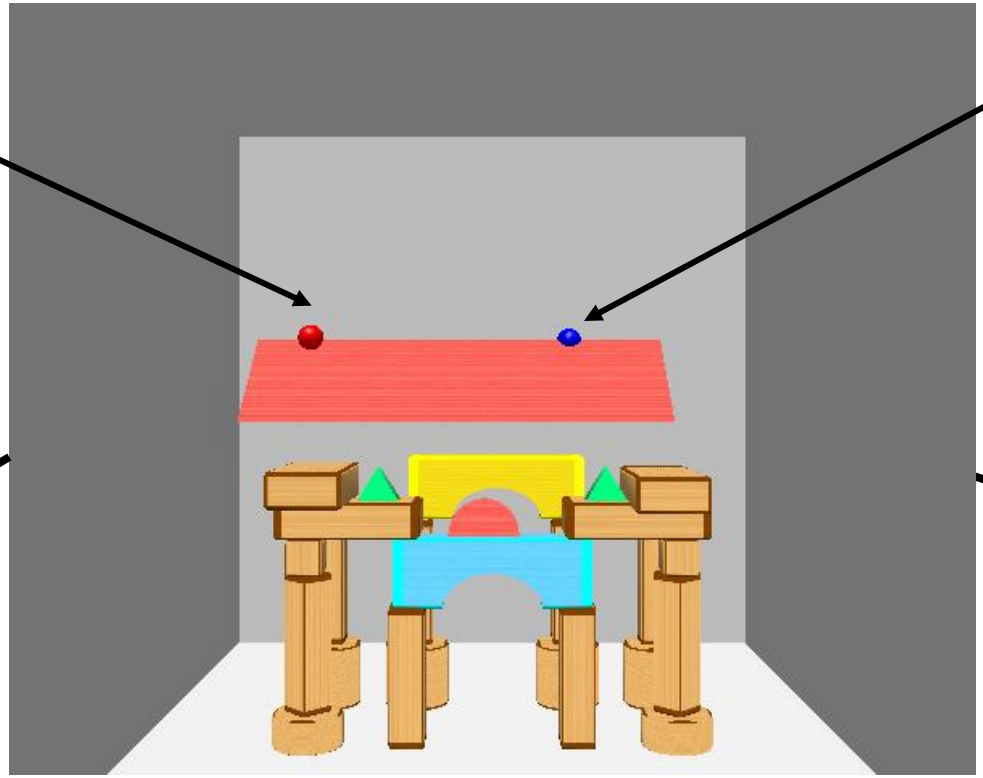
Synchronization maestro scheme

- Propose a group synchronization control scheme with prediction
- Use the VTR (Virtual-Time Rendering) for intra-stream synchronization
- Investigate the effectiveness of the scheme by experiment

Haptic Play with Building Blocks

Cursor of server terminal

Cursor of client terminal



Server terminal

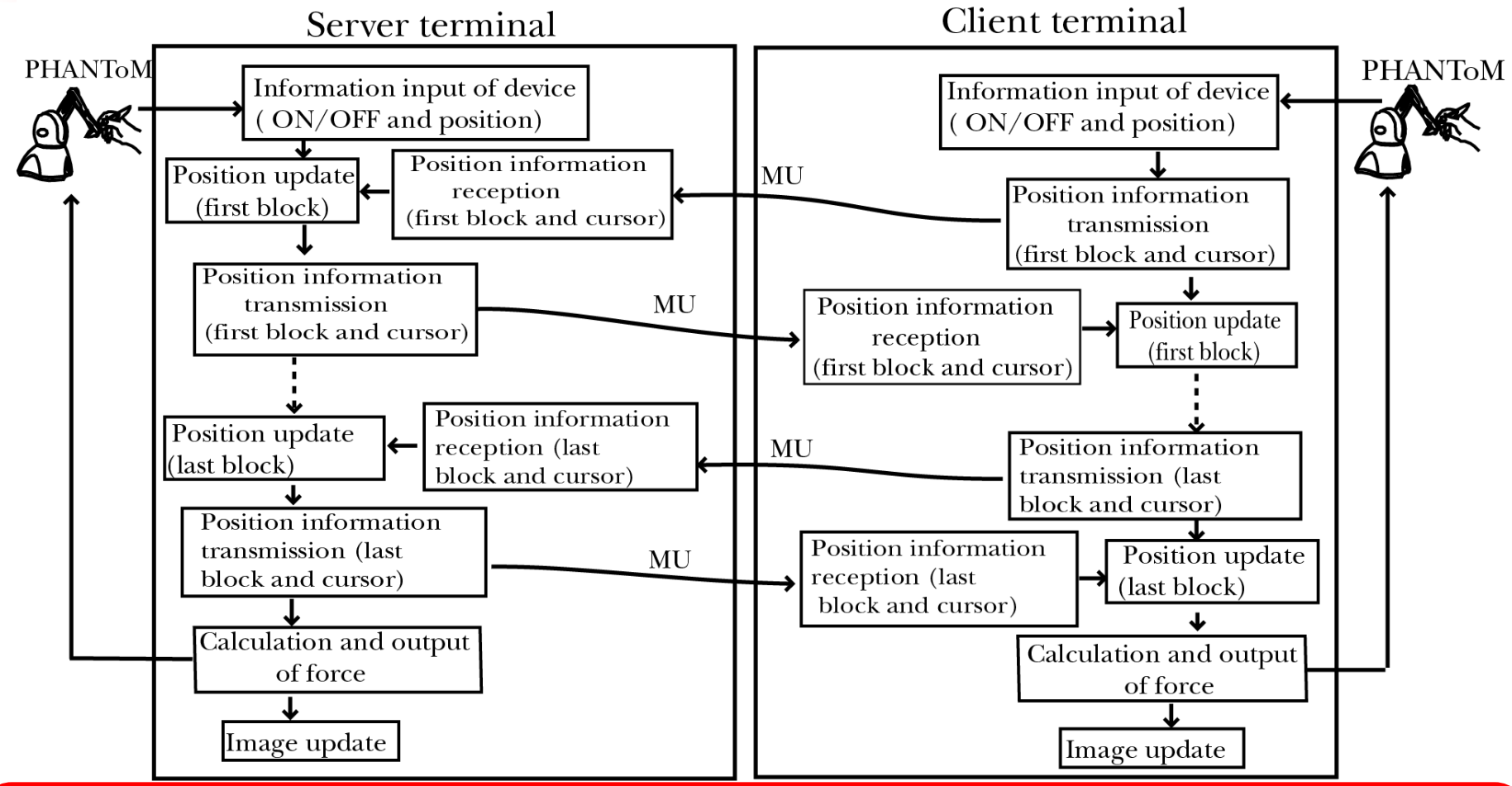
PHANToM Omni

Client terminal

PHANToM Omni

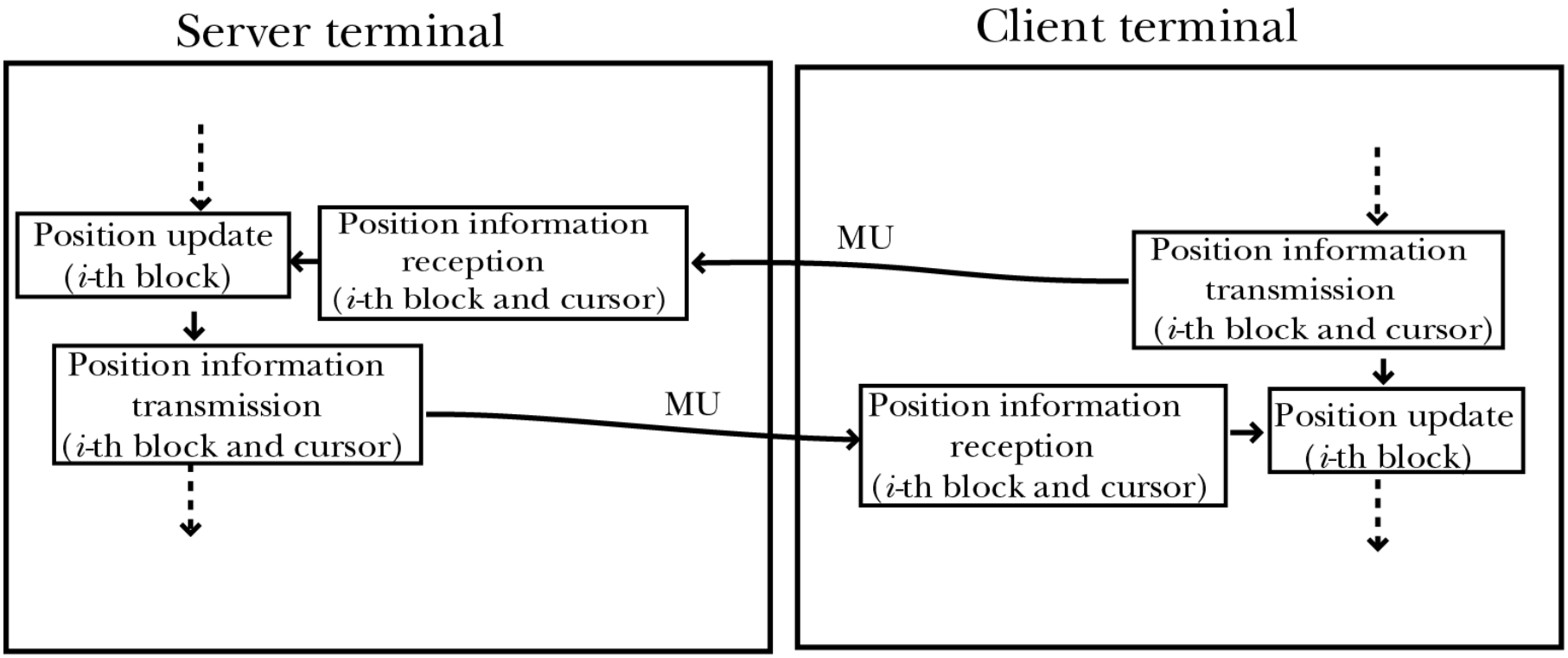
- Two users pile up building blocks collaboratively to build a dollhouse in the virtual space.
- The dollhouse consists of 26 blocks (i.e, objects).
- We carry out collision detection among the blocks, and the cursors.

System Model (1/3)



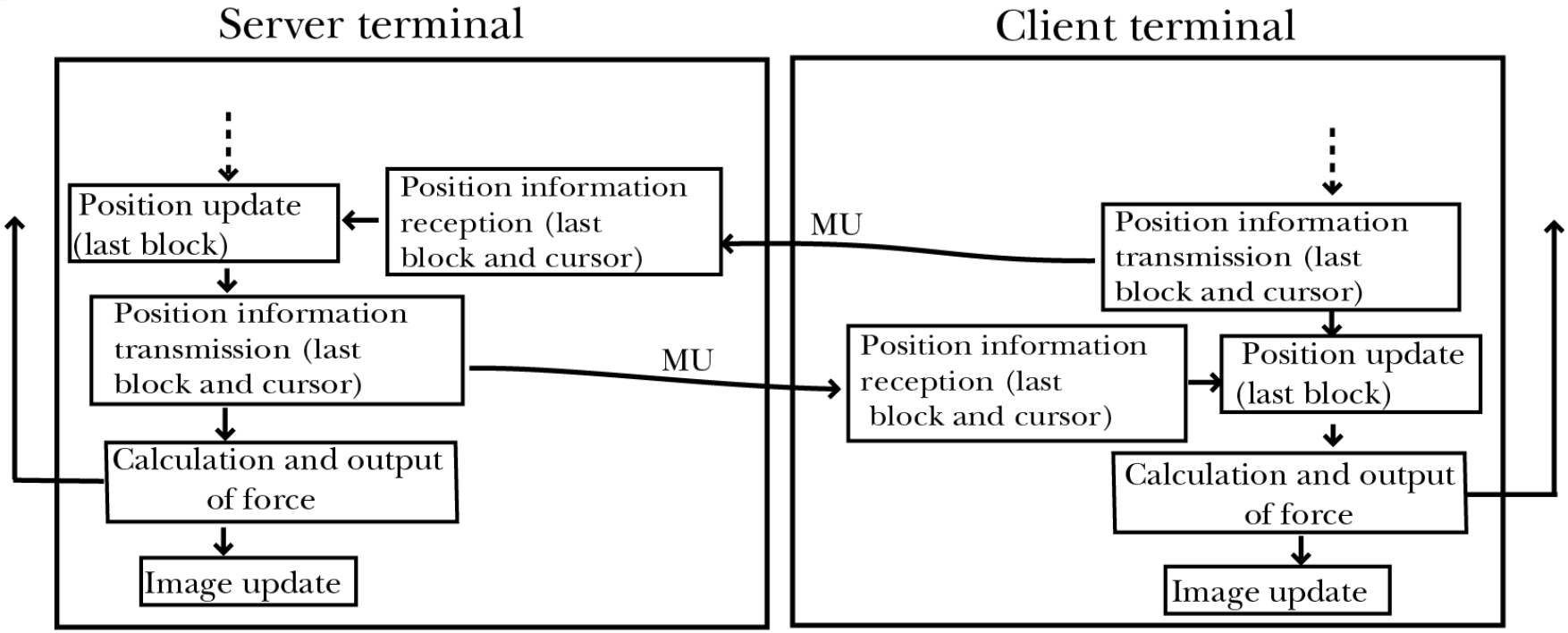
The client and server terminals transmit a stream of MUs, each of which includes the sequence number, the information about the stylus button (ON/OFF), and the position information of the *i*-th block.

System Model (2/3)



When the server terminal updates the position of the ***i***-th block, the position of the block is set to the middle between the position of the server terminal's ***i***-th block and that of the client terminal's ***i***-th block. The client terminal updates the position of the ***i***-th block by using the position information which is transmitted from the server terminal.

System Model (3/3)



- The client and server terminals calculate the reaction force applied to the users and update the image after updating the position of the last block.
- We carry out the *group synchronization control scheme with prediction* at the client and server terminals.
- The function of the synchronization maestro is implemented at the server terminal.

Group Synchronization Control Scheme with Prediction (1/3)

The prediction time $T_{predict}$ to keep the interactivity high is used.

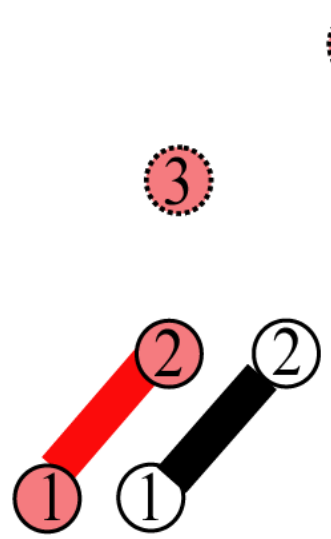
- **Output each MU by predicting the future position later than the received MU by $T_{predict}$ ($\geqq 0$) milliseconds**

For simplicity, the first-order prediction is used in the scheme.

- **Advance the output timing of MUs at the local terminal by $T_{predict}$ milliseconds**

Group Synchronization Control Scheme with Prediction (2/3)

Tracks of cursors in scheme which carries out only group synchronization control

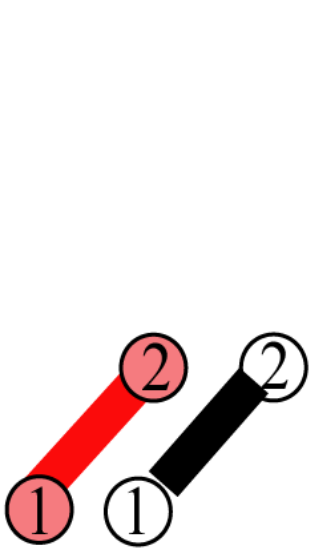


i : Server terminal's MU with sequence number of *i* which has been output

i : Server terminal's MU with sequence number of *i* which has not been output

j : Client terminal's MU with sequence number of *j* which has been output

(a) Server terminal



i : Server terminal's MU with sequence number of *i* which has been output

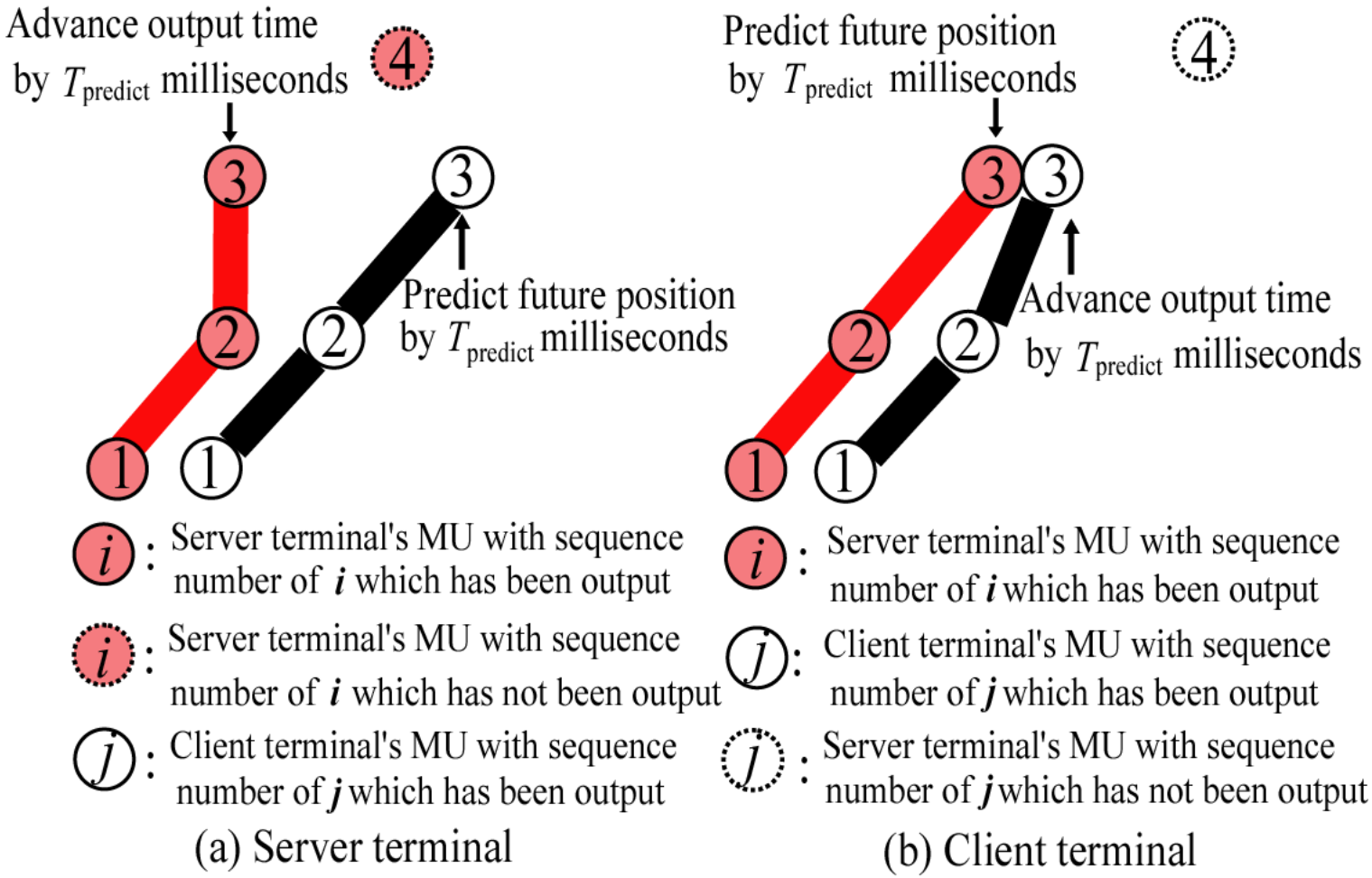
j : Client terminal's MU with sequence number of *j* which has been output

j : Server terminal's MU with sequence number of *j* which has not been output

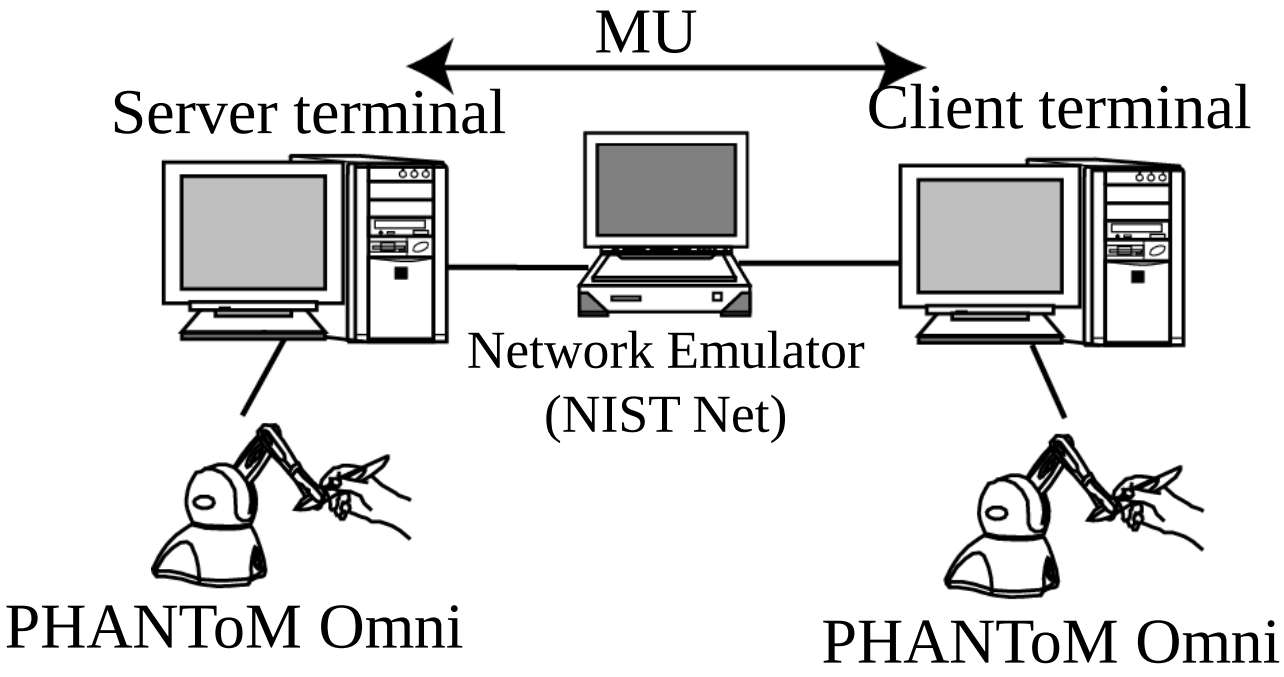
(b) Client terminal

Group Synchronization Control Scheme with Prediction (3/3)

Tracks of cursors in group synchronization control scheme with prediction



Experimental System



NIST Net generates an additional delay for each MU transmitted between the client and server terminals.

- **Additional delay : Pareto-normal distribution**

Experimental Method

Network delay

Packet loss rate: 0%

- Average additional delay: 50 ms
  Standard deviation: 0 ms, 5 ms, …, 20 ms

- Average additional delay: 100 ms
  Standard deviation : 0 ms, 10 ms, …, 40 ms

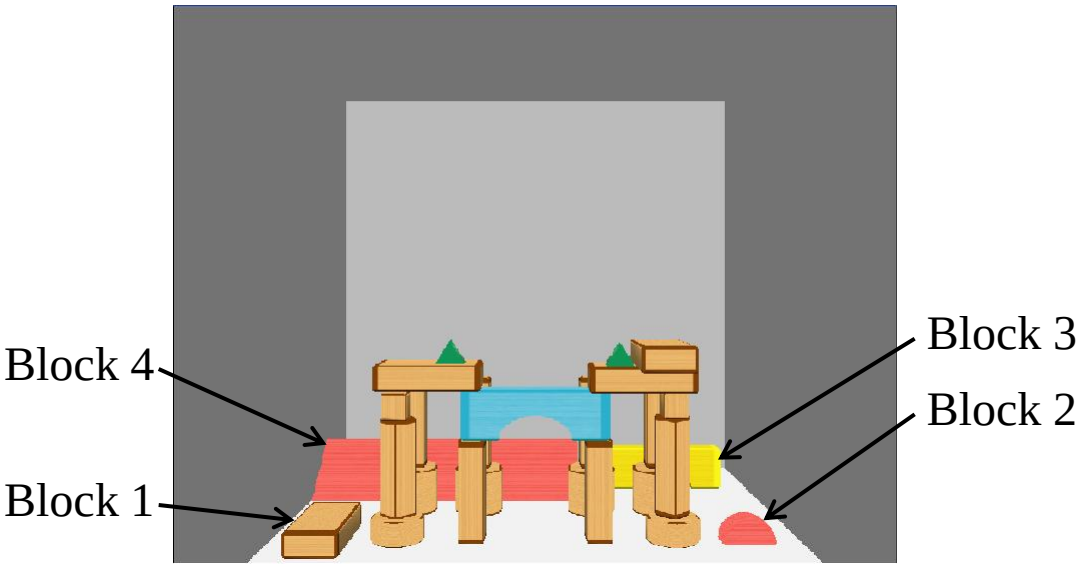
Prediction time ($T_{predict}$)

0 ms,
10 ms, 20 ms, 30 ms, 50 ms

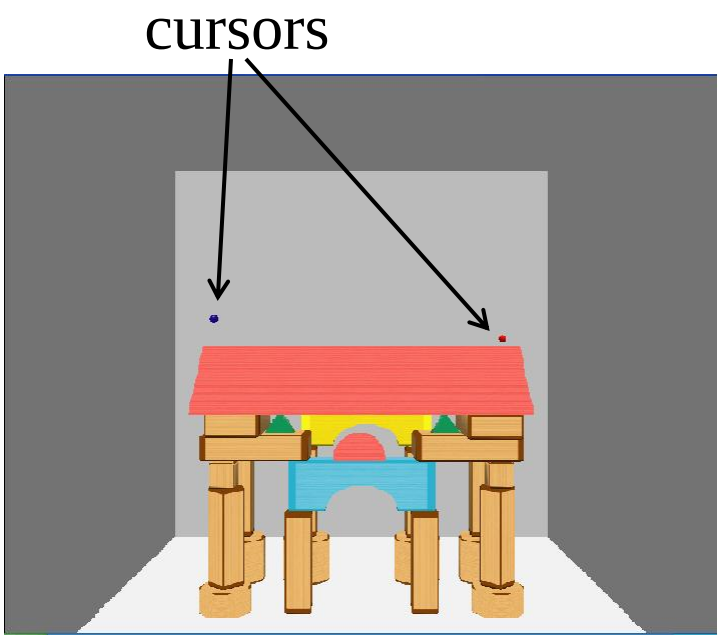
When $T_{predict}$ = 0 ms, the prediction is not used.
Only the group synchronization control is carried out.

We selected average additional delay, standard deviation of additional delay, and prediction time randomly for each pair of subjects.

Assessment Method (1/3)



Displayed image of virtual space before collaborative play



Displayed image of virtual space after collaborative play

- The users pile up four building blocks (blocks 1, 2, 3, and 4) to build a dollhouse.
- The other 22 blocks were built up before the experiment.

Assessment Method (2/3)

Subjective assessment

◆**Before the assessment, each pair of subjects was asked to do the collaborative play on the condition that there was no additional delay or packet loss.**

◆**To obtain the Mean Opinion Score (MOS), each subject judged the operability of his/her haptic interface device in collaborative work when there are constant additional delay, standard deviation of additional delay.**

Five-grade impairment scale

Score	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Assessment Method (3/3)

Objective assessment

Average operation time

The average time from the moment the play is started until the instant all the blocks are piled up.

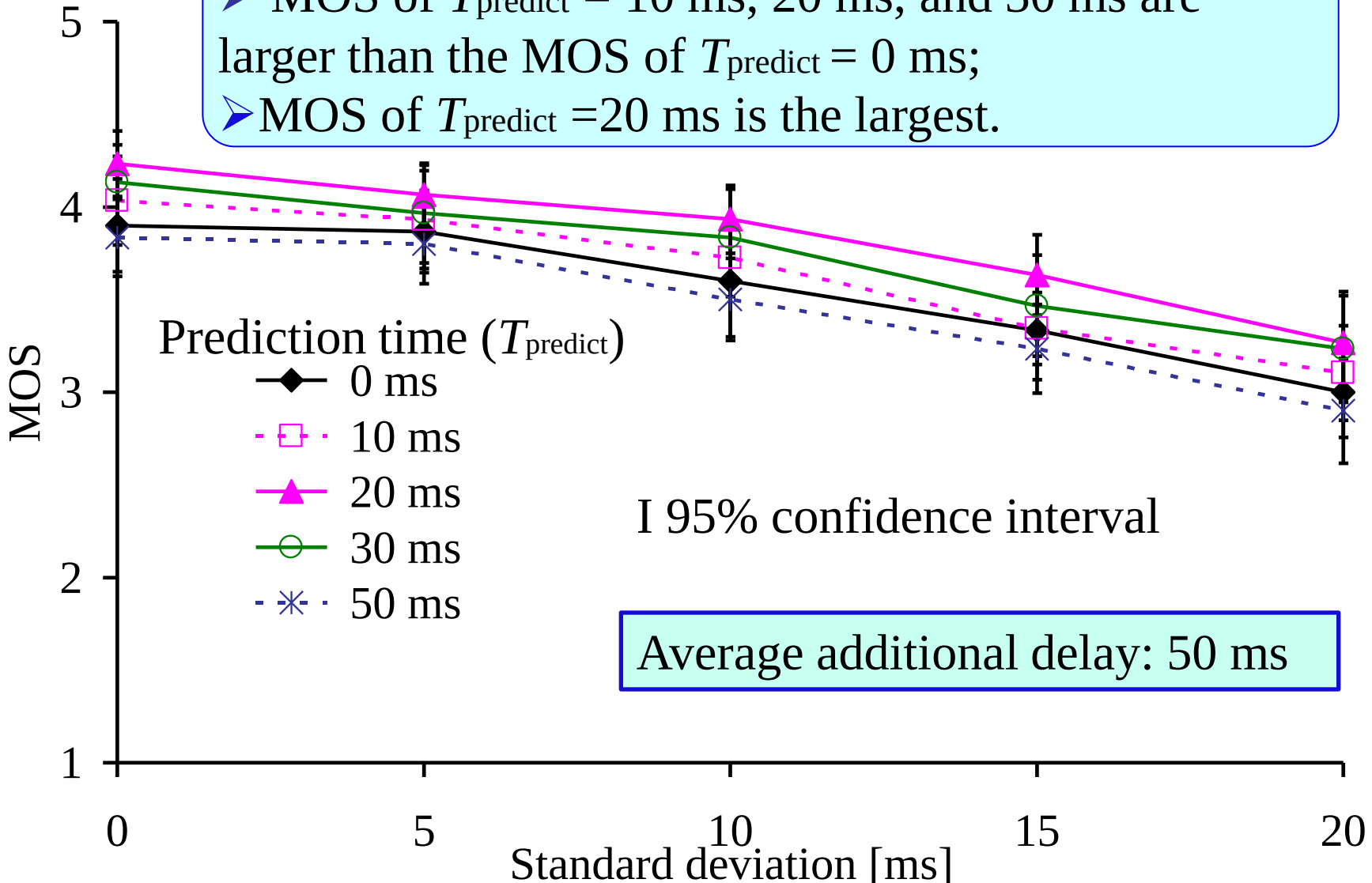
Total assessment time

2 hours/pair

- **Number of subjects: 30**
- **Age: 21-25**

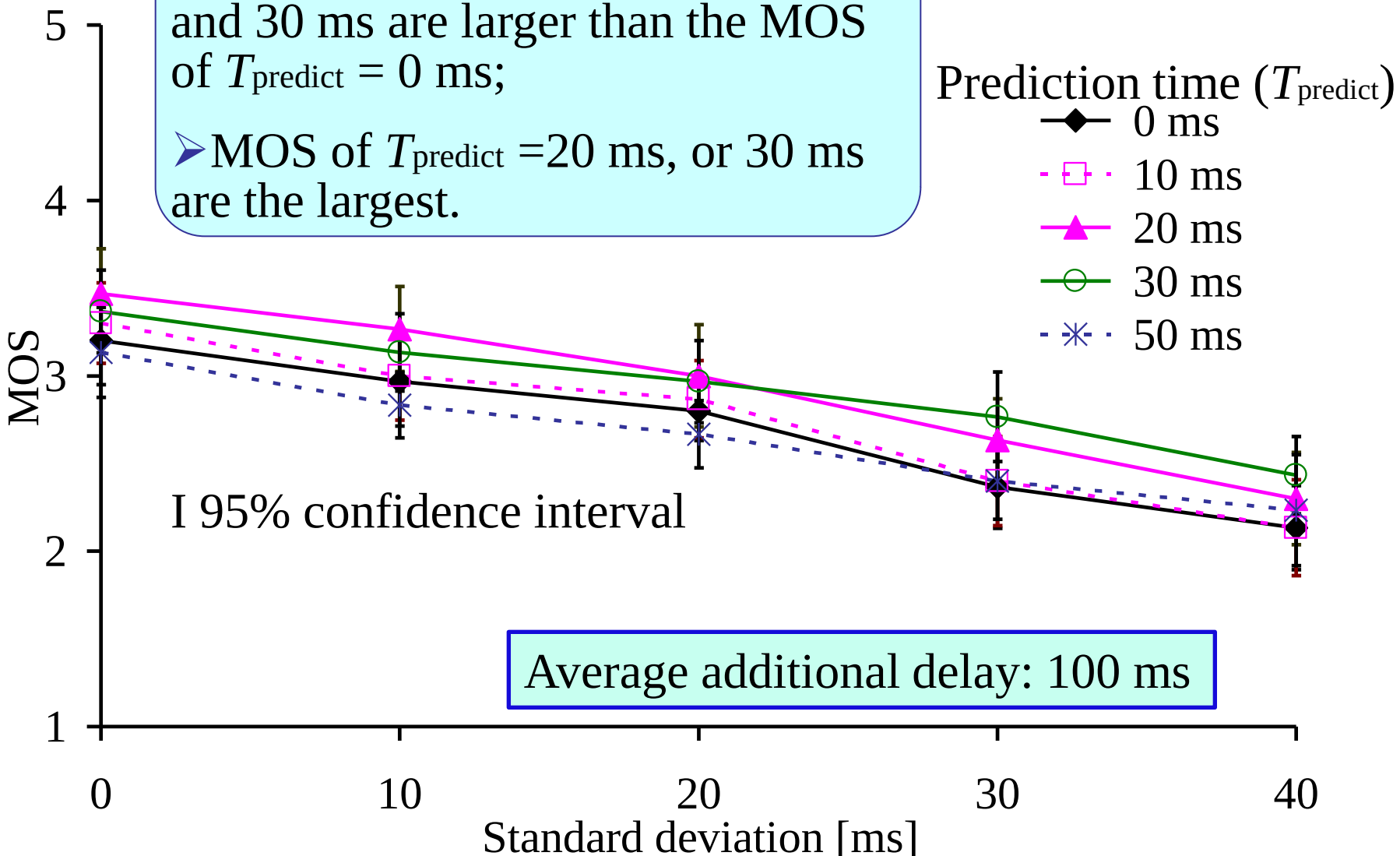
MOS versus Standard Deviation of Additional Delay (1/2)

- MOS of $T_{predict}$ = 10 ms, 20 ms, and 30 ms are larger than the MOS of $T_{predict}$ = 0 ms;
- MOS of $T_{predict}$ =20 ms is the largest.

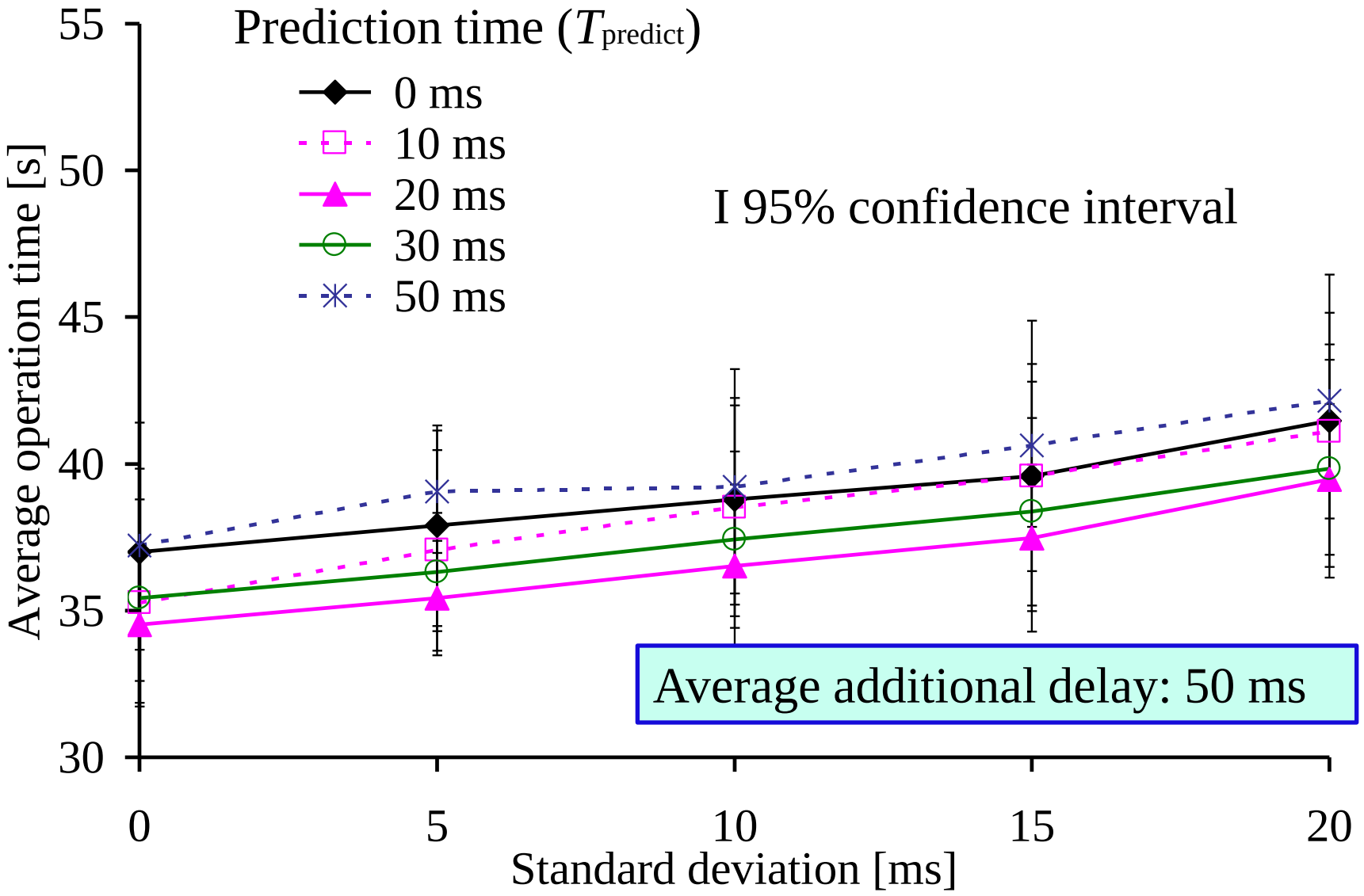


MOS versus Standard Deviation of Additional Delay (2/2)

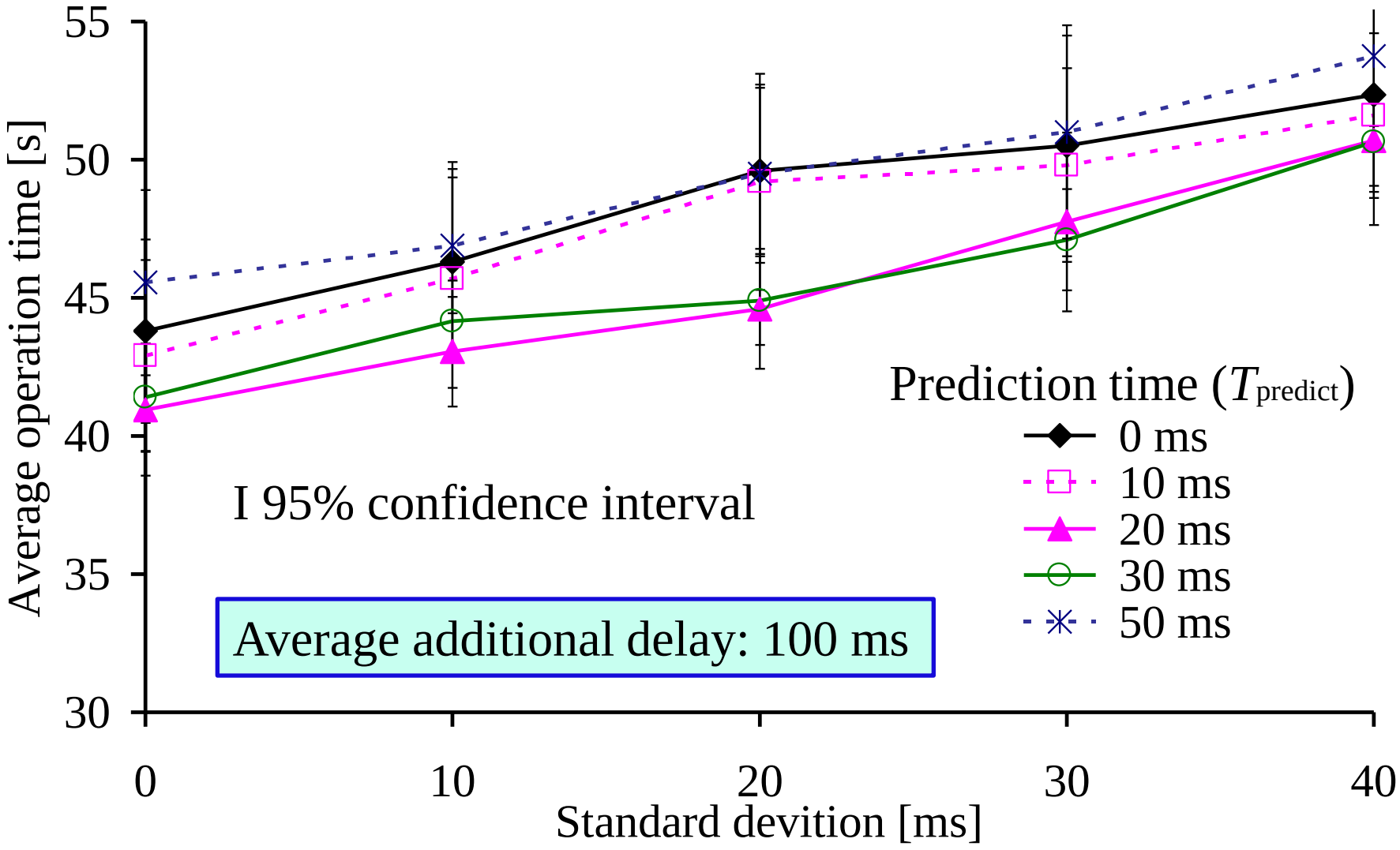
- MOS of $T_{predict}$ = 10 ms, 20 ms, and 30 ms are larger than the MOS of $T_{predict}$ = 0 ms;
- MOS of $T_{predict}$ =20 ms, or 30 ms are the largest.



Average Operation Time versus Standard Deviation of Additional Delay (1/2)



Average Operation Time versus Standard Deviation of Additional Delay (2/2)



Relationship between the Average Operation Time and the MOS

In order to investigate the relations between the average operation time and the MOS, we carried out regression analysis

Obtained equation

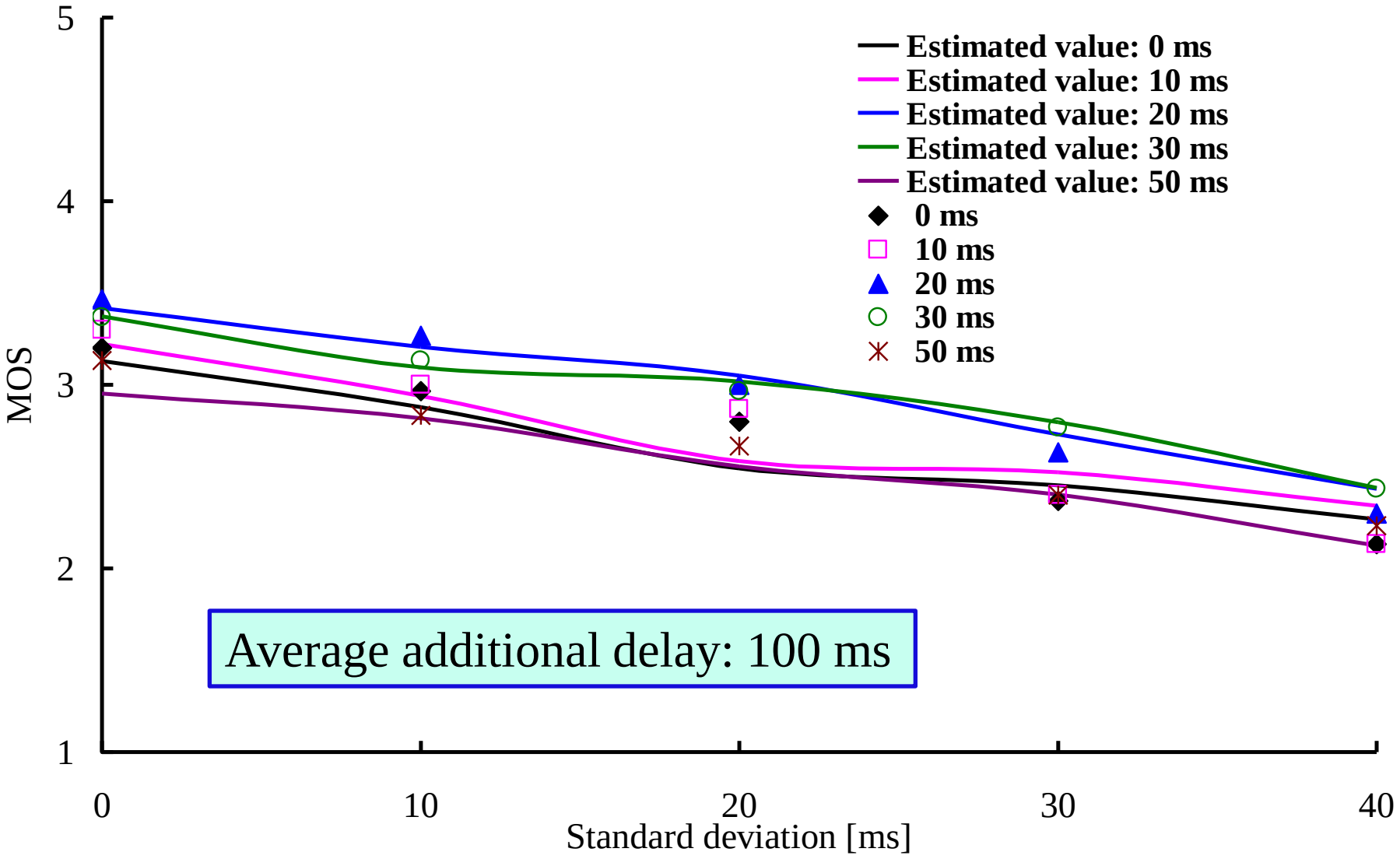
$$V_{mos} = 7.554 - 0.101 T_{ope}$$

V_{mos}: Estimated value of the MOS

T_{ope}: The average operation time

Contribution rate adjusted for degree of freedom: 0.921

MOS and Estimated Value of MOS



Conclusions

- Proposal of a group synchronization control scheme with prediction in collaborative haptic play with building blocks
- Examination of the effectiveness of the scheme by experiment

- The proposed scheme can keep the media output quality high.
- The proposed scheme improves the interactivity of group synchronization control.
- There is an optimum value of the prediction time. The optimum value depends on the average additional delay and the standard deviation.
- We can estimate the MOS from the average operation time with a high degree of accuracy.

Future work

- Experiment in a variety of network environments
- Plan to deal with voice as well as haptic media so that users can play games while having a conversation