QOE ASSESSMENT AND CONTROL IN NETWORKED HAPTIC GAMES

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QoE Assessment and Control in Networked Haptic Games

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This is to certify that we have examined the thesis entitled "QOE ASSESSMENT AND CONTROL IN NETWORKED HAPTIC GAMES", submitted by MS. MAY ZIN OO, Roll Number: 12Ph.D - 4, 2017-2023, in fulfillment of the requirements for the degree of Doctor of Philosophy in Information Technology and we recommend it to the Steering Committee for the Ph. D. Programme for acceptance.

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ABSTRACT

In recent years, with the advancement of high speed communication networks, multimedia applications which consists of a collection of multiple media such as text, graphics, images, sound, and video became popular. Due to the difference of network delay is large among the terminals, simultaneous output of media cannot be done. Therefore, Quality of Experience (QoE) such as synchronization quality of media at each terminal or consistency among the terminals may seriously be degraded. In order to investigate the influences of network delay on such kinds of QoE assessment, the focus is on networked weight balance game and a networked balloon bursting game.

To solve the above causes, it is necessary to examine influences of various factors as well as on the collaborative work with the network delay to carry out Quality of Service (QoS) control more efficiently. This is very important to improve collaborative work not only in the 3D virtual space but also in the daily life industries such as construction. Moreover, QoE assessments and QoS control are required to address in order to know that how the softness features change, when the network delay becomes larger. It is preferred to perform palpation and remote surgery in medical fields.

In the networked balance game, the researcher examined the effects of network delay and moving velocity on the effectiveness of the work where two users collaboratively lift up a weighted ball with haptic sense in a virtual environment. Also, the researcher examined the influence of the initial position of the ball.

Through the use of haptic interface device in the networked balloon bursting game, the researcher illustrated that how accurately each subject can perceive the difference of softness by QoE assessment in a networked virtual environment. By evaluating the QoE, the researcher also looked into how local lag affected people's perceptions of softness with haptic sense in a networked virtual space. The researcher dealt with a networked balloon bursting game that featured two balloons with various softness values. In the assessment, the subjects determined whether the softness of the balloon is “same”, “softer” or “harder”.

Furthermore, the researcher examines the effect of adaptive reaction force control on human perception of softness with haptic sense in a networked virtual environment by QoE assessment. To maintain the consistency of the game states between terminals, the researcher produces the local lag, which is set to the network delay, at each terminal; however, as the local lag increases, the softness of balloon becomes harder. The adaptive reaction force control solves the problem by changing the elastic coefficient according to the local lag. Assessment results demonstrate that the adaptive reaction force control can keep the human perception of softness constant for a wide range of the local lag.

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CHAPTER 1
INTRODUCTION

In the recent years, multiple media collection such as sound, video, images, graphics and text have risen in popularity for high speed networked applications. The networked real-time games with haptic sense have been focused on a large number of researchers. However, the output of media cannot be done simultaneously when the network delay difference becomes larger between the terminals. Therefore, Quality of Experience (QoE) factors like media synchronization quality at each terminal or consistency between the terminals may significantly deteriorate. To clarify the influence of network delay on these types of QoE assessment, the focus is on a networked weight balance game and a networked balloon bursting game.

The various researchers have been attentive to networked haptics in 3D virtual spaces. As a result of the delay jitter, packet loss, and network delay, the features of object may exchange in various ways; as an example, when the network delay become larger, the objects may become harder and/or heavier. It is necessary to inspect features of human perception such as the weight, shape and softness of an object for effective Quality of Service (QoS) control. However, the features of human perception has not yet been adequately expressed. Using the haptic sense in a 3D virtual space, each user can perceive an object's weight, softness, and shape. Among them, the specialization is on weight and softness of object with haptic sense as follows:

- Examining the influence of network delay and moving velocity on the weight perception
- Investigating the human perception of the softness of object
- Clarifying the influence of network delay on the softness of object
- Applying the adaptive reaction force control to the softness perception of object to keep the reaction force constant even if the networked delay become larger

1.1 Application Areas for Haptics

The technology of haptic sense which provide the sense of touch with remote objects without the need of actual contact. Haptics broadly describes technologies that a user experiences through touch. Typical applications incorporate vibrations of phones and game controllers, but tactile feedback can also be created using other methods, such as sound waves and air. There are various and enlarge application areas by haptic technologies and they are as follows:

- Medical training and surgical simulation
- CAD(Computer-Aided-Design), painting, sculpting
- Standard user interface and basic interaction methods like opening and shutting windows and interacting with menus
- Military applications including as space and military simulations and exercises
- Assistive technology for people who are blind or have vision problems
- Gaming areas

1.2 Problems in Virtual Environments with Haptic Sense

Applications are used in Quality of Service (QoS) network like the Internet are not guaranteed, and so simultaneous output may not be done through delay jitter, network delay, and packet loss. This brings on detraction of Quality of Experience (QoE) like as deterioration of consistency, and fairness among the users, interactivity, quality of media synchronization, operability of haptic interface devices. To solve the above problems, it is necessary to carry out QoS control such as prediction control and the adaptive reaction force control to improve the human perception of softness [1]. In this research, the adaptive reaction force control have been applied.

1.3 Motivation of Research

The author can enhance the value of the effectiveness of collaborative work with haptic sense. In a three dimensional environment, each subject can sense with a haptic interface device, an object's "shape", "softness" and "weight". However, when the information about the 3D virtual space is distributed in the internet with Quality of Service (QoS) over non-guaranteed networked. So, it is necessary to examine features of human perception like that an object's shape, softness, and weight. Even so, human perception of the features has not explained adequately up to now. The time to receive information on different terminals may differ due to delay jitters, network delays, packet loss, etc. So, the performance of collaborative work may degraded seriously.

To solve the above causes, it is required to examine influences of various factors as well as on the collaborative work with the network delay to carry out QoS control more efficiently. This is very important to improve collaborative work not only in the 3D virtual space but also in the daily life industries like construction. Also, it needs to address QoE assessments and QoS control to clarify the softness features how change when the network delay becomes larger. It is important to perform palpation and remote surgery in medical fields.

1.4 Application Areas of Research

A number of researchers have been paying their attention to networked haptic time games. However, when the difference of network delay is large among the terminals, simultaneous output of media cannot be done. Therefore, QoE such as synchronization quality of media at each terminal or consistency among the terminals that can cause seriously damage. There are various application areas for multimedia communication system. Among them, the focus is on two application areas in multimedia communication with haptic sense. In such kind of research the influences of network delay on such thing in assessment of QoE, it is needed to consider to network weight balance game and a network balloon bursting game.

1.4.1 Networked Weight Balance Game

In a networked weight balance system, the influences of moving velocity of the ball on human perception of weight have not been described yet. Therefore, the examinations about this with haptic sense in the networked balance system and how influences on the efficiency of work to the network delay and moving velocity and the influence of the initial position of the ball have been done.

1.4.2 Networked Balloon Bursting Game

Networked haptic balloon bursting game, in which we investigate how can correctly perceive the difference of softness by each of subject with QoE assessment in a networked virtual space. And also, it is important to know the imperceptible range and acceptable range in difference of softness. And then, how largely effect the softness perception via network delay or local lag are clarified. Because, the local lag are produced, which is set to the network delay, at each terminal; however, as the local lag increases, the softness of balloon becomes harder. To solve the above the problem the author need to apply the effective QoS control in order to the QoE assessment high. Therefore, the examination on the effect of the adaptive reaction force control on human perception of softness have been done.

1.5 Objectives of the Research

Due to the increased network delay between the terminals, simultaneous media output is not possible. As a result, QoE assessment like media synchronization quality at each terminal or consistency between the terminals may significantly suffer. In this research, the author deal with the networked balance system [2]-[4] and networked balloon bursting game [6]-[9] by QoE assessment how largely effect the delay jitter, network delay and other factors on such types of networked media.

A weighted balance system with the haptic interface device over a network, which has two PCs with a haptic device are connected via a network, a user of each PC can move his/her cursor. It indicates the position of the tip of haptic device’s stylus. There are walls, a floor, and a ceiling in the weighted balance system. The stick's length between its two ends can be freely stretched or shrunk. The weights of the two cursors are 0 gf (zero) whose are fixed on a stick’s two ends. While lifting up the stick by the user who can sense the weight of the ball that is proportional to the distance between the cursor of his/her to the ball. A ball whose weight is 270 gf is placed on the two ends of the stick.

Other application area like that a networked balloon bursting game, there are two terminals each one with a PC and display, a headset and a haptic device (a 3D Systems Touch) [10]. Each player controls the virtual stylus with the help of their haptic device in the virtual environment. The stylus's point matches the cursor of haptic interface device. The player can get the sense of balloon’s softness when they touch it with the tip of the device’s stylus, the force feedback can be perceived via haptic device. When the player penetrates the balloon with the stylus, it bursts. If you push too hard, the balloon deforms greatly. It should be denoted that in [11], a balloon is deemed to have burst when its volume becomes smaller than a threshold value; this is untrue. If you applied force to the balloon is larger than a certain threshold value then the balloon bursts and disappears. After that you can hear an explosion sound through the headphones.

The purposes of this study are as follows:

- To examine how largely changes the delay jitter, packet loss, and network delay affect the human perception on the network haptic games in virtual space.
- To analyze which types of QoS control should be applied in network haptic games to maintain QoE assessment at high possible.
- To hold the synchronization quality of media unit at high in the network haptic game.
- To apply the proposed methods not only in virtual environments, but also in everyday life.
- To apply the usage of AI for advanced collaboration with humans and robots by force feedback.

1.6 Contributions of the Research

It is necessary for multiple users to do collaborative work while watching the same displayed images simultaneously in a 3D virtual space. The receiving times of the information at different terminals may be different from each other owing to network delays, delay jitters, packet loss and so on. Therefore, we examine the influences of various factors as well as the network delay on the collaborative work to carry out QoS control more efficiently. Experimental results demonstrated that it is possible to keep the ball around at the center when the network delay is small. It is also show that there exists the optimal moving velocity of the ball depending on the network delay. By using a haptic interface device, the features of objects may change in different ways. They may become harder and/or heavier as the network delay increases. Therefore, we investigate human perception of softness of an object. Assessment results clarify the imperceptible range and allowable range of softness difference. The influence of local lag on human perception of softness are also clarified. As a result which illustrates that the human perception of softness is dependent on the local lag. Therefore, the adaptive reaction force control is applied on human perception of softness to maintain the consistency of the game states between terminals. Assessment results demonstrate that the adaptive reaction force control can keep the human perception of softness constant for a wide range of the local lag.

The benefits of the proposed system are as follows:

i. Examine the influences of the network delay and moving velocity on the efficiency of work with QoE assessment and also examine the influence of the initial position of the ball.
ii. Clarify human perception of softness by QoE assessment in 3D virtual space with network haptic sense.
iii. Investigate the influence of local lag on human perception of softness by QoE assessment in a 3D virtual space with network haptic sense. Setting local lag to networked delay enables local lag control to preserve consistency in game state between multiple terminals.
iv. Propose adaptive reaction force control on softness of the object to hold the reaction force constant when the networked delay become larger.

1.7 Organization of the Research

This research study is organized with six chapters. Chapter 1 includes an introduction, the motivation of the research, the problem description, objectives and contribution of the research work. The remaining parts of the research are ordered as follows: Chapter 2 surveys the challenges and feature of QoE assessment and control in networked haptic virtual environments. The theoretical background of 3D virtual space with network haptic sense is shown in Chapter 3. The configuration of the proposed system and the proposed methods with haptic sense in multimedia communication areas are detailed in Chapter 4. The illustration and execution of the proposed system are explained in Chapter 5. In Chapter 6, the experimental results by doing assessment with the proposed methods with haptic sense are described. The conclusion and the brief of the research study are described and the consideration of the works for the future and intention based on the research are also mentioned in Chapter 7.

CHAPTER 2
LITERATURE REVIEW

A number of researchers have been studying networked haptic sense in virtual environments [12]-[15]. Using the haptic sense can improve the effectiveness of the networked virtual environment. The times of the received information at various terminals may be different of the other one in such work Quality of Service (QoS) when transmitting about information over a network, such as the Internet, is not guaranteed due to delay jitters, network delays, and other factors. As a result, the effectiveness of collaborative work may be seriously compromised because different displayed images may have been perceived simultaneously by users at different terminals. The reason is that while some of the terminals may have received the .information already, others may not have.

To clarify the above problem, as QoS control, it is necessary to perform the group synchronization control [16]. There are many other controls like that the adaptive Δ-causality control [17] can be operated, the local lag control [18], simultaneous output-timing control [19] which absorbs delay differences among different terminals, and adaptive reaction force control.

2.1 Multimedia Communication Systems

There are many types of application areas for multimedia communication systems. Examples of multimedia communication system are as follows;

- TV conference
- Networked real-time games
- Networked haptic museum
- Collaborative work with haptics
- Haptic play with building blocks
- Haptic media and video transmission
- Networked haptic air hokey game
- Remote haptic calligraphy
- Remote haptic penmanship
- Networked haptic penalty shootout game

- Drum performance system with haptic in network
- Fruit harvesting game with haptic and olfactory senses in network
- Balloon bursting game with haptic and olfactory senses in network
- 3D object identification fame with haptic, olfactory, and auditory senses in network
- Remote robot control with haptics

2.2 Networked Haptic Balloon Bursting Game

The system constructs the two PCs called terminals, each PC which has a headset, a 3D Systems Touch [20], and a display. In Figure 2.1, players use haptic devices to burst balloons in a virtual environment. The number of balloons that have burst is the point of competition between the two players. For convenience in the virtual environment, each terminal had two balloons. The virtual stylus is moved by each player using their respective device with haptic sense in a virtual environment. The cursor means that the tip of the stylus of the haptic device in a virtual space.

2.2.1 QoE Assessment of Operability and Fairness for Soft Objects

The authors clarified that operability of haptic interface device for each player and fairness among players by QoE assessment in a network haptic real-time game as in [21]. They discussed a game where two players burst balloons in a 3D virtual environment using network haptics in real time. Pushing a balloon causes its volume

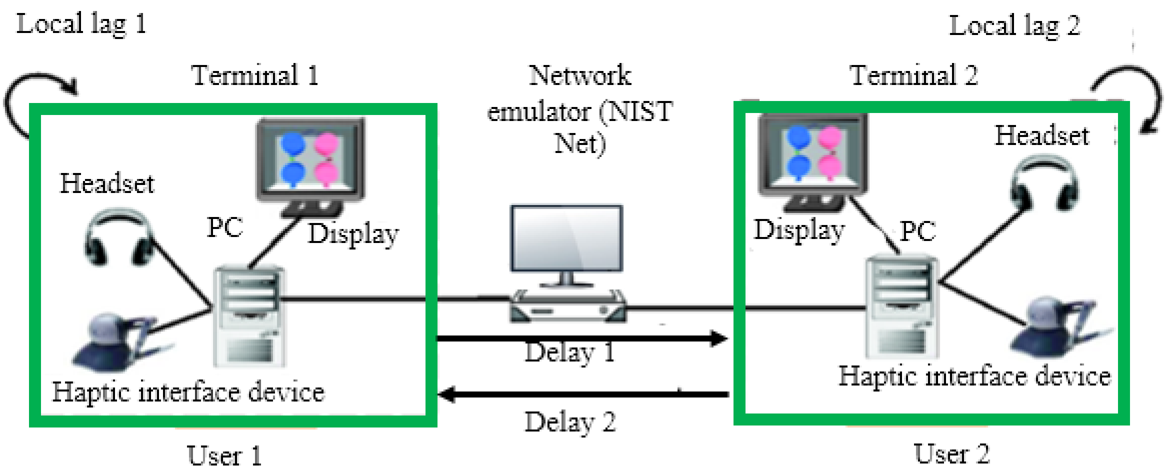


Figure 2.1 System Configuration of Networked Haptic Real Time Game

to drop below a certain point, at which point it bursts. Then they went on to demonstrate how the network delay affects operability and how the difference in network delay between the terminals of the players affects fairness. However, they neglected to address for soft object how impact of local lag on people perceive their features.

2.2.2 Influences of Network Delay on Quality of Experience for Soft Objects

In [22], the author discovered that the haptic interface device's functionality depends on the local lag, which is calibrated to the network delay. They look into a networked balloon bursting game in which two players compete for the most balloons popped via haptic sense in a 3D virtual space. Additionally, they confirmed such as operability and fairness had a trade-off relationship. However, the impact of local lag on how people perceive the characteristics of an object has not been studied.

2.3 Networked Weight Balance Game

The system includes two terminals (called PCs 1 and 2 here) as shown in Figure 2.4, each of which has a haptic interface device (3D Systems Touch). By operating the haptic interface device, a user of each PC can move a cursor which denotes the position of the device stylus's tip in the space which is surrounded by a floor, a ceiling, and walls. The two cursors are fixed at two ends of a stick whose weight is 0 gf. The stick can be stretched or shrunk freely between the two ends. A ball whose weight is 270 gf is placed on the stick between the two cursors (i.e., the two ends of the stick).

2.3.1 Assessment of Weight Perception with Haptics Senses

In [23], the influences of weight changes on human perception of weight in a networked virtual space with haptic sense have been investigated. In Figure 2.2 shows that the configuration of networked weight balance system. In their QoE assessment, each user has one end of a bar by using a haptic interface device with a certain weight in a 3D virtual space, and when the weight is changed, the user give the answers whether the weight has been differenced or not. They demonstrate that if weight changes are smaller than or equivalent to roughly 10 gf, the user will have difficulty in seeing them. They, however, only addressed the human perception of weight.

2.3.2 Influence of Network Delay on Human Perception of Weight

In [24], two users, each controlled a haptic device, and they worked together to upraise a stick by keeping it between two ends of the stick in a three-dimensional virtual space. The authors conducted an experiment to look at how network delay affects how people perceive weight in a networked virtual environment. They demonstrated how local lag control can increase the effectiveness of group work. Additionally, as the network delay become larger, saving the ball's position at the center of the stick becomes harder without implementing local lag control. The ball can be held in place in the middle if the network delay become smaller around 25ms. However, they only made clear how local lag affects how people perceive weight.

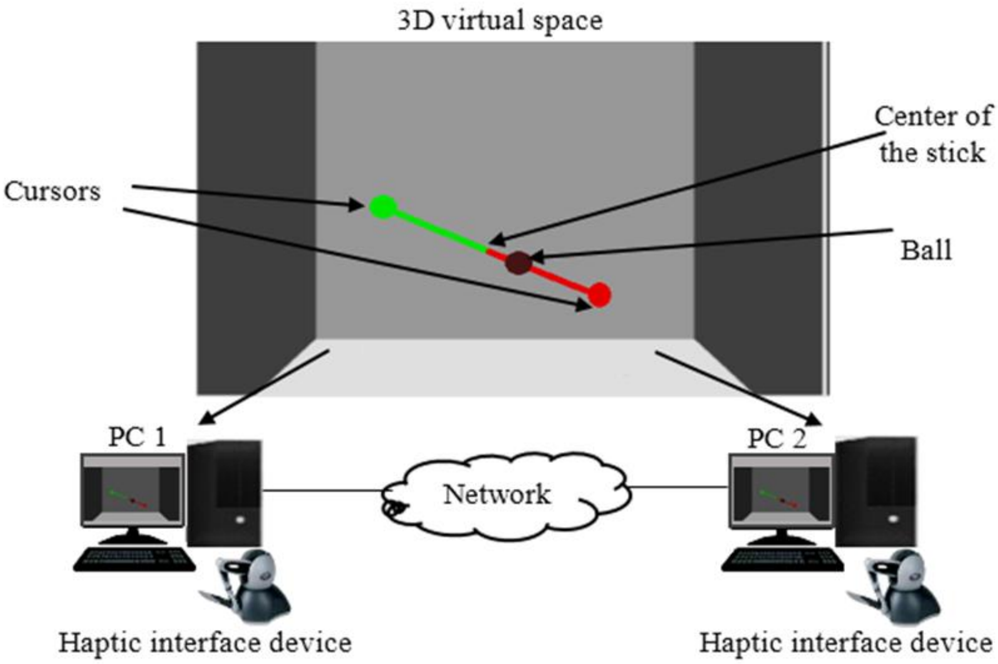


Figure 2.2 System Configuration of Networked Weighted Balance Game

2.4 Remote Robot System with Force Feedback

Figure 2.3 shows the configuration of the remote robot system with force feedback. The system is mainly composed of the master terminal, the slave terminal, a haptic interface device (3D systems Touch), and an industrial robot. The master terminal and the slave terminal are connected to each other via a network. The master terminal is used to control the haptic interface device. The slave terminal is employed to control the industrial robot.

2.4.1 QoE Assessment of Weight on Human Perception

The authors in [25] investigated how a user could control a remote robot with haptic device to evaluate the impact of weight changes on weight by QoE assessment. Due to this, users find it difficult to notice weight changes within about 10 gf; however, if the absolute difference become larger 20 gf, subjects can access weight changes. However, researchers have looked into how weight change affects how people perceive their own weight.

2.4.2 Effect of Adaptive Reaction Force Control in Remote Control System

A remote control system with haptic media and video was proposed in [26] with adaptive reaction force control. Accordance to the network delay which dynamically changes the reaction force presented to a user. They also suggested a formula for calculating the reaction force under control. They use haptic sense and video in the remote control system to implement adaptive reaction force control shown in Figure 2.3. Then they looked into the impact of the QoE assessment control. Additionally, if network delay significantly changes, they perform another assessment. They also suggested a formula for calculating the reaction force under control. Then, they used QoE assessment to show how effective the control. The results of the assessment demonstrate how successful the adaptive reaction force control.

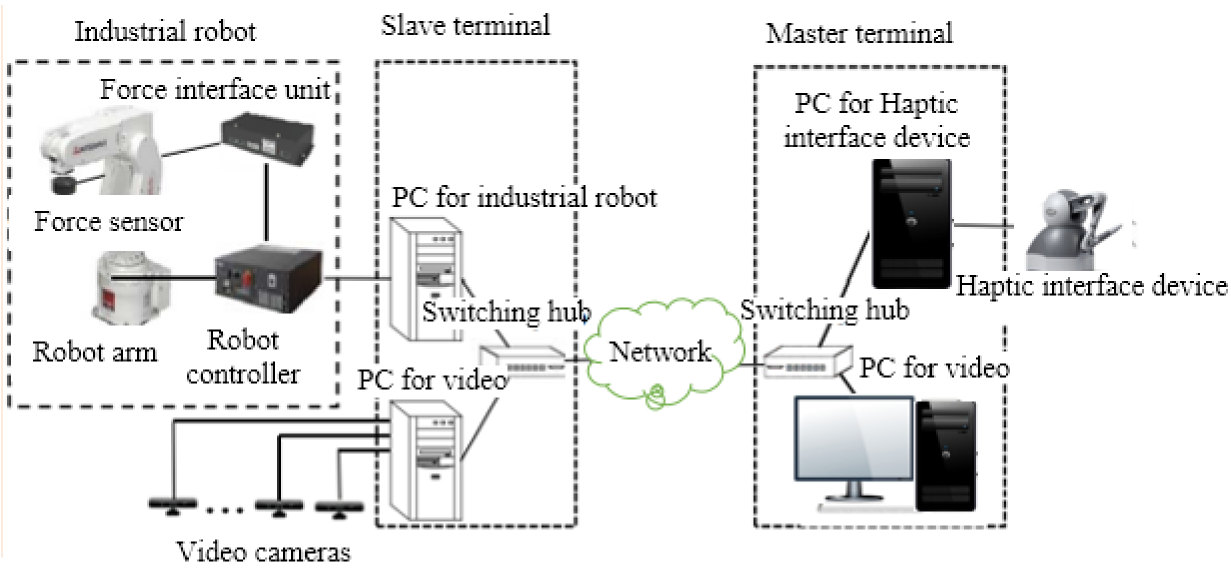


Figure 2.3 System Configuration of Remote Robot Control

2.5 Remote Teaching System

In Figure 2.4, the haptic remote teaching system makes it possible for a learner to interact with the sense of force while an instructor uses a brush to draw. Each user of PHANToM Omni paints figures on a canvas made up of computer graphics (CG) in a three-dimensional virtual space. By applying force that is proportional to the space between each user's paintbrush positions, they each pull their brushes apart.

2.5.1 QoE Assessment of Group Synchronization Control Scheme with Prediction

A group synchronization control technique with prediction in work using haptic media is proposed by the author in the publication [27]. The system maintains a high level of interaction while adjusting the output timing among several terminals. It produces position information by forecasting future positions that are a fixed length of time behind the positions included in the most recent information. It adds the same number of time to the time of output of location information at each local terminal. To show the efficiency of the plan, they used haptic sensation to do two separate types of tasks. They used a QoE assessment to determine the output quality of haptic sensation for the two types of labor in a subjective and objective manner. Additionally, they made explicit the connection between subjective and objective assessment results.

2.5.2 QoE Comaprison of Haptic Control Schemes in Remote Instruction System

For a remote teaching system with haptic, video, and speech by Quality of Experience (QoE) assessment, they compared haptic control schemes in [28], mentioning position-position and position force control schemes. Characters can be actively written by a teacher, who can also show a pupil how to draw them. Additionally, the student may actively sketch the characters, and the instructor can check the accuracy of the student's writing. For the two scenarios, they look at the impact of network delay. They dealt with the haptic media, video, and voice-based remote instruction system's position-position and position force control systems. By doing QoE assessment, they compared the two control schemes. They discovered that the QoE of both control schemes declines as the network delay rises as a result. They discovered that, particularly when a student actively draws a character, the QoE of the position-force control scheme declines more significantly than that of the position-

position control scheme. This means that the position-position control scheme is better than the position force control scheme. Nevertheless, they chose not to test the effects of network delay on quality of experience with various work types.

2.5.3 Adaptive Control of Viscosity in Remote Control System

In [29] the collaborative task, two players move an object simultaneously to take out a target in a virtual space. By using only haptics or vision and haptics, the users communicate their intentions regarding the movement direction of object to one another. They performed subjective and objective QoE assessments to investigate the impact of network delay on will transmission. Additionally, they explored the best forces to use for will transmission, how vision affects will transmission by haptics, and how to transmit wills by haptics. They specifically dealt with collaborative tasks where participants are on an equal footing and object movement directions are not predetermined. To investigate the effects of network delay on will transmission, they conducted subjective and objective QoE assessments.

2.5.4 QoE Assessment of Adaptive Viscoelasticity Control

In [30], they proposed adaptive viscoelasticity control due to the network delay, the movement speed of a haptic interface device, which dynamically modifies the elasticity and viscosity coefficients. They also looked at the optimal viscosity coefficient's wide range. The effectiveness of the control is then evaluated using a QoE assessment. By combining the two types of control mentioned above, they discussed adaptive viscoelasticity control in this paper. The obtained equation was used in the control to establish the ideal elasticity coefficient in light of the network delay. Then, they looked into the range that the ideal viscosity coefficient has for a specific network delay and haptic interface device movement speed. The effectiveness of the control by QoE is then examined. Additionally, using multiple regression analysis, they are able to derive an equation that calculates the ideal viscosity coefficient from the network delay and moving speed. They did not, however, investigate the adaptive viscoelasticity control's dynamic behaviors when moving speed and the network delay were altered.

2.5.5 Adaptive Control of Viscosity in Remote Control System

In [31], they suggested that the viscosity coefficient in accordance with the network delay dynamically changes by adaptive viscosity control. A remote control system in which a user controls a haptic interface device at a remote location while viewing video with another haptic device. First, they suggested the ideal viscosity coefficient exists depending on the network delay. They then obtained equations that used the network delay to calculate the ideal viscosity coefficient. The effectiveness of the suggested control is then demonstrated by an evaluation of the Quality of Experience (QoE). They used haptic device and video with an assessment of QoE to show how well the remote control system works. They provided an example of adaptive viscosity control for the force-feedback in the remote control system. Additionally, they discovered that the adaptive viscosity control worked well. Additionally, they observed that the network delay determines the optimal viscosity coefficient. However, they have not studied adaptive viscoelasticity control, which modifies both the elastic and viscosity coefficients in accordance with network delay.

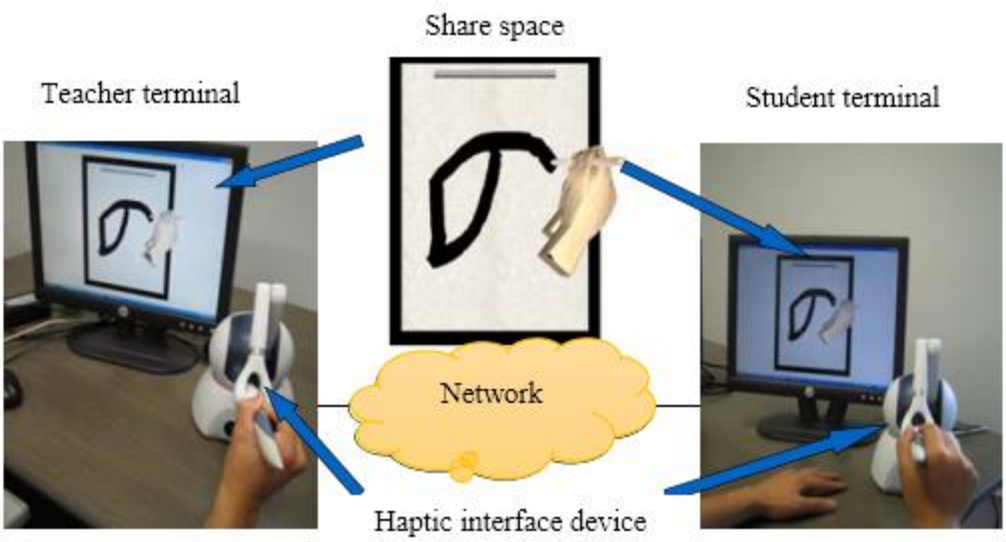


Figure 2.4 System Configuration of Remote Haptic Drawing Instruction

2.6 Networked Haptic Drum Performance System

In Figure 2.5, depicts the set-up of the networked haptic drum system in a 3D virtual environment, complete with a snare drum, high-hat cymbals, bass drum, and floor tom. The haptic network drum system has two terminals, each of which has two PCs linked to one another by an Ethernet switching hub. It connected PC has a haptic interface device called Geomagic Touch. At each terminal has two haptic interface devices are used to simulate a pair of drumsticks in the virtual environment. Additionally, PC 1, at each terminal is connected via a display and a headset. Through haptic interface devices, each user feels the feedback force when they strike a drum piece with a drumstick.

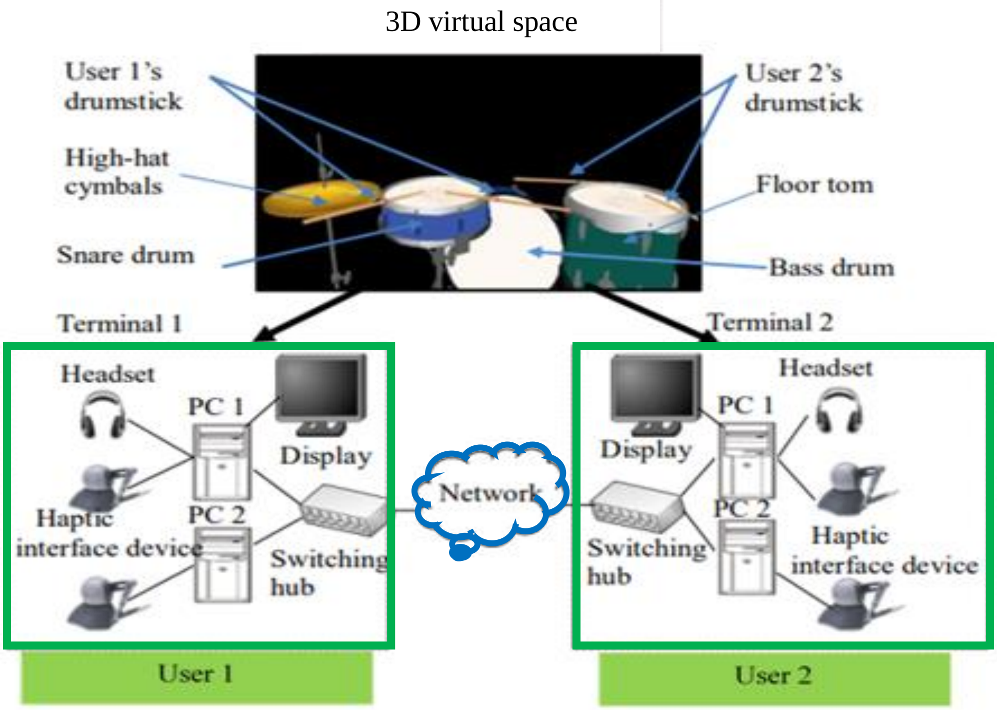


Figure 2.5 Configuration of Networked Haptic Drum System

2.6.1 Influence of Network delay on Ensemble Application

In [32], Arimoto et al. dealt with a music ensemble system with networked haptic sense. A pair of users played drums. In the system, packet loss and the network delay degrade collaboration performance between the users. They illustrated that the role of haptic sense, the effect of media synchronization control and the influence of network delay in the networked virtual environment. To this end, they illustrated that via the sense of haptic interface device to the auditory and visual senses can enhance the collaboration performance and improve the sense of togetherness among individuals taking part in the work. However, they clarified only the influence of network delay in the environment; they did not examine influences of other factors such as the velocity of hitting drums.

2.6.2 Effects of Dynamic Local Lag Control on Sound Synchronization and Interactivity

In joint musical performance [33], the author proposed the effect of the local lag dynamically in synchronization of sound system. They examined that the comparison of fixed-value local lag control and dynamic local lag control in the combined operation of a network haptic drum system using subjective and objective QoE measurements. They also investigated the association between MOS values and objective performance metrics. Since the efficacy of dynamic local lag management was discovered. Furthermore, they demonstrated that MOS values can be accurately determined using the root mean square of sound or/and the local lag.

2.6.3 Effect of Dynamic Local Lag Control with Dynamic Control of Prediction Time

In paper [34], they handled a system of drum performance in a network 3D virtual space. The two users employed a drum set with the same rhythm at the same tempo. They suggested combining dynamic local lag control with dynamic prediction time control as a means of enhancing interactivity. They demonstrated that the proposed control can maintain a high level of sound and interaction synchronization. They also use the different values of the local lag and prediction time according to the network delay dynamically. Hence, they demonstrated that the control is effective.

2.7 Fruit Harvesting Game

When the fruit is picked by the player from a tree, the player can perceive the feedback force, and via an olfactory display SyP@D2 [35], the players can get the fruit's smell output since the fruit approaches player's viewpoint; by blowing air into a smell cartridge attached to the main body, SyP@D2 produced a smell. Many players can compete against one another in the fruit harvesting game in a 3D virtual environment. Each participant acted in a harvester or harvest impeder manner. The game can also be played by two pairs of players, one player as the role of a harvester and next player as a harvest impeder are playing. The fruit harvesting game's system model and images of the virtual environment are displayed in Figure 2.6.

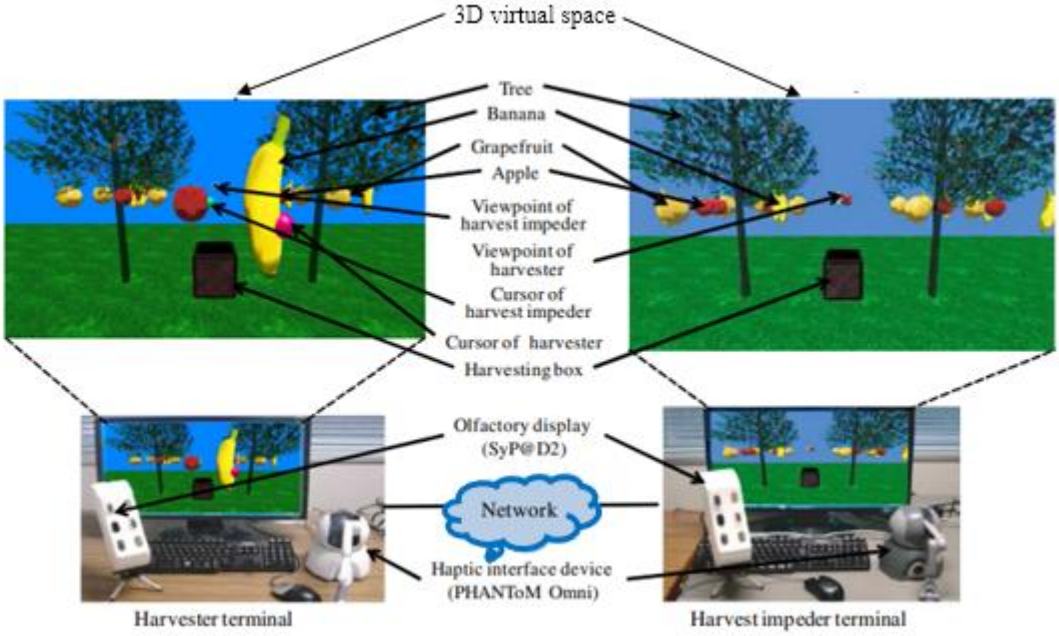


Figure 2.6 System Configuration of Fruit Harvesting Game

2.7.1 QoE Assessment of Fairness in Networked Game with Olfaction

It was investigated how fairness among the players with olfaction is affected the fruit harvesting game in a networked [36]. It took a time that the player to get a smell. The constant delays is changed to produce by the terminals during the assessment, they altered the amount of time it takes for a scent to reach a player. As a result, they demonstrated if the constant delays become less than 500 ms, the fairness between players is hardly affected. Also, they observed that the fairness is high when one terminal's constant delay is 700 ms and difference the absolute value of the constant delay between the two terminals is less than or equal to roughly 200 ms. They discovered that fairness is also high when one terminal produces a constant delay of 1,000 ms and the other produces a constant delay of more than 900 ms.

2.7.2 Influence of Olfactory and Auditory Senses on Fairness between Players

It is anticipated that it will play network games with a strong sense of presence by utilizing the haptic and olfactory senses. Although it's crucial to treat each player fairly, injuries occasionally prevent some senses from being used. In which determine whether or not olfactory and auditory senses [37] are active. Such kind of work with haptic senses for fairness of 3D object is done in a networked mvirtual identification game.

2.8 Summary

This chapter covered the analysis of various haptic sense applications in virtual environments. The analysts demonstrate how using the haptic device to the visual and auditory senses can improve collaboration performance and the sense of community among those participating the work in network haptic drum performance system. They also discovered that the dynamic local lag control works well. In next as application, a game of fruit harvesting, they investigated the impact of fairness between players it takes amount of time for a smell to reach them.

They assessed the quality of experience in the balloon-bursting game, taking into account each player's ability to use the haptic interface and fairness. The assessment's findings indicated that fairness and network delay affect operability. They then go on to demonstrate that operability and fairness have a trade-off relationship.

In a weight balance system with networked haptic sense, the author discusses the effects of perception of human on weight changes in a networked haptic environment. As well as, the effects of network delay and moving velocity on cooperative virtual haptic work through experimentation. A number of other papers were discussed in the section that followed in this chapter, including ones by using force feedback in a remote robot system, a remote teaching system, and QoE evaluation and QoS management in the context of networked haptic environments.

CHAPTER 3
BACKGROUND THEORY

With the recent advent of high-speed communications networks, multimedia applications which incorporate a range of media, including text, graphics, photos, sound, and video have grown in popularity. Furthermore, with the advent of high-performance computers, classic 2D computer graphics are giving ways to high-quality 3D computer graphics with virtual worlds. The users who are located around the world in networked virtual environments can interact with each other in real time [38] [39], [40] and [41]. Haptic media can now be used in multimedia applications with networked virtual environments together with conventional visible and acoustic media [42]-[46]. People can get the force feedback from the haptic (i.e., the sense of touch) when they touch objects in a virtual space. Additionally, they are able to detect an object's shape, weight, and softness. The haptic technology is widely used, including video games, teleoperations, distance learning, and others.

It depends on the types of application area being used, simultaneous media output from multiple terminals as well as each terminal is essential when users apply these kinds of applications over a network. Making the output timings of media the same is referred to as simultaneous output of media. The media at a terminal could be the same, different, or the same media at various terminals. For instance, in a networked balance system, users can significantly improve teamwork efficiency by utilizing haptic sense. When data about a 3D virtual space is broadcast over an unreliable network, Quality of Service (QoS) is not guaranteed, like the internet. As a result, serious declines in collaboration's effectiveness may occur. This is essential to enhancing teamwork in both the 3D virtual environment as well as in real-world fields like construction.

As another example, in networked balloon bursting game, it is necessary to study QoE assessments and QoS control for softness how their features change to due to network delay increase. Because the network delay becomes larger, the characteristics of softness of the objects may become heavier and/or harder. To conduct remote surgery operations and palpation in the medical fields, this is necessary.

This study designated two areas to investigate how the inability to output media simultaneously at each terminal or across terminals affects various QoE parameters and which QoS control should be employed to the work in order to keep the highest QoE. The two applications areas which used in this research are namely as the network haptic weight balance system and network haptic balloon bursting game in virtual space.

The following section, in the rest of this chapter, Section 3.1 is where we express haptic interface technology. Section 3.2, describes with communication media with haptic sense and then in Section 3.3, virtual environments in networked area are explained. In Sections 3.4 and 3.5 go into great detail about QoS and QoS control. The topic of quality of experience (QoE) is covered in Section 3.6. Finally, the summary have been described in Section 3.7.

3.1 Haptic Interface Technology

There are different types of haptic interface devices shown in Figure 3.1. The haptic which means that the Greek word: ἁπτικός (haptikos), tactile, pertaining to the sense of touch [47]. Devices called haptic interfaces enable hands-on interaction with virtual environment systems. Easy and simple haptic gadgets like joysticks, steering wheels, and game controllers are frequently used. They are used for activities like manual object manipulation and exploration that are typically carried out with hands

Figure 3.1 Haptic Interface Device

in the real world. By putting pressure on the user or vibrating or moving something, haptics can simulate the sensation of touch. The science of haptics is the application of force (kinesthetic) or tactile feedback to computer applications to simulate the feel of touch and control. Users can feel and manipulate virtual 3D objects via specialized input/output devices known as haptic devices with a haptically enabled application. The method of feedback used to elicit the tactile sense is taken into consideration by the type of haptic device being used.

By allowing the creation of controlled tactile virtual objects, tactile technology advances the study of how the human senses work.. Most researchers divide human touch-related sensory systems into three categories; ‘haptic’, ‘cutaneous’, and ‘kinaesthetic’. Both passive and active forms of touch are possible, and the word "haptic" is frequently used to represent touch that is used actively to communicate or identify objects.

3.1.1 Haptic Feedback

In order to simulate an in-game action, haptics manages vibrations at predetermined frequencies and intervals. In addition to rumbling, it can also "bumps," "knock," and "tap" your hand or fingers, among other things [47].

An eccentric rotating mass actuator, which consists of an imbalanced weight coupled to a motor shaft, is commonly used in electronics that use vibrations to generate haptic feedback. The actuator and the attached device shake as a result of the irregular mass spinning as the shaft rotates. Devices that use force feedback use motors to control how an object being held by the user moves. It is frequently employed in driving simulators and video games in which players turn the steering wheel to mimic the forces felt by a real vehicle as it corners. The highest-end force feedback racing wheels for strength and fidelity are direct-drive wheels, which are based on servomotors. In arcade games, especially racing video games, haptic feedback is frequently used. In 1997, "Tatsumi's TX-1" was the first video game to include force feedback for driving. In 1999, haptic feedback was added to a pinball machine in the video game "Earthshaker".

3.2 Characteristics of the Haptic Communication Media

Sense of haptic can be sent between user terminals as media units in networked virtual environments. The media units (MUs) [48] are information units for media synchronization that each contain information about the reaction force, the timestamp, which denotes the input time, and the media unit's sequence number. They also include position information for the haptic interface device. In haptic media transmission, there are at least two control strategies [49]. The position-position control scheme [50] and the position-force control scheme [51] are two of the schemes. Each terminal determines the force feedback applied to its own haptic interface device or object based on the position-position control scheme (i.e., the position of the haptic interface device or an object at the other terminal) and device position information provided by the other terminal. According to the position-force scheme, each terminal computes the reaction force that will be applied to its haptic interface device based on the information sent from the other terminal about the reaction force. The gain coefficient is multiplied by the feedback force transmitted by another.

3.2.1 Haptic Interface Devices

Users can experience force feedback via a haptic sense when interacting with virtual objects in networked virtual space. Haptic devices require higher update rates for the sensation of realistic touch when compared to video update rates. The input/output frequency of current haptic devices is 1kHz or higher [52] and [53]. Users can experience touch in virtual environments naturally thanks to this high frequency rate. Haptic interface devices come in a variety of forms, including 1-DoF (Degree-of-freedom), 2-DoF, 3-DoF, and 6-DoF devices [53] and [54]. Degree-of-freedom refers to an object's freedom of motion in 3D space. The device becomes more intuitive and natural as the degrees of freedom (DoF) rise, but it also gets more complex sensors of a haptic and actuators rises.

Figure 3.2 Geomagic Touch

The virtual object can be moved in the directions of left/right, up/down, and forward/backward while also changing orientation by using 6-DoF(i.e., pitch, yaw, and roll). Geomagic Touch (as shown in Figure 3.2), HapticMaster [55], Geomagic Touch X [56], PHANTOM Premium 1.5 [57], Omega [58], SPIDAR-GAHS [59], Falcon [60], Virtuose [61], CyberGrasp, CyberForce [62], and other haptic interface devices are examples. With the exception of CyberGrasp and CyberForce, each device is primarily controlled by a single interaction point that the user uses. A user operates a single interaction point on each device, with the exception of CyberGrasp and CyberForce, to touch an object. As a haptic interface tool for the works in this thesis, we use Geomagic Touch, formerly known as Sensable Phantom Omni. The workspace for the device is 6.4 inches wide, 4.8 inches high, and 2.8 inches diagonally. Positional sensing can be obtained in 6-DoF, while 3-DoF force feedback is also possible. The most force that can be applied is 3.3 N.

3.3 Virtual Environments in Networked Area

Users of networked virtual environments produced by CG have the impression that other users who are in different locations are present in the same 3D virtual space with them. Thanks to advancements in haptic technology, users now feel as though they are physically present in virtual environments, in addition to the usual CG and sound. The concurrent interaction between users and virtual objects or other users in networked virtual environments used in multimedia applications. In some applications, users are represented by avatars—humanoid agents that each have control over a unique avatar in a networked virtual world. In networked virtual environments, users typically collaborate and cooperate in real-time. In real-time virtual environments that are networked, users compete with one another. Creating a realistic environment is a key component of the environments. Computer graphics, video, and sound help users feel a high level of realism in traditional virtual environments. In addition to traditional video and audio, haptic technology has advanced recently, enabling users to experience more realism.

3.3.1 Haptic Sense in Networked Virtual Space

Ability of user to connect with each other or objects in the same networked virtual environments is constrained when they can only use their visual and auditory senses. Haptic technology enables users to interact with 3D objects by touching, sensing, and moving them. As a result, networked virtual environments with haptic feedback enable users to have more immersive experiences. Haptic sense is used in numerous applications in networked virtual environments. Applications of this type include networked real time games like haptic battle pong, fruit harvesting game in network, haptic 3D virtual museums, remote calligraphy and remote ikebana.

3.4 QoS (Quality of Service)

The Quality of Service (QoS) is the ‘totality of features of a telecommunications service that bear on its capacity to meet expressed and inferred demands of the user of the service,’ according to the International Telecommunication Union (ITU) (ITU, 1994) [63]. To put it another way, we can say that QoS is a concept that denotes the quality of the service. A QoS parameter is a scale that quantitatively measures QoS. QoS is characterized by a number of parameters collectively referred to as QoS parameters. The QoS parameters in a traditional telephone network include specifications for every aspect of a connection, including service response time, loss, signal-to-noise ratio, crosstalk, echo, interrupts, and loudness levels. In telecommunications networks, QoS factors such as bit rate, frame rate, throughput, transmission speed, delay, and jitter are examples. The six levels of QoS over the Internet are broken down into by [64] in order to decrease: user level QoS, application level QoS, end-to-end level QoS, network level QoS, node level QoS, and physical level QoS. Quality of Experience (QoE) is another term for user-level QoS [64]. Guarantees of quality of service are crucial for multimedia communications. However, when media streams like sound, video, and haptic material are delivered across a QoS non-guaranteed network like the Internet, QoS may be substantially damaged due to packet loss, delay jitter and network delay. To maintain the highest level of service quality, the implementation of QoS controls is required.

3.4.1 QoS Parameters

The following are the criteria that organizations can use to gauge QoS:

- Packet Loss: Due to severe network overload, packet loss happens when network devices drop incoming data packets. Packet loss occurs as a result of packets not reaching their intended location.

- Latency: It takes amount of time for a packet to move from its source to its destination across the network is referred to as latency. The better, the lower the latency. Unwanted communication bottlenecks can result from high latency.

- Jitter: Jitter is a result of routing changes or network congestion. As packets are delayed and arrive out of order, it is formally known as packet delay variation (PDV).

- Bandwidth: A number of data that can be transferred over a network path at once. What applications require more bandwidth than others is determined by QoS.

3.5 QoS Control

Quality of Service (QoS) in networking is a traffic management technique that enables businesses to modify their overall network traffic in accordance with the needs of particular time-sensitive applications. It lessens frequent quality degradation problems like packet loss, network jitter, and high network latency. For multimedia communications, there are several forms of QoS control, including control over media synchronization, causality, consistency, and errors.

3.5.1 Media Synchronization Control

It may be hampered by network delays and skews, which can occur by many reasons, consists of different times spent capturing media across terminals, different times spent processing protocols, media interleaving, network delay jitter, packet loss, different times spent decoding during playback, and different times of the day. The control of media synchronization is done to make up for network delay jitter. Object (or event-driven) and continuous synchronization control are the two categories of media synchronization control that we can distinguish [65]. Control over object synchronization refers to control over synchronization between multimedia objects. The control modifies the media's initial output timings in response to a scenario. The output timings (such as output times and speeds) of media streams can be synchronized with one another under continuous synchronization control. There are three different categories of media synchronization control: intra-stream, inter-stream [66]-[73], and group (or inter-destination) synchronization control [74]-[75].

(1) Intra-Stream Synchronization Control

To keep the temporal connection between media units (MUs), such as video frames and audio packets in a single media stream, which each serve as informative

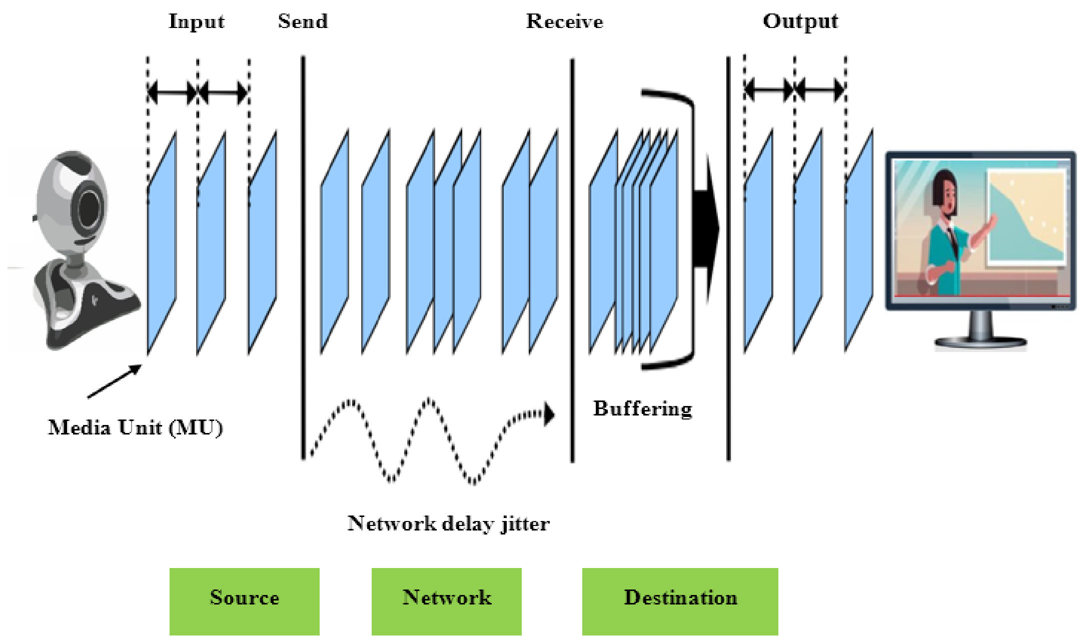


Figure 3.3 MU Output under Intra-Stream Synchronization Control

units for media synchronization, maintained, intra-stream synchronization management is required. Network delay jitter disrupts the intervals between input MUs. When the destination outputs MUs after buffering, as shown in Figure 3.3, the intra-stream synchronization control restores the intervals when the destination produces the MUs. There are numerous techniques for managing intra-stream synchronization, including media adaptive buffering, virtual time rendering (VTR) [76], buffering, adaptive buffer control (ABC) [77] and queue monitoring (QM) [78].

(2) Inter-Stream Synchronization Control

For the purpose of maintaining the temporal relationship between media streams, inter-stream synchronization control is necessary. Lip-synching, a type of inter-stream synchronization, is the coordination of a speaker's spoken voice with the movement of their lips. A master stream and slave streams are typical divisions of media streams. According to Figure 3.4, the slave streams are synchronized with the master stream. Since voice is more susceptible to intra-stream synchronization error than video, the voice is typically chosen as the master stream in lip-sync. Each slave

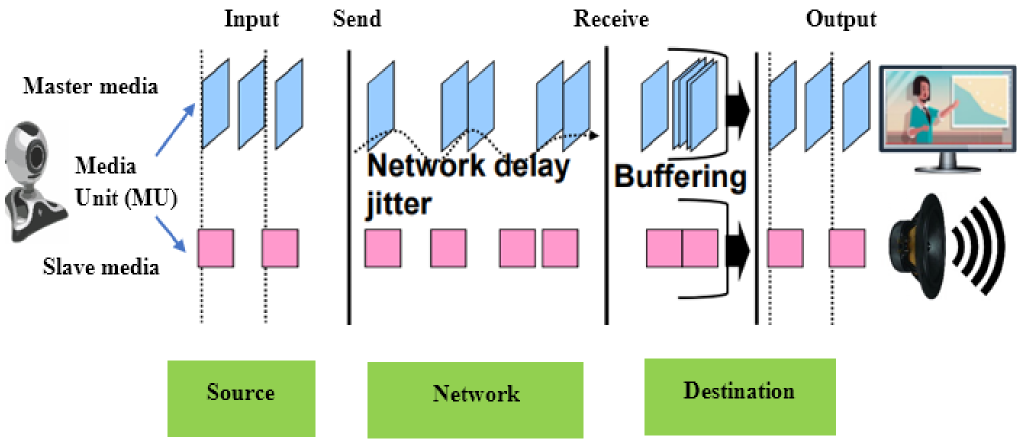


Figure 3.4 MU Output under Inter-Stream Synchronization Control

stream is output in synchrony with the master stream thanks to the inter-stream synchronization control. As a result, the inter-stream synchronization control may significantly degrade the slave stream's intra-stream synchronization quality.

(3) Group Synchronization Control

In multicast communication, group synchronization control outputs each MU concurrently to numerous destinations, as depicted in Figure 3.5. The three group synchronization control systems are distributed control, synchronization maestro, and master-slave destination. The Virtual-Time Rendering (VTR) media synchronization algorithm is the foundation for all three schemes, which use it to determine each MU's output timing so that it is consistent across all destinations. 1.5.2 Control of causality refers to the temporal order or causal relationships between events. The causal relationships must be maintained in networked real-time games. The common examples of causality control are Δ-causality control [79] and adaptive Δ-causality control [80]. A MU, in the Δ-causality control, is hold in a buffer up until the time limit, at which point it is output, if it is received within a time limit (i.e., its generation time plus (> 0 ms)) of the MU. The MU is discarded if it is received after the allotted time because it is deemed useless. Even though the MU is received after the time limit, it is not discarded in the adaptive Δ-causality control. The control predicts the

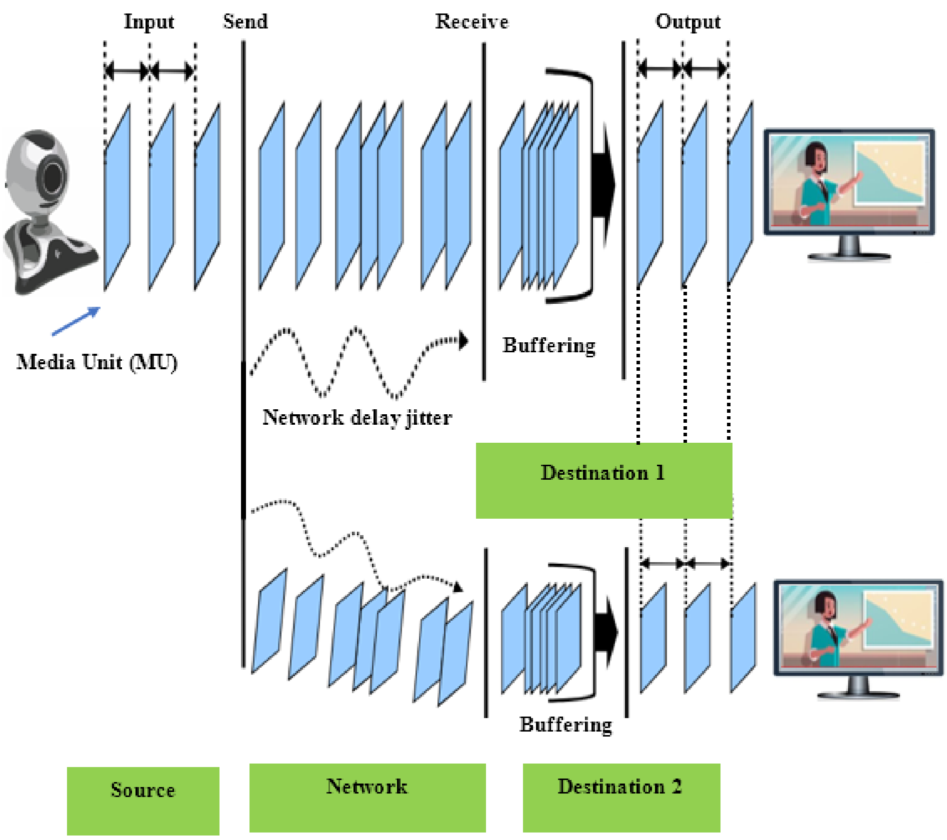


Figure 3.5 MU Output under Group Synchronization Control

future position without output using the late MU. The value of is adjusted dynamically based on the maximum network delay experienced by user terminals.

3.5.2 Local Lag Control

The consistency between user terminals is crucial in networked multimedia applications in virtual environments where users collaborate in a 3D virtual environment. Use the local lag control, which buffers local data for a predetermined period of time called the local lag in accordance with the network delay from the local terminal to the other terminal, to maintain consistency. Therefore a significant network delay reduces interactivity.

3.6 QoE (Quality of Experience)

According to [81], that the QoE (Quality of Experience) is the final user's judgment of the general acceptability of an application or service. The simplest way to assess QoE is through subjective QoE assessment. Subjects evaluate the quality of services using predetermined evaluation criteria in the subjective QoE assessment. However, subjective evaluations take a lot of time and money. Therefore, it is also necessary to conduct objective QoE assessments.

3.6.1 Subjective Assessment

User feedback on quality of experience is gathered subjectively (for instance, a haptic interface device's usability, sound synchronization, and video smoothness). The rating scaling approach [82], SD (Semantic Differential) method [83], pair comparison method [84], constant method, and questionnaire method [85] are a few examples of subjective assessment techniques.

(1) Rating Scale Method

The rating scale method is one of the most popular techniques for evaluating subjective QoE. In the method, participants make a decision based on a category scale after conducting an assessment. ACR (Absolute Category Rating) and DCR are the two primary scales of rating (Degradation Category Rating). According to Table 3.1, ACR uses a five-grade quality scale, while DCR uses a five-grade impairment scale. The five-grade scale is a common example of the rating scale method, in which subjects are asked to give a score between 1 and 5 for each stimulus. The MOS (Mean Opinion Score) [86] is calculated by averaging the results of all subjects who took the test.

(2) Pair Comparison Method

According to this method, each subject compares the first and second stimuli's quality and determines which is superior. Although it is simple for subjects to form an opinion, the assessment process requires more time than the other methods because there are so many different combinations.

(3) SD Method

The SD method is typically used to quantify an object's or system's connotative meaning. The QoE can be subjectively assessed using this method. A list of numerous pairs of bipolar terms, including "heavy-light," "adequate-inadequate," and "valuable-worthless," are given to subjects as part of the method. For each pair of polar terms, for instance, each subject is asked to assign a score between 1 and 5. The most appropriate bipolar terms are selected after considering various assessment system viewpoints.

(4) Constant Method

The constant method involves repeatedly presenting the same set of stimuli at random throughout an experiment. The technique can be used to gauge how much each stimulus's slightest system change affects how people perceive it.

(5) Questionnaire Survey

By asking a series of questions, the questionnaire survey method aggregates user opinions. For all subjects, the questions in a subjective evaluation must be pertinent, significant, and simple to understand. Each subject has to answer according to the Table 3.1 scale.

Table 3.1: Five-grade Impairment Scale

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

3.6.2 Objective Assessment

Users' perceptions of the quality of services can be inferred from objective measures by conducting objective assessments concurrently with subjective assessments and examining the relationship between objective and subjective results. Various objective measurement techniques are available depending on the applications.

3.6.3 QoS Mapping

It is possible to define QoS via the Internet in a hierarchical structure, as was mentioned in Subsection 3.4, and the QoS parameters at each level of the hierarchy differ from those at lower levels. QoS mapping is the process of mapping the QoS parameters between the levels. It is possible to shorten the process and lower the cost of subjective evaluation by performing the mapping from lower level QoS parameters to QoE parmeters. In this study, QoS mappings between QoE parameters and application level QoS parameters are carried out. In this study, we employ regression analysis to look into the connection between subjective and objective assessment results [87]. Regression analysis is a popular statistical method for determining how dependent and independent variables in an experiment relate to one another. The independent variable is the experiment's input or cause, and the dependent variable is the result of the effect. Regression analysis allows us to understand the normal value of the dependent variable. It may better comprehend the relationships between the user's mean opinion score and objective metrics in QoE assessment by using regression analysis and making the subjective evaluation results and objective assessment findings, respectively, the dependent variables and independent variables.

3.7 Summary

This chapter presents the haptic interface technology at first. And then, it describes the haptic media and sense. This chapter also describes about virtual environments in networked area. And then, it presents the QoS parameter and the various types of QoS control in detail. Finally, this chapter mentions the number of QoE assessment.

CHAPTER 4
THE PROPOSED SYSTEM ARCHITECTURE

Networked virtual environments with haptic sense have been the subject of research by several researchers. By utilizing haptic sense, the effectiveness of networked haptic games can be significantly increased. In this type of work, it is necessary for multiple users to work together while concurrently viewing the same displayed images in a 3D virtual environment. The time when received the information from different terminals, however, may differ from one another due to network delays, delay jitters, and other factors when the information about the space is transmitted over a Quality of Service (QoS) non-guaranteed network like the Internet. In other words, while the information may have reached to some terminals, others may not have. Because multiple users may be viewing different displayed images simultaneously at the terminals, the efficiency of collaborative work may then significantly decline.

To address the above issues, group synchronization control, local lag control, simultaneous output-timing control, which accounts for delay differences between different terminals, and adaptive Δ-causality control can all be used as QoS controls.

4.1 The Proposed System Design

This research study focuses on QoE assessment and control in multimedia communication especially networked haptic games. So, there are two categories in this study, QoE assessment of human perception and then according to the assessment result, it desires to apply what kind of QoS control to be used. The work as QoE assessment in which we investigate the influence of networked delay and moving velocity in networked balloon bursting game. The author also clarifies the human perception of softness and influence of local lag on softness via networked balloon bursting game. According to the QoE assessment results, the adaptive reaction force control is proposed to keep the force feedback at constant. It is described as a diagram in the following, Figure 4.1;

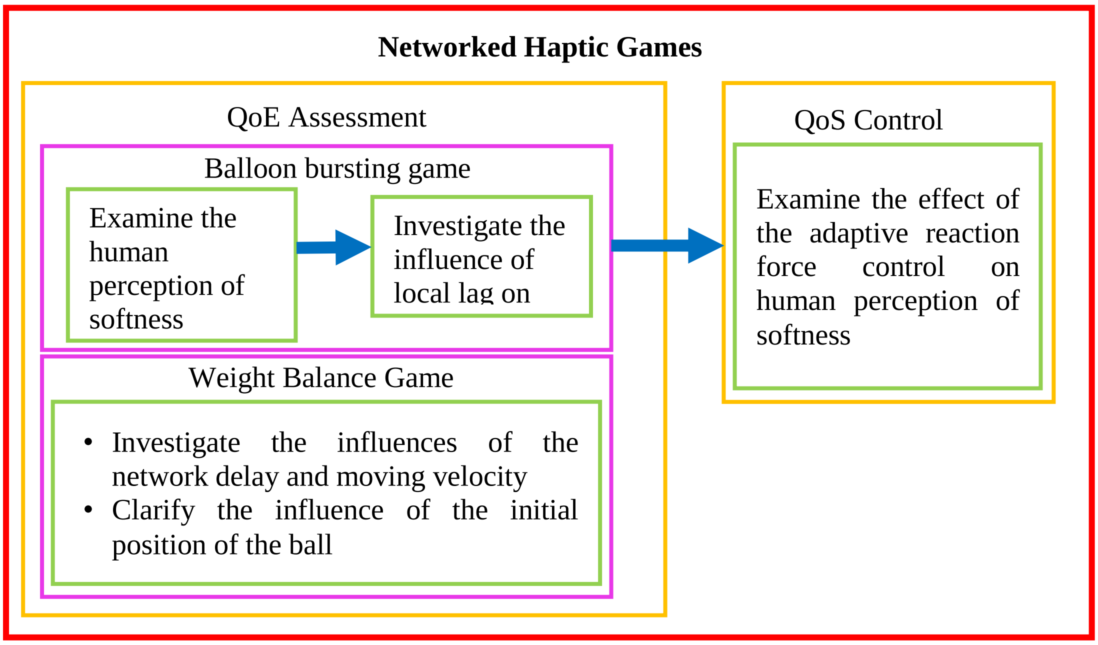


Figure 4.1: Design of Proposed System

4.2 System Architecture

This proposed system totally consists of three PCs. The two terminals each of which has a haptic Interface Device (3D Systems Touch) and connected via 100BASE-TX networked cable, shown in Figure 4.2. The network emulator produces additional delay by applying in Ubuntu with Netem delay in Figure 4.2.

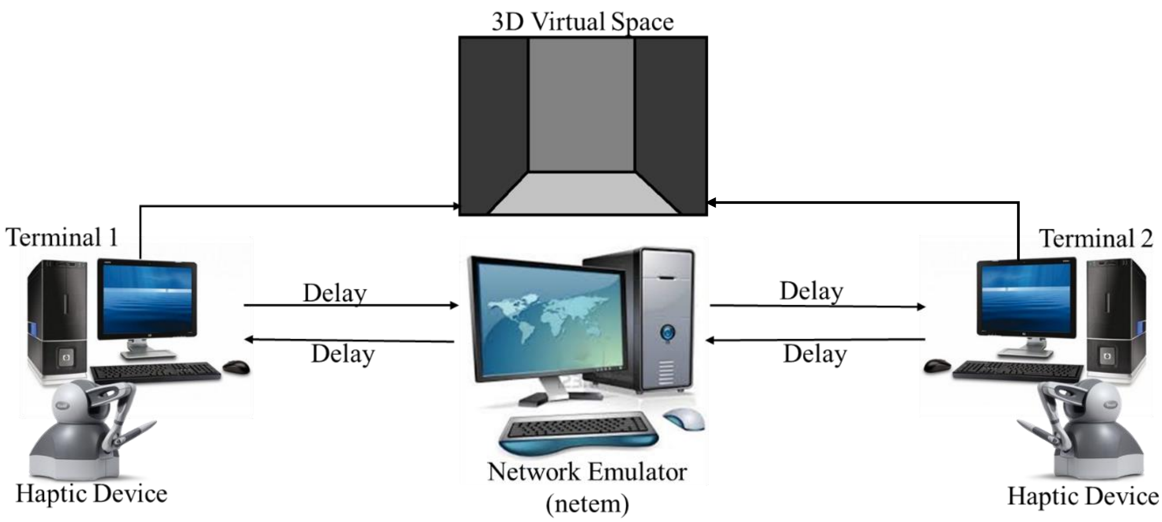


Figure 4.2: Configuration of Proposed System

Traffic for applications is delivered using a routed protocol. In order to allow a packet to be forwarded from one network to another, it provides the necessary addressing information in its network layer or internet layer. A routed protocols include Internet Protocol (IP) and Internetwork Packet Exchange (IPX). The direction of network traffic from a subnet or gateway is determined by a set of rules called routes that are contained in a route table. Data is sent from a router to the next device along the selected path in order to eventually reach its destination. The device and the router may be linked to the same network or different networks. This system employs two distinct networks, as shown in Figure 4.2.

4.3 Adaptive Reaction Force Control

A force feedback of the haptic device is typically estimated from force felt by the force sensor in each remote robot system that uses force feedback (shown in Figure 4.3). The spring-damper model may be used to determine the response force when the master terminal receives position data from the slave terminal. Elasticity and viscosity are part of the response force in the spring-damper concept. The force of elasticity is produced when a rubber or spring is deformed. For instance, the elasticity of a spring when it is pushed or pulled is determined by multiplying the depth of the spring by the elastic spring coefficient as shown in Figure 4.3.

The feedback force delivered to a haptic device grows as the network delay

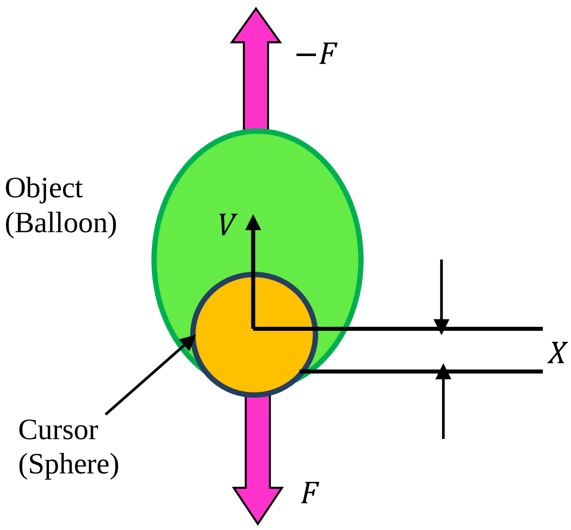


Figure 4.3: Calculation of Reaction Force.

increases, which results in a more substantial decline in the output quality of haptic media. In this study, an adaptive reaction force control is employed to the balloon-bursting game to address this issue. This control depends on the object's level of softness to maintain a consistent reaction force while the networked delay increases.

4.4 Regression Analysis

Regression analysis is a popular statistical tool for the investigation of relationships between dependent variables and independent variables which are used in an experiment. The dependent variable is the output of effect, and the independent variable is the input or cause of the experiment. By the regression analysis as shown in Figure 4.4, we understand how the typical value of the dependent variable changes when any one of the independent variables is varied. In order to clarify the relationship between softness of object and haptic device's force feedback, we use the regression analysis, in this research. According to the graph of regression analysis, it can be seen that the softness of the object is directly proportional to the force feedback and the following equations are gained;

$$\boldsymbol{Y\ (N) = 0.2485 * X + 0.365} \quad \textbf{(4.1)}$$

$$\boldsymbol{X = Y - 0.365/0.2485} \quad \textbf{(4.2)}$$

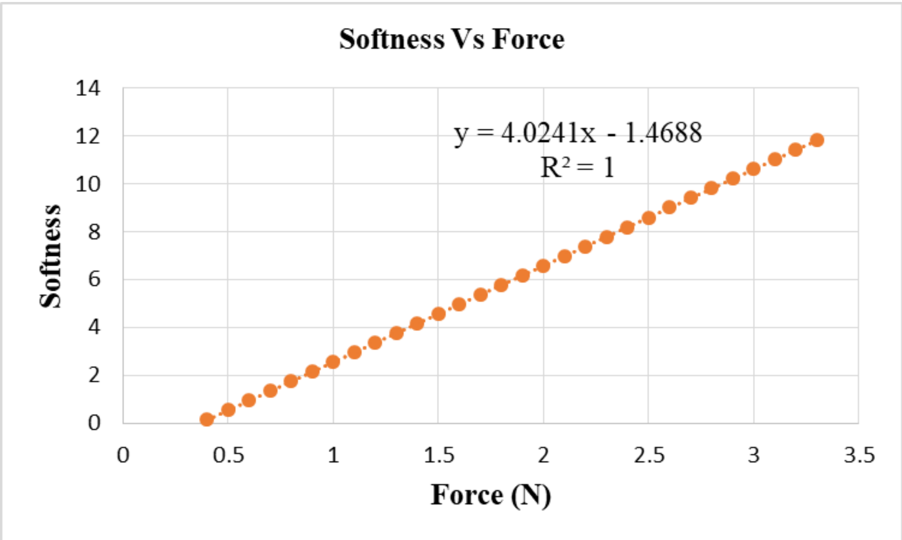


Figure 4.4: Relation between Softness and Force

The haptic rendering engine, which produces the reaction force applied to the haptic interface device, computes the reaction force using the object's shape and material properties like stiffness and friction. The Table 4.1, shows the function which produces the reaction force of haptic interface device. In order to get the reaction force against a player via the haptic interface device, the following function of the Open Haptics HLAPI (Haptic Library Application Programing Interface) are used:

hlGetDoublev (HL_REACTION_FORCE, r_force),

where hlGetDoublev() is a function used for getting the reaction force (HL_REACTION_FORCE) from the haptic rendering engine, and r_force is a user-defined parameter which receives a returned value of HL_REACTION_FORCE. When a player pushes a balloon with a stylus, the parameter from HL_CURRENT_FORCE returns the amount of force that was applied to the balloon. In a preliminary experiment, it is confirmed that the value of HL_CURRENT_FORCE is almost equal to that of HL_REACTION_FORCE; that is, a player feels almost the same reaction force to the force pushed by him/her. When the penetration depth of the stylus becomes larger, the player’s force feedback increases. 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. The volume can be obtained from the haptic rendering engine.

4.5 Summary

Chapter 4 has been described the architecture of networked multimedia communication system by using haptic sense which consists of two terminals and connected by Ethernet cable. For production to the additional delay, in the system we use the Ubuntu terminal.

This study applied two applications which are networked weight balance game and networked haptic balloon bursting game in a 3D virtual environment. The assessment method of the proposed system is discussed in chapter 5.

CHAPTER 5
DESIGN AND IMPLEMENTATION OF THE PROPOSED SYSTEM

This research emphasizes on two application areas for networked communication system with haptic sense. Namely, one is networked weight balance system with haptic sense in virtual space and another one is networked balloon bursting game with haptic sense in virtual environment. It can be dealt with the networked weight balance system with haptic sense, and investigated the influences of the network delay and moving velocity on the work efficiency. Also, the influence of the initial positions of the ball are examined.

The authors also clarified softness via human perception of haptic sense in network balloon bursting game by QoE assessment. In the assessment, two balloons with various values of softness are burst by each subject in a 3D virtual space. And then, each subject gives one answer which balloon is "Harder", "softer" or "same" than the other one. Then, using quality of experience method by haptic sense, we examined how local lag affects and how softness is perceived by people in a networked virtual space. The author used only one terminal for the assessment. By changing the various value of local lag, each participant uses a haptic interface to burst two balloons while indicating which balloon is harder or not. According to these QoE assessment results, the adaptive reaction force control has been proposed to keep the feedback force from haptic device at a stable condition.

5.1 Networked Weight Balance System

The configuration of the networked balance system with haptic sense and a displayed image of the 3D virtual space is shown in Figure 5.1. The system includes two terminals (called PCs 1 and 2 here) each of which has a haptic interface device (3D Systems Touch).

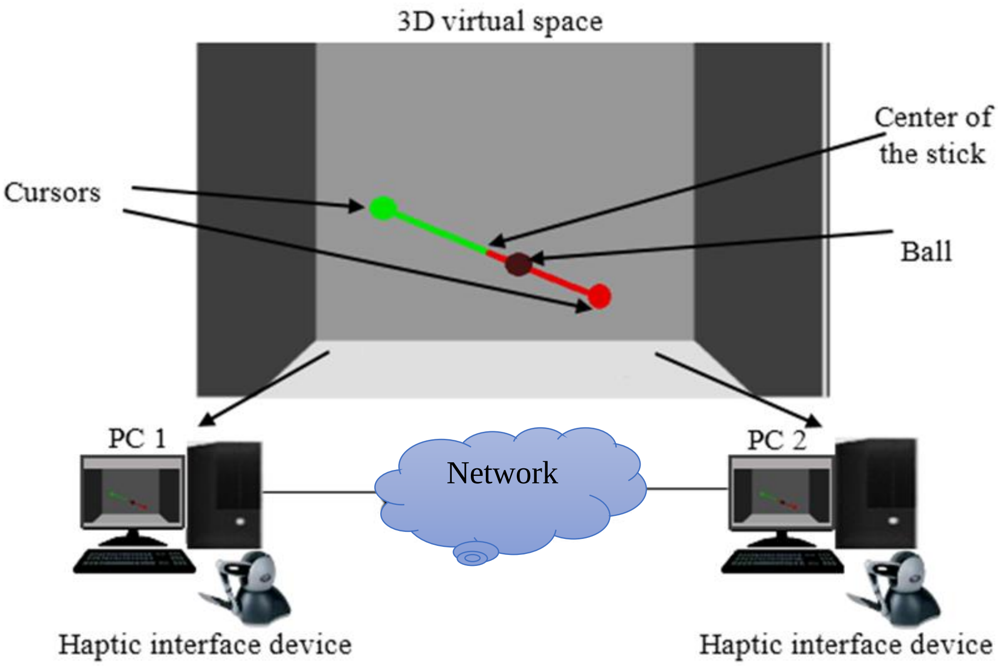


Figure 5.1: Configuration of Networked Balance System with Haptic Sense

By operating the haptic interface device, a user of each PC can move a cursor which denotes the position of the device stylus's tip in the space which is surrounded by a floor, a ceiling, and walls. The two cursors are fixed at two ends of a stick whose weight is 0 gf. The stick can be stretched or shrunk freely between the two ends. A ball whose weight is 270 gf is placed on the stick between the two cursors (i.e., the two ends of the stick).

5.1.1 Calculation Method of Reaction Force

The reaction force applied to a user is proportional to the distance from the user's cursor to the ball (as shown in the 3D virtual space of Figure 5.1, the right side of the center is green cursor, and the left side of the center is red cursor). The author show the calculation method of reaction force in Figure 5.2, where the proportion of the distance from the red cursor to the ball to the distance from the green cursor to the ball is set to k : $(1.0 - k)$. Also, m is the mass of the ball, and g $(9.8\ m/s2)$ is the gravitational acceleration. The reaction force applied to the red cursor's user is $(1.0 - k)\ F$, and that applied to the green cursor's user is $k\ F$. The ball moves towards the lower cursor along the stick if there exist altitude differences between the two cursors. In this study, it is assumed that there is no viscous resistance. The users try to keep the ball at the middle of the stick while lifting up the stick.

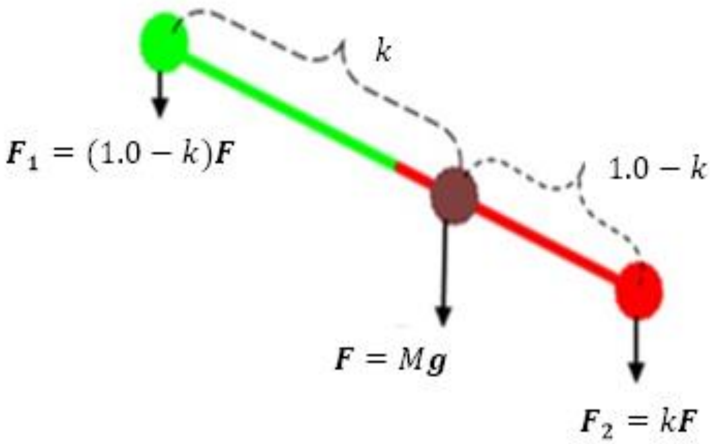
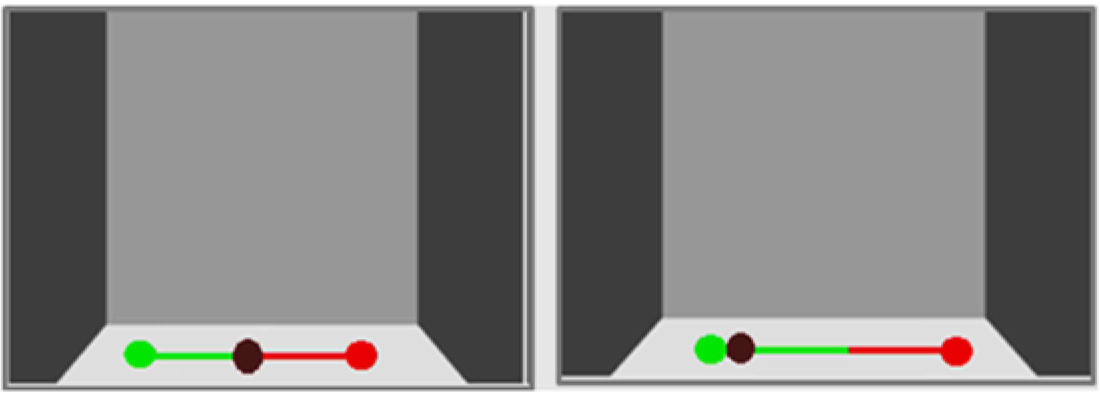


Figure 5.2: Calculation Method of Reaction Force

5.1.2 Influences of Network Delay and Moving Velocity

In this experimented system, a network emulator (netem) is employed instead of the network in Figure 5.1 to generate a constant delay (called the additional delay in this study) for each packet transmitted between the two PCs. In the experiment, two methods (called Method 1 and 2) are handled. In Method 1, the users started to lift up the ball from the initial state in which the weighted ball was placed at the center of the stick, and the two cursors were placed on the floor (as shown in Figure 5.3 (a)). The initial position of the ball in Method 2 is different from that in Method 1; the ball was placed at the far left of the stick (as shown in Figure 5.3 (b)). In both methods, the users were asked to lift the ball up to a height of 16.7 (we assume that the diameter of cursor is 1 in this study) collaboratively while trying to keep the ball at the middle of the stick and to move at a constant velocity (as shown in Figures 5.4 and Fig. 5.5). The movement distance of 16.7 corresponds to 10 cm in the real space when each user raises the stylus of the haptic interface device vertically.

If the ball was not located at the center, each user tried to adjust the place of the ball by moving up his/her cursor or stop moving. Then, the author investigated the influence of the additional delay and moving velocity, and the author also examine whether the optimal velocity exists for each additional delay.



(a) Ball at Centre (Method 1) **(b) Ball at far Left (Method 2)**

Figure 5.3: Displayed Images of Initial State in Experiment

The author carried out the experiment in which the additional delay from PC 1 to PC 2 was set to the same value as that from PC 2 to PC 1, and the additional delay was changed from 0 ms to 150 ms at intervals of 50 ms. The moving velocity was changed from 0.1 to 0.9 at intervals of 0.2 and from 1.0 to 13.0 at intervals of 2.0.

The positions of the ball and operation time were measured in the experiment. We defined the position of the ball as the distance between the ball and the center of the stick. Positions on the right side of the center are denoted by plus values, and those on the left side are done by minus ones. The operation time is defined as a time interval from the moment one user starts to raise the cursor until the instant one user's cursor reaches the maximum height of 16.7.

In this experiment, for both methods, the combinations of the additional delay and moving velocity were selected in random order for each work. The experiment was conducted by two users (female), whose ages were 35, and continued up to ten times.

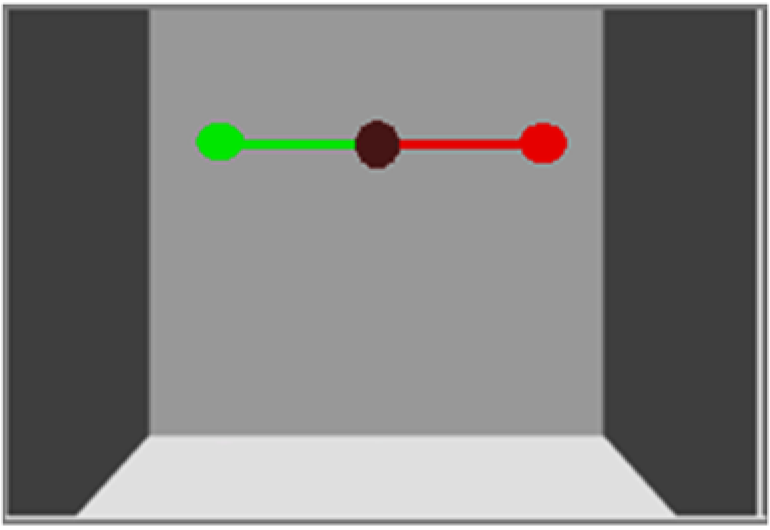


Figure 5.4: Displayed Images of End State in Experiment

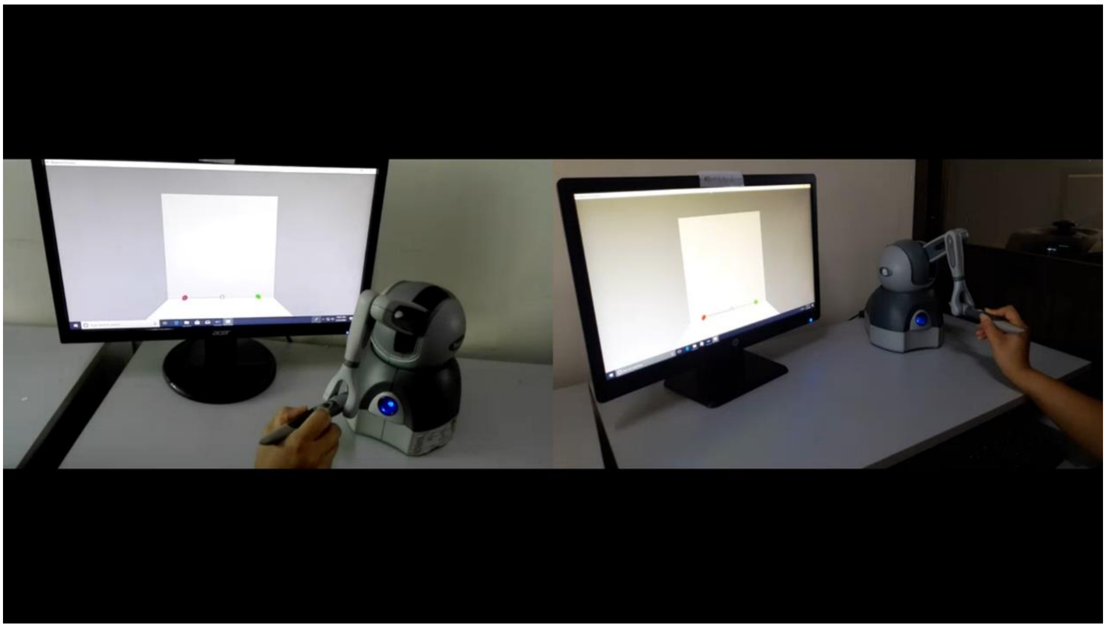


Figure 5.5: Playing the Weight Balance Game

5.2 Networked Haptic Balloon Bursting Game

Each user is able to sense the shape of an object, softness of an object, and weight of an object by using a haptic interface device in a three-dimensional (3D) virtual space. The consistency (e.g., the positions of an object at terminals are the same) among users and the operability of haptic interface devices may significantly deteriorate when such environments are built over a network like the Internet, which does not guarantee QoS. This is because of network delay, delay jitter, and packet loss. This is important because the characteristics of objects may change in different ways; for instance, they get to be harder and/or heavier due to the network delay increases [88]. To avoid these deterioration, the authors have to address the QoS control. For effective QoS control, it is necessary to investigate the characteristics of human perception such as the object's shape, softness, and weight. However, characteristic of human perception has not clarified sufficiently up until now.

This research clarifies human perception of softness in the networked haptic balloon bursting game by QoE assessment. In the assessment, each subject bursts two balloons with different values of softness in a 3D virtual space, and the subject answers which balloon is softer or harder than the other.

5.2.1 Design of the Proposed Methods

Figure 5.6 displays the networked haptic balloon bursting game's system configuration. Each of two players bursts balloons by using his/her stylus of haptic interface device in a 3D virtual space. The two players compete against one another for the most balloons that have burst. Two balloons are used for simplicity in the virtual space, as shown in Figure 5.6, where consists of two terminals (called terminals 1 and 2 here), each of which has a PC with a display, a haptic interface device (3D Systems Touch), and a headset. In the virtual space, each player moves his/her virtual stylus by using haptic interface device. The cursor (i.e., the point of contact with an object) of the haptic interface device is represented by the stylus' tip. The player can sense the softness of the balloon when they push the balloon with the tip of the stylus. Then, they perceived the force feedback through the haptic interface device; he/she can feel the softness of the balloon. When the player pushes the balloon with the stylus, the balloon is damaged. When he/she pushes it strongly, the

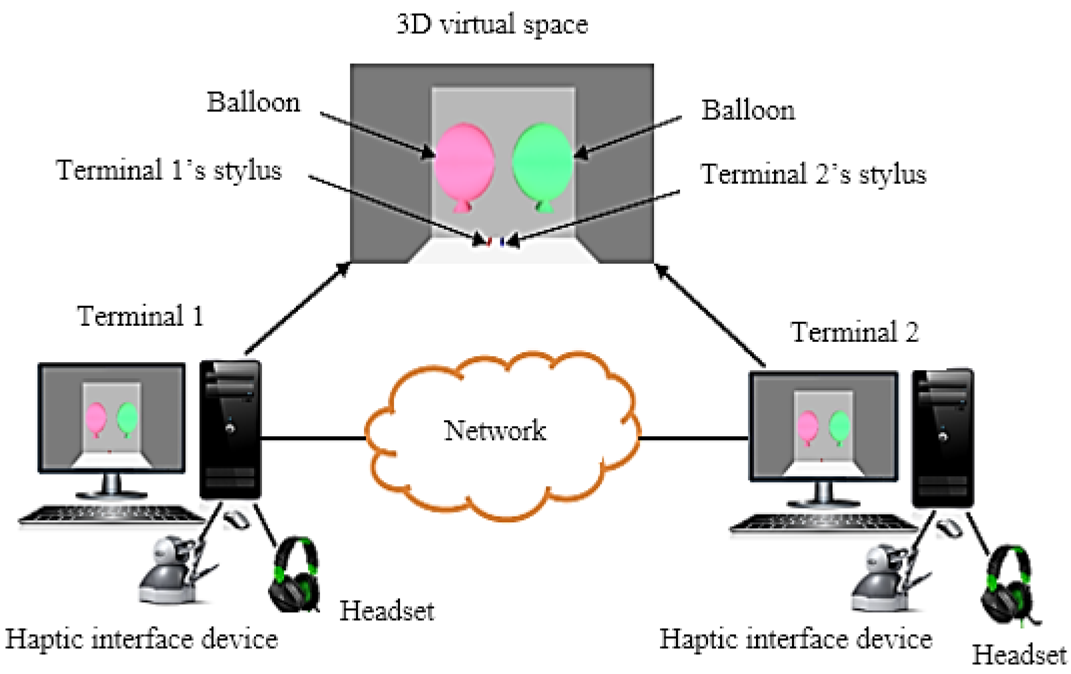


Figure 5.6: Configuration of Networked Haptic Balloon Bursting Game

balloon is largely distorted. If the force worked to the balloon go beyond a threshold value then the balloon is burst and disappeared and then he/she hears a sound of bursting it via the headset. It should be noted that in [21], when the volume of the balloon becomes less than a threshold value, a balloon is burst; this is not real. Therefore, in this study, the author determines when a balloon is burst by force. In the game, the softness of the balloon can be changed, even the number of players, and so on. In this research, the author decided the number of players is set to one as shown in Figure 5.7.

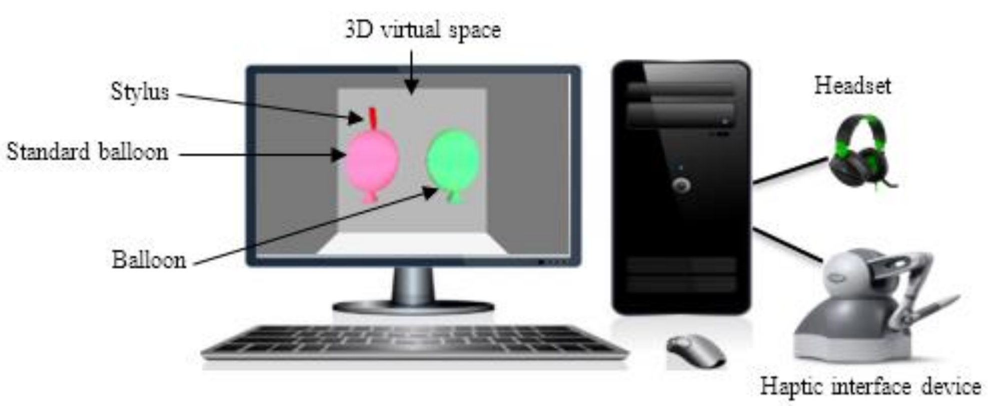


Figure 5.7: Configuration of Assessment System

5.2.2 Calculation of Reaction Force

In [62] described the haptic rendering engine, which uses the object shape and material properties like that stiffness and friction for calculation of the force feedback, which generates the reaction force applied to the haptic interface device. If the player touches the balloon with the stylus, the force applied to a balloon is equal to the reaction force against the player. It takes note that the force is in the opposite direction. As penetration depth of the stylus become large, the user experiences harder pressure [89]. Figure 5.8 shows penetration depth of the stylus which is the distance between its tip and the balloon's surface.

$$\boldsymbol{F_t} = -K_S \, \boldsymbol{p_t} \qquad \textbf{(5.1)}$$

Where $\boldsymbol{Ft}$ denotes the reaction force at time t (> 0), $\boldsymbol{pt}$ i is the penetration vector at time t, and Ks is the elastic coefficient (or spring) of the balloon.

5.2.3 QoE Assessment of Human Perception of Softness

In the assessment, the authors used only one terminal for simplicity as mentioned earlier (as shown in Figure 5.7). In this study, this is because we just investigate the human perception of balloon softness. The authors judged the softness of a balloon by the force when the balloon is burst. The authors set two balloons at the same time in the virtual space; one has constant values of softness (the balloon is

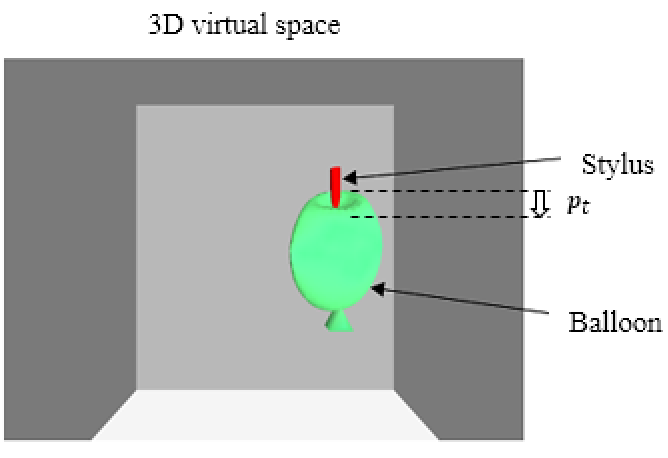


Figure 5.8. Example of Displayed Image of Virtual Space before Green Balloon is Burst

called the standard balloon, and the softness of the standard balloon is referred to as the standard softness in this paper), and the other has various values of softness. The authors prepared the following three different values as the standard softness: 1.2 N, 2.0 N, and 2.8 N (note that the maximum force feedback of the haptic interface device is 3.3 N). In the virtual space of Figure 5.7, the pink balloon on the left hand side has the standard softness, and the green one on the right hand side has other values of softness. QoE assessment was made with 15 subjects (1 male and 14 females) whose ages were up 25 to 35.

Before the assessment time, each subject was practiced for about two minutes how to burst a balloon with the haptic interface device. Firstly, each subject bursts the pink balloon (i.e., the standard balloon) by pushing the tip of the balloon with his/her stylus in the assessment (like that Figure 5.9). After that the subject bursts the green balloon (i.e., the other balloon) which of the value of softness is different or same from/as the pink balloon. Then, by comparing with the standard softness, he/she

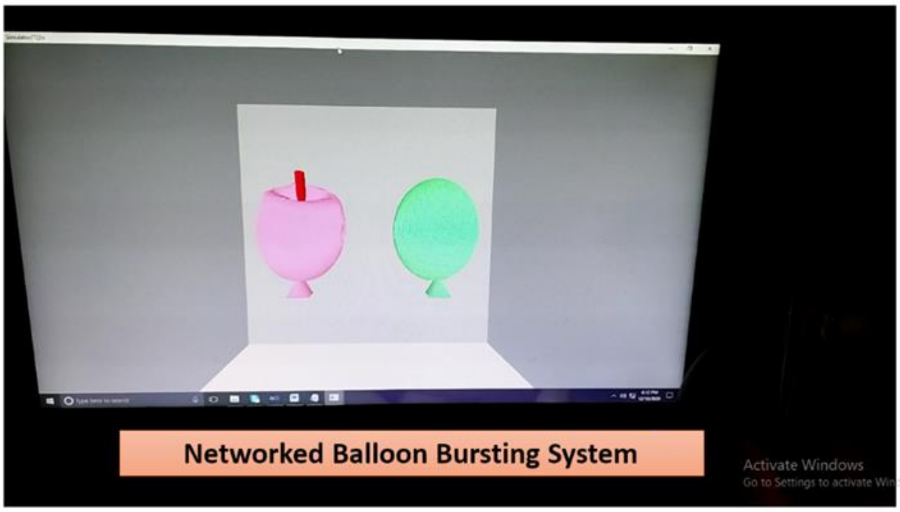


Figure 5.9 Playing the Balloon Bursting Game

selected one answer from among the following three answers: “Softer,” “same,” and “harder”. It takes about one hour for a subject to do the assessment including brake time.

5.3 Influence of Local Lag on Soft Object

The primary cause of this is that the characteristics of objects can change in a variety of ways. For instance, as the network delay increases, they might become harder and/or heavier [89]. In order to prevent the deterioration, it is necessary to implement QoS control like local lag control, dynamic local lag control, adaptive Δ-causality control, which also makes use of local lag control, and adaptive viscoelasticity control. The control, however, may have negative effects. For instance, the local lag control that we discuss in this research, which produces the local lag to achieve a high level of consistency, may make the operability and interactivity; a longer local lag enhances the consistency but degrades the interactivity and operability. In other word, there is a trade-off relationship under the control. Therefore, we should clarify human perception of characteristics such as the softness, weight, and softness of an object for effective QoS control. However, human perception of the features has not examined sufficiently thus far. In this research, the author uses quality of experience (QoE) assessment to examine the impact of local lag on how softness is perceived by human in a networked virtual environment with haptic sense. In the assessment, we employ only one terminal in the networked haptic balloon bursting game although there are two balloons in a 3D virtual space. The softness of one balloon has a standard value and the local lag is set to 0 ms, and the softness of other has a different value and the local lag is set to a certain value. And then, each subject pushes two balloons with the stylus of a haptic interface device and determine which balloon is softer or not.

5.3.1 Local Lag Control

We can use the local lag control to maintain a high level of consistency, which buffers local information at a local terminal for a predetermined period of time called the local lag in accordance with the network delay from the local terminal to the other terminal. As a result, the control reduces operability and interactivity when there is a significant network delay. Because the local lag is based on the network delay, when we apply it to the networked haptic balloon bursting game, it might alter the softness of the balloon in accordance with the network delay. That is, a balloon might be harder because of the local lag. Consequently, in this study, we examine the impact of local lag on how softness is perceived by people. It is crucial to understand the impact of local lag because it is used under several different types of QoS control, including the adaptive Δ-causality control and dynamic local lag control, both of which were previously described. In this research, we get the increased softness from the calculation as shown in Figure 5.10;

Calculation (A)

The answer is "same".

if Local lag = 125 ms, Rate 0%, <= 0.1 N

1.2 N + 0.1 N= 1.3 N

1.3 N – 0.7 N = 0.6 N

Local lag 125 ms increases the softness by 0.6 N.

Calculation (B)

The answer is "softer" or "harder".

if Local lag = 200 ms, Rate 100%, >= 0.4 N

1.2 N + 0.4 N= 1.6 N

1.6 N – 0.7 N = 0.9 N

Local lag 200 ms increases the softness by 0.9 N.

Figure 5.10: Calculation of Increased Softness by Local lag

5.3.2 Assessment Method of Local Lag on Soft Object

In our assessment system, the networked haptic balloon bursting game, we only use one terminal as shown in Figure 5.7. There are two balloons in a 3D virtual space where the softness of one balloon is a standard value (called the standard softness) and the local lag is set to 0 ms, and the softness of other balloon has a different value (called the other softness) and the specific value has been set for the local lag. And then, both of balloons are alternatively burst each subject via a haptic's stylus. After that each subject compare these two balloons and gives the one answer of "Harder", "softer" or "same". For each subject, we randomly ordered the following three different values as the standard softness: 1.2 N, 2.0 N, and 2.8 N (Note: the softness is expressed in force (newton) in this study). The maximum force feedback of the haptic interface device is 3.3 N). We modified the threshold value of force used to determine when the balloon is burst. For each standard softness, we modified the other softness from the standard softness minus 0.5 N to the standard softness at intervals of 0.1 N. For example, from 0.7 N to 1.2 N for the standard softness of 1.2 N. We also modified the local lag from 0 ms to 250 ms at intervals of 25 ms. Additionally, for each standard softness, the author applied combinations of the other softness and local lag in a random order. When there is a delay, only the haptic device moves initially; changes to the virtual space come later.

Before the assessment, each subject uses the haptic interface device to practice how to burst a balloon for around two minutes. In the assessment system, each subject bursts the pink balloon with standard softness and the local lag set to 0 ms, firstly by pushing the top of the balloon with the stylus of the haptic interface device (as shown in Figure 5.3). Next, the subject bursts the green balloon with the different value or the same value of softness from/as the pink balloon and it sets the specific value for local lag. After that, by comparing with the standard softness, he/she selected one answer from among the following three answers: “Softer,” “same,” and “harder”. The assessment was done with 20 subjects (including 19 females and 1 male) whose ages were up 25 to 35. Each subject took around one hour including break time to carry out the assessment.

5.4 The Effect of Adaptive Reaction Force Control on Human Perception of Softness

The control changes the elastic coefficient K_s (or local lag) dynamically according to the network delay; that is, it decreases K_S as the network delay increases. This is because $\boldsymbol{F_t}$ is proportional to K_S and $\boldsymbol{p_t}$ in equation 5.1; if $\boldsymbol{p_t}$ becomes larger, we should decrease softness.

5.4.1 Elastic Coefficient which Absorbs Hardening

To clarify how largely the local lag increases the softness in [91], which shows the hardening with delay, which is here defined as the force increases when the local lag is changed. The hardening with delay are calculated as follows; in the case, the standard softness is 1.2 N, other softness is 0.7 N and local lag is 100 ms; the noticed difference rate is 0%. This means that all the subjects cannot notice any difference between softness. So, the difference softness is +/-0.1 N which is imperceptible for human perception of softness [102]. The standard softness 1.2 N plus or minus 0.1 N is equal to 1.1 N and 1.3 N (1.2 N - 0.1 N = 1.1 N and 1.2 N + 0.1 N= 1.3 N). And then, 1.1N minus other softness 0.7 N and 1.3 N minus other softness 0.7 N is 0.4 N and 0.6 N. Therefore, the local lag 100 ms increases the softness by 0.4 N-0.6 N. As another case, the noticed difference rate is 100% when the standard softness is 1.2 N, the other softness is 0.7 N and local lag is 200 ms; which means that all the subjects noticed the difference between softness. So, the difference softness is greater than or equal to 0.4 N [89]. Therefore, it can be calculated as the standard softness 1.2 N plus 0.4 N is equal to 1.6 N (1.2 N + 0.4 N= 1.6 N) and then 1.6 N minus other softness 0.7 N is equal to 0.9 N (1.6 N – 0.7 N = 0.9 N). So, the local lag 200 ms increases the softness by 0.9 N. According to this calculation (Table 5.1 (a), (b) and (c)) are filled up.

Table 5.1. Elastic Coefficient (Ks') which Absorbs Hardening

(a) Standard softness: 1.2 N

		Local lag (ms)								
		0	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**
Other softness (N)	**0.7**	1.3	1.0	-	-	-	-	-	-	-
	1.0	2.6	2.2	1.9	1.5	1.1	-	-	-	-
	1.2	3.4	3.0	2.6	2.3	1.9	1.6	1.2	-	-

(b) Standard softness: 2.0 N

		Local lag (ms)								
		0	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**
Other softness (N)	**1.5**	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6
	1.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
	2.0	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6

(c) Standard softness: 2.8 N

		Local lag (ms)								
		0	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**
Other softness (N)	**2.3**	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
	2.6	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	2.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8

5.4.2 Assessment Method of Adaptive Reaction Force Control

It is an important issue that how largely the local lag changes the human perception of softness under the local lag control for the game. This is because, when the local lag increases, the balloon becomes harder.

To solve the above problem, it is necessary to carry out QoS control such as prediction control and the adaptive reaction force control [92] to improve the human perception of softness. In this research, the author deal with the adaptive reaction force control. Under the adaptive reaction force control, the author change the elastic (or spring) coefficient depending on the local lag for the networked haptic balloon bursting game. This means that if the elastic coefficient is decreased as the local lag becomes larger, the control can keep the reaction force constant. The author examines the effect of the adaptive reaction force control on human perception of softness with haptic sense by QoE assessment.

The networked haptic balloon bursting game has two balloons in a 3D virtual space. One balloon has the standard softness and the local lag is set to 0 ms, the other has different softness and the local lag is set to other value. In our assessment, we used just one terminal for the game. The author made a comparison between "with" reaction force control and "without" reaction force control. In "without" reaction force control, each subject burst both balloons alternatively by using a stylus of the haptic interface device and answered which balloon is harder or softer. The author presented the following three different values as the standard softness in random order for each subject: 1.2 N, 2.0 N, and 2.8 N (note that the softness is expressed in force (newton) in this paper, and the maximum reaction force of the haptic interface device is 3.3 N); we changed the threshold value of force which is used for judgment of bursting. For each standard softness, the author changed the other softness from the standard softness minus 0.5 N to the standard softness at intervals of 0.1 N; for example, from 0.7 N to 1.2 N for the standard softness of 1.2 N. The author also changed the local lag from 0 ms to 200 ms at intervals of 25 ms. The author presented combinations of the other softness and local lag in random order for each standard softness. When there is a delay, only the haptic device moves first and the changes in the virtual space occur later.

In the case "with" reaction force control, the author also use three different values as standard softness in random order for each subject: 1.2 N, 2.0 N, and 2,8 N; the author uses the various different values of reaction force control according to the local lag. For each standard softness, the author uses the different other softness which is smaller than the standard softness. For example, if the standard softness is 1.2 N, the author used different other softness (0.7 N, 1.0 N and 1.2 N). Furthermore, the author changed the local lag from 0 ms to 200 ms at intervals of 25 ms. The order of combinations is randomly for each subject.

Before the assessment, each subject practiced how to burst a balloon by using the haptic interface device for about two minutes. In the "without" reaction force control assessment, each subject firstly burst the pink balloon which has the standard softness and the local lag of 0 ms by pushing the top of the balloon with the stylus. Next, the subject burst the green balloon which has a different value or the same value of softness from/as the pink balloon and the local lag of certain value. Then, he/she selected one from among the following three answers: "Softer," "same," and "harder" compared with the pink balloon in terms of softness when the balloons were burst. In the "with" reaction force control assessment, each subject bursts the pink balloon which is the same condition as that of the above method and then he/she bursts the green balloon which use the adaptive reaction force control to keep the softness at stable. We carried out the assessment with 15 subjects whose ages were up 18 to 38. The total assessment times including break times was about 3 hour per subject.

5.5 Summary

This chapter has mentioned the assessment methods that are the influences of the network delay and moving velocity on the work efficiency by using haptic sense in networked weight balance system. And then the influence of the initial position of the ball is dealt with.

In networked balloon bursting game, the human perception of softness with haptic sense by QoE assessment are examined. In the assessment, each subject bursts two balloons with different values of softness by using stylus in a 3D virtual space, and the he/she answers which balloon is softer or harder than the other.

After that, the assessment method which human perception of softness how effect of local lag are clarified by using haptic interface device with QoE assessment in a networked virtual space. Only one terminal is used in this assessment and there are two balloons in a 3D virtual space where the softness of one balloon is a standard value and the local lag is set to 0 ms, and the softness of other balloon is a different value and the specific value has been set for the local lag. Then, each subject bursts two balloons with a stylus of a haptic interface device and determine whether the balloon is softer or not.

The assessment results of the proposed system are discussed in chapter 6.

CHAPTER 6
EVALUATION OF EXPERIMENTAL RESULTS

This research emphasizes on two application areas with haptic sense and they are as follow:

i) Networked weight balance system by haptic sense

ii) Networked balloon bursting game by haptic sense

Firstly, in the networked weight balance system, by doing experiment, the author investigates the effects of network delay and moving velocity on virtual cooperative work with haptic sense. Each of two users controls a haptic interface device in the work, and the two users lift up a stick together in a 3D virtual space. The stick has a weighted ball, and the ball moves to the lower end of the stick when one end of the stick is lower than the other. While raising the stick up, they try to hold the ball at the center of the stick.

In networked balloon bursting game, the author investigates human perception of softness in a networked haptic virtual space using Quality of Experience (QoE) assessment. In our assessment, each subject bursts two balloons with different values of softness as soft objects by pushing the top of each balloon with a haptic interface device in a 3D virtual space. Then, the subject compares these two balloons and answers which balloon is softer or harder than the other.

The influence of local lag on human perception of softness are also examined by QoE assessment with haptic sense in a networked virtual space. Only one terminal are employed to do this assessment in networked balloon bursting game. The local lag control can save the game state consistent across several terminals by setting the local lag to the network delay. There are two balloons in a 3D virtual space. The purpose of the assessment is to examine how largely the local lag changes the human perception of softness because the local lag may make the softness harder. The two balloons are burst by each subject with the tip of the stylus of the haptic device, and they give the answer of “Harder”, “softer”, or “same” as to balloon.

6.1 Results Discussion

The ball can be kept moving around in the center according to experimental results when the network delay decreases. It is also demonstrated that the optimal moving velocity of the ball depends on the network delay.

By measuring the quality of the experience (QoE), the author investigates how softness is perceived by people in a networked haptic virtual environment. The difference between the imperceptible range and the permissible range of softness is made clear by the assessment results.

The author illustrates that the human perception of softness is affected by local lag. For instance, when the local lag is larger than or equal to around 100 ms, the softness of 1.2 N increases by at least about 0.2 N.

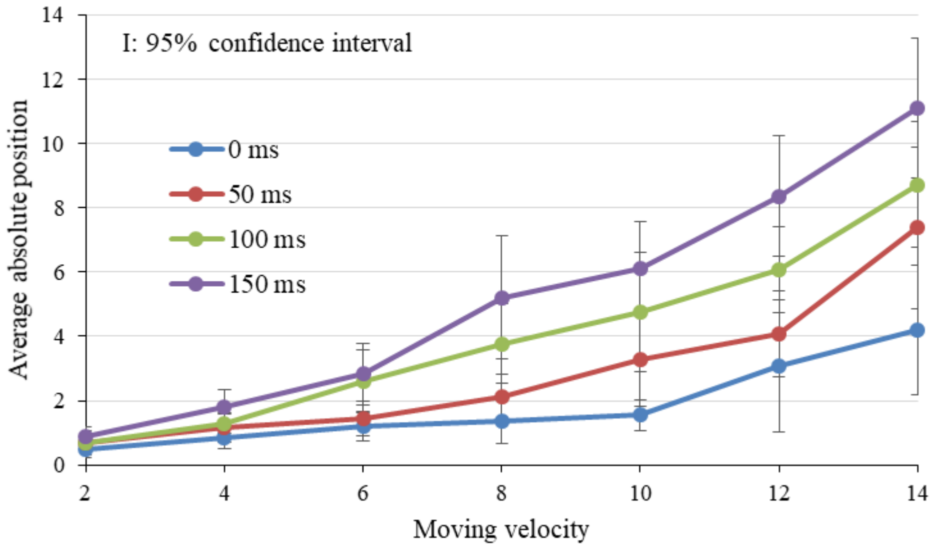
6.2 Influences of Network Delay and Moving Velocity in Networked Weight Balance System

The author shows the average of average absolute position (i.e., the mean of 10-times average absolute position) versus the moving velocity at PC 1 and PC 2 in Figures 6.1 (a) and (b), respectively, for Method 1. Figure 6.2 shows the average operation time versus the additional delay for Method 1. Figures 6.3 (a) and (b) plot the average of average absolute position versus the moving velocity at PCs 1 and 2, respectively, for Method 2. Figure 6.4 shows the average operation time versus the additional delay for Method 2. In Figure 6.1, we see that in Method 1, as the additional delay and moving velocity increase, the average of average absolute position becomes larger. This means that when the moving velocity is faster than around 10, it is difficult to hold the ball at the middle of the stick. It is also noticed in the figure that the average of average absolute position is smaller than about 2 for the velocity less than around 4; the ball was almost always kept in the center, in this case. It can further be observed that the results of PC 1 are somewhat different from those of PC 2. The positions at PCs 1 and 2 can be adjusted by performing simultaneous output-timing control; this is our further study.

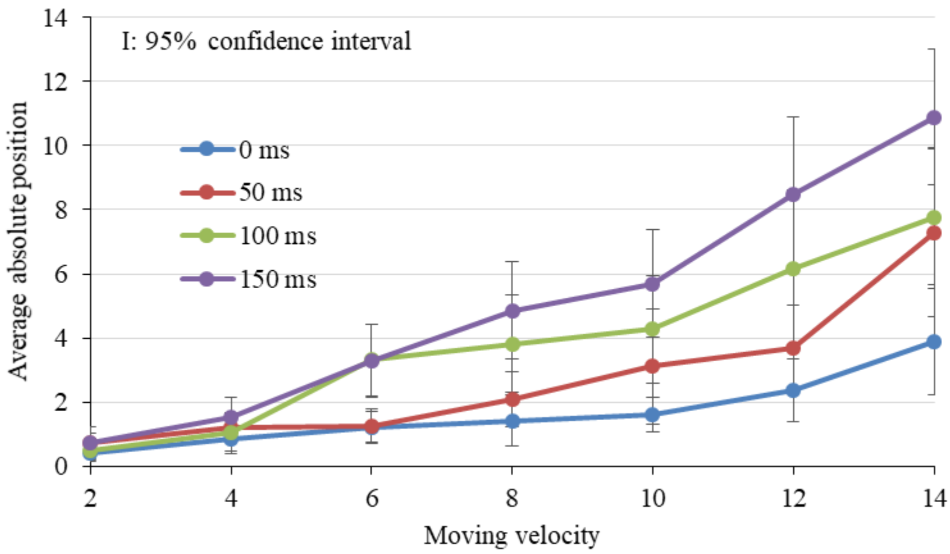
From Figure 6.2, it can be found that the average operation time increases as the moving velocity and additional delay become larger. Therefore, the users tried to adjust the ball many times when the moving velocity and additional delay were large.

From Figure 6.3, it can be noticed that there exists the optimal moving velocity for each additional delay in Method 2. It should be noted that the optimal moving velocity has the smallest average of average absolute position. Thus, the users can more easily adjust the ball at the middle of the stick at the optimal velocity. This is because when the moving velocity is too small, it takes a long time to move the ball to the center, and when the moving velocity is too large, to control the ball at the middle of the stick is very hard. It should be noted that smaller values of the moving velocity are better in Method 1. Furthermore, the author confirms in Figure 6.3 that the results of PC 1 are largely different from those of PC 2 when the moving velocity is larger than about 3.0.

Figure 6.4 reveals that the average operation time becomes shorter as the moving velocity increases. The ball can easily be kept at the center by lifting the cursors up timely when the initial position of the ball is far left; that is, the user at PC 1 lifts the cursor at first, and then the user at PC 2 lifts the cursor while watching the ball so that the ball can stops at the center. Therefore, the influence of the initial position of the ball on the operation time is large.



(a) PC 1



(b) PC 2

Figure 6.1: Average Absolute Position versus Moving Velocity in Method 1

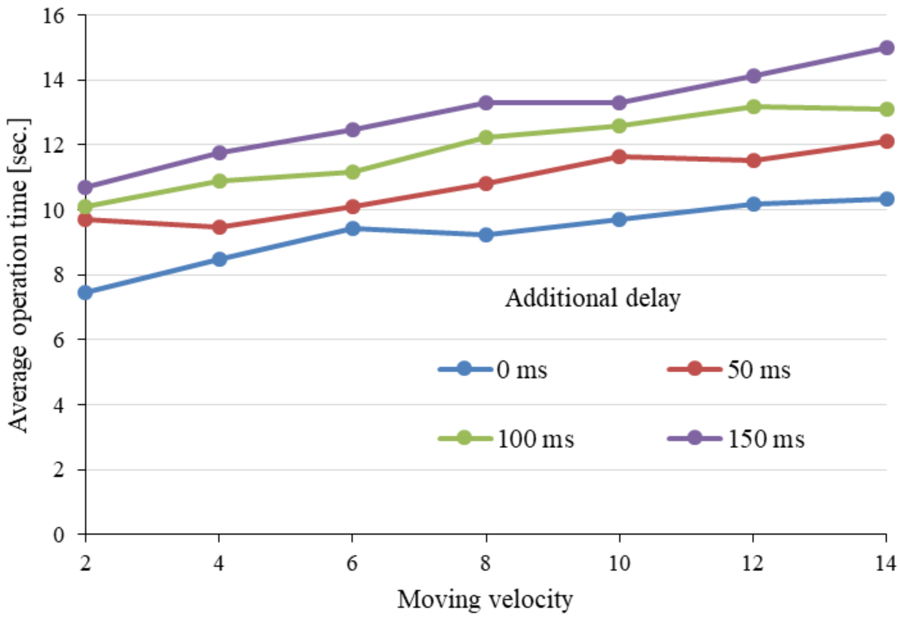
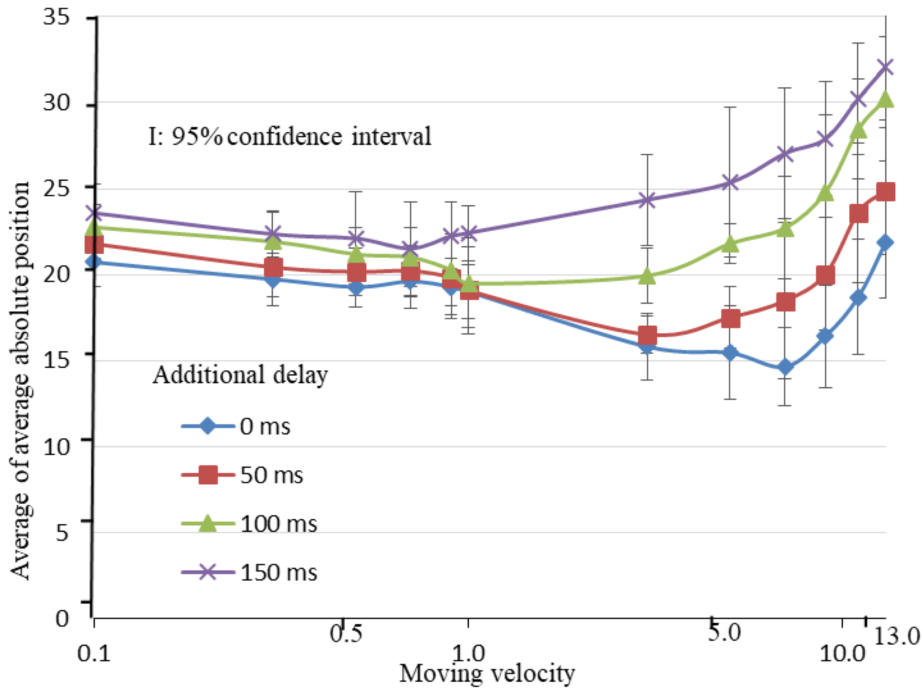
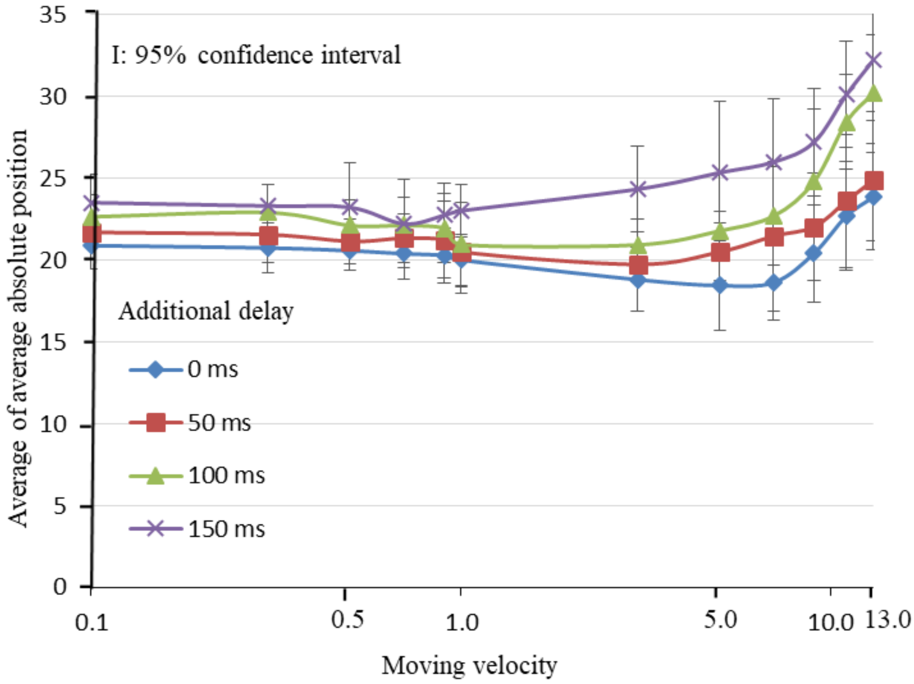


Figure 6.2: Average Operation Time versus Moving Velocity in Method 1



(a) PC 1



(b) PC 2

Figure 6.3: Average Absolute Position versus Moving Velocity in Method 2

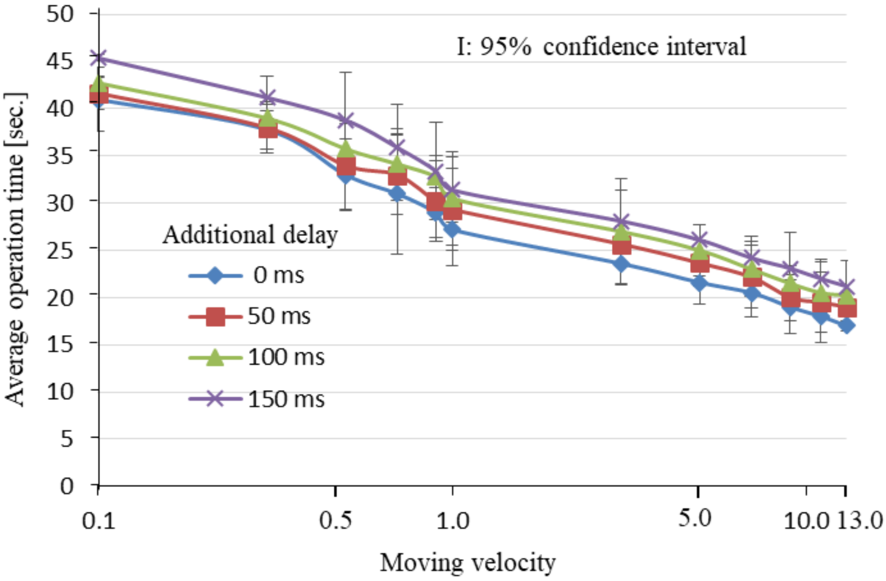


Figure 6.4: Average Operation Time versus Moving Velocity in Method 2

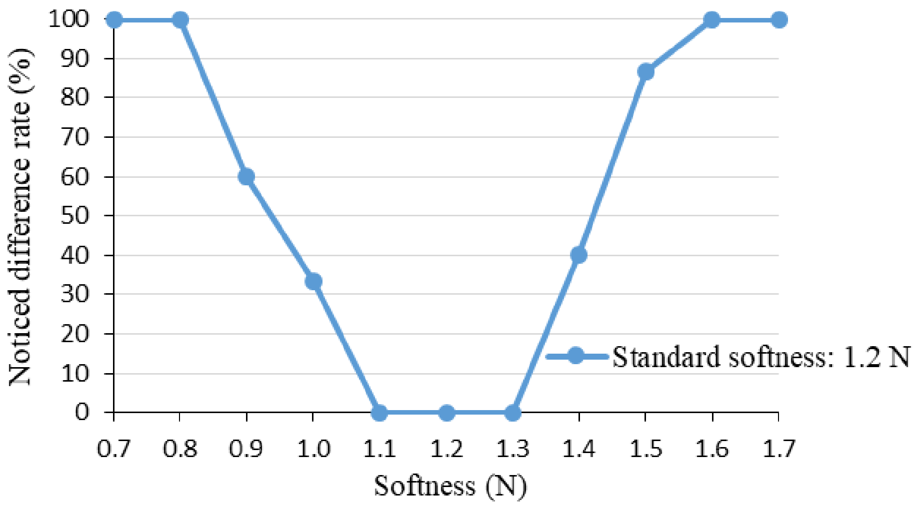
6.3 QoE Assessment of Human Perception of Softness

Figures 6.5 and 6.6 show the noticeable difference rates and correct answer rates versus softness for the three standard softness values (1.2 N, 2.0 N, and 2.8 N), respectively. The ratio of the number of answers in which there is a difference between the standard softness of the pink balloon and the other softness of the green balloon to the total number of answers is known as the rate of noticed difference. The correct answer rate is calculated by dividing the number of correct answers by the total number of answers.

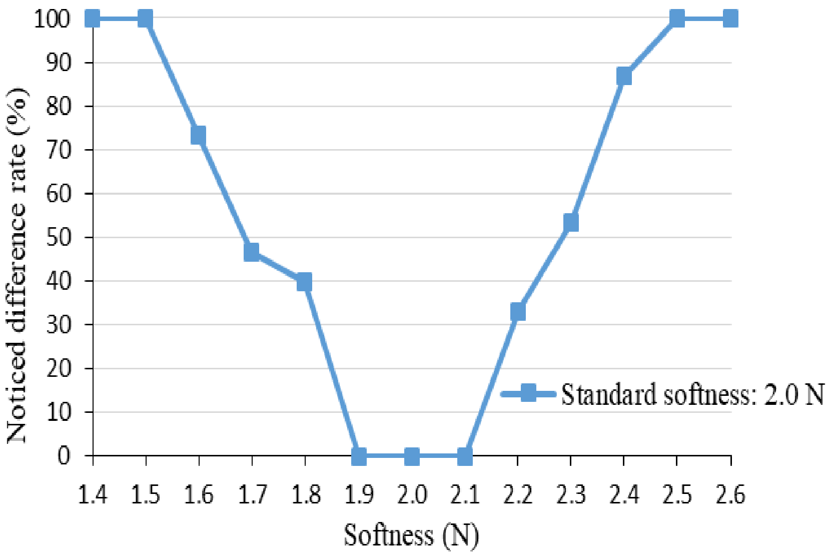
According to Figures 6.5 and 6.6, it can be seen that the noticeable difference rate and the correct answer rate tend to increase as the absolute difference between the values of the standard softness and other softness become exceeds about 0.1 N. Fig. 6.5 shows that when the standard softness and other softness are exactly the same, the noticed difference rate is 0%, and the correct answer rate is 100%; in Figure 6.6. This indicates that all of the subjects responded with "same." In the figures, it can also be seen that when the absolute difference of softness is close to 0.1 N, the noticed difference rate and the correct answer rate are both less than 10%, implying that it is nearly impossible to perceive softness.

Furthermore, from Figure 6.5, the authors can determine the difference in softness which are the imperceptible ranges and the allowable range. Assume that the imperceptible range is one with a noticed difference rate of less than 20% as in, the range of the absolute difference in softness is around 0.1 N. If the allowable range is assumed to be a range with a noticed difference rate greater than or equal to 60% (the value of 60% is merely an example), the difference range is approximately -0.2 N to +0.2 N.

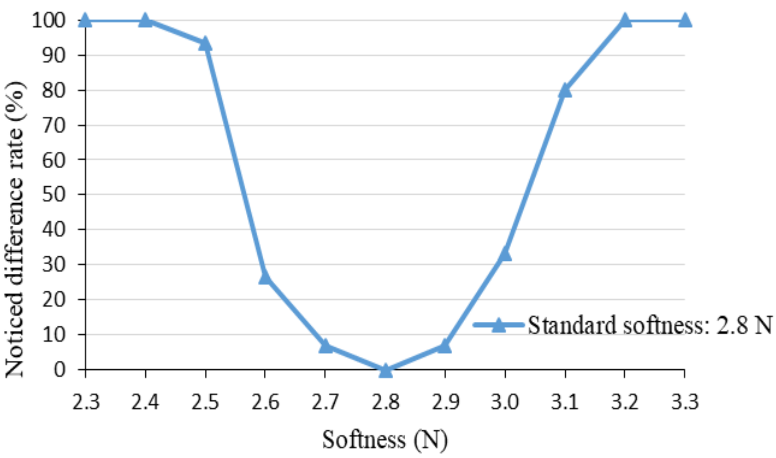
Furthermore, the noticeable difference rate and the correct answer rate in the diagram which are nearly symmetric with respect to a vertical line at the standard softness in Figures 6.5 and 6.6. To examine whether there are significant differences between the values is smaller and larger than the standard softness, we conducted t-test for the noticed difference rate and the correct answer rate in Figures 6.5 and 6.6. As a result, no significant difference was confirmed. Also, it can be concluded that the shapes are nearly line symmetric.



(a) Standard softness: 1.2 N

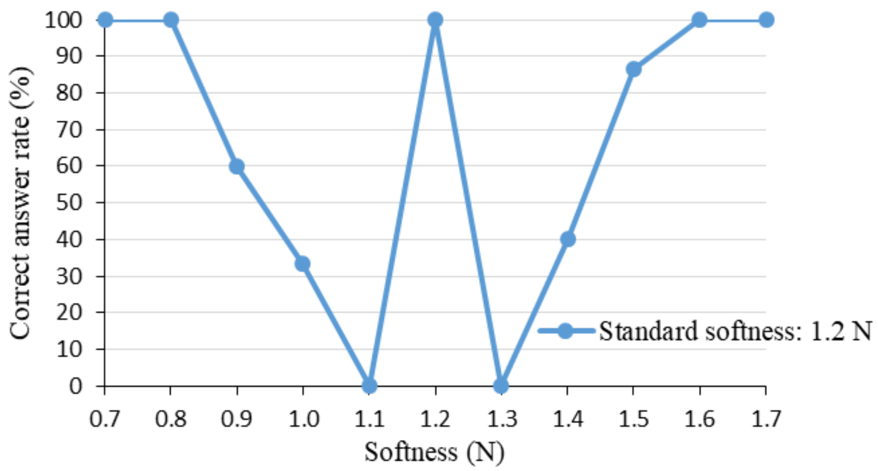


(b) Standard softness: 2.0 N

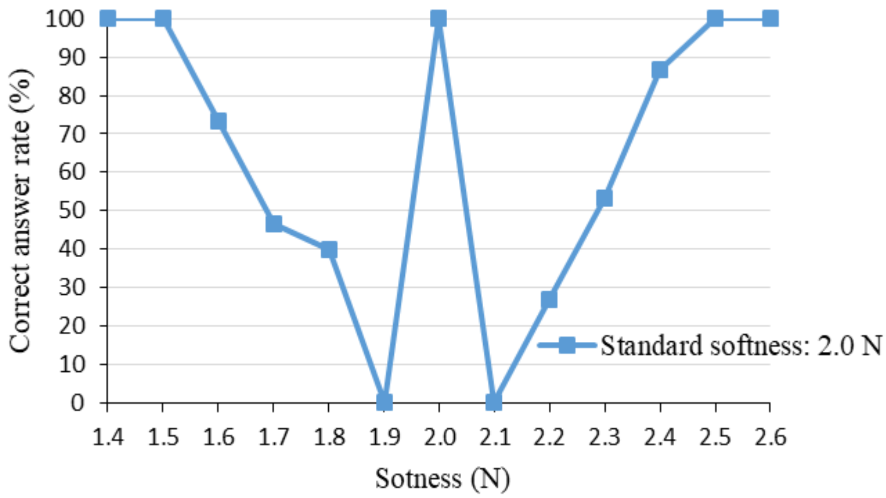


(c) Standard softness: 2.8 N

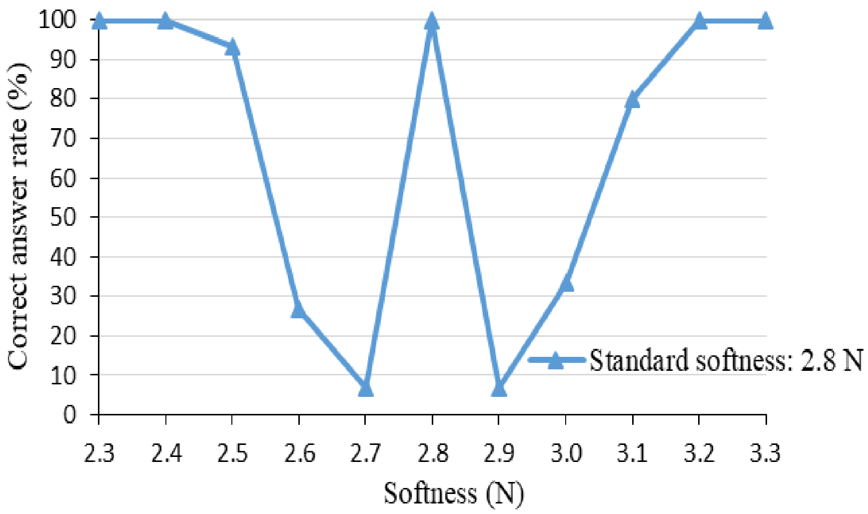
Figure 6.5. Noticed Difference Rate versus Softness



(a) Standard softness: 1.2 N



(b) Standard softness: 2.0 N



(c) Standard softness: 2.8 N

Figure 6.6. Correct Answer Rate versus Softness

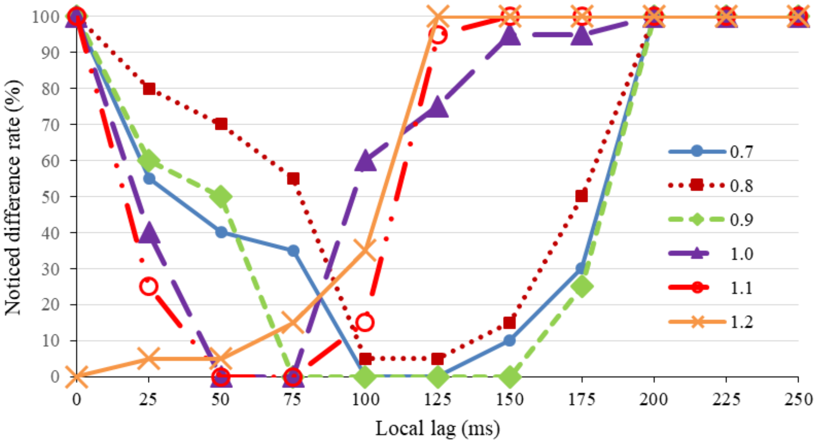
6.4 Influence of Local Lag on Softness

Figure 6.9 illustrates the noticeable difference rates versus the local lag for three standard softness values (1.2 N, 2.0 N, and 2.8 N). The ratio of the number of answers where there is a difference between the standard softness (the pink balloon with a local lag of 0 ms) and the other softness (the green balloon with a local lag of a specific value) to the total number of answers is known as the noticed difference rate. When all subjects answered "same", indicates the noticed difference rate of 0% in the figure. Additionally, the noticed difference rate on the left hand side of the noticed difference rate of 0% displays the ratio of the number of answers that the other softness is softer than the standard softness to the number of total answers. While on the right hand side the rate represents the ratio of the number of answers that the other softness is harder.

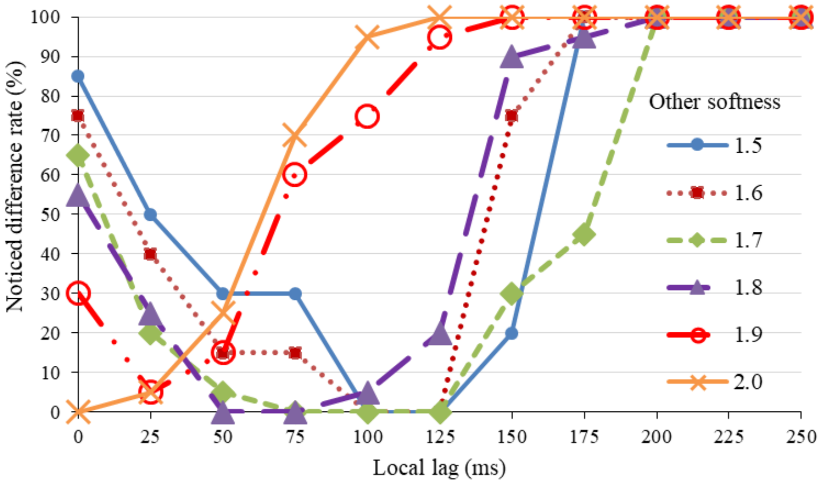
According to Figure 6.9, it can be found that all subjects are unable to detect any difference if the difference values between the standard softness and other softness are zero and the local lag is 0 ms while the noticed difference rate is 0%. Additionally, it can be observed that if the other softness is the same as the standard softness then the noticed difference rate becomes larger as the local lag rises up to approximately 125 ms. When the standard softness is not equal to the other softness, the noticeable difference rate first decreases down to almost zero and then increases as the local lag becomes larger. Moreover, we see that as the other softness increases, the noticeable difference rate tends to start being large at a smaller local lag; the rate has a tendency to reach 100% earlier. These factors lead us to the conclusion that the balloon harder because of the local lag.

To demonstrate significantly the softness increases by the local lag, in Table 6.1, the authors illustrate the hardening with delay, which is express here as the force that increase when the local lag is modified. The hardening with delay was calculated as follows; people can hardly notice absolute difference in softness when the other softness is nearly as the standard softness; according to [89]. When the absolute differences larger than or equal to about 0.1 N, most of subjects start to notice. If the other softness is larger than the standard softness by around 0.4 N then the most of subjects can notice the difference of softness. It can be noticed that in Figure 6.9 (a), for instance, when the other softness is 0.7 N and the local lag is between about 100 ms and 125 ms while the noticed difference rate is 0%; then, the softness perception should be between about 1.1 N and 1.3 N (= the standard softness (1.2 N) ± 0.1 N). This means that the increased softness is about 0.4 (= 1.1 N – 0.7 N) to 0.6 (= 1.3 N – 0.7 N). Similarly, Table 1 can be filled out the yellow range where the noticed difference rate is 0%. On the other hand, in Figure 6.9 (a), the authors find that for example, when the other softness is 0.7 N and the local lag is larger than or equal to about 200 ms, the noticed difference rate is 100%; then, the perceived softness is larger than about 1.6 N (= the standard softness (1.2 N) + 0.4 N); this indicates that the increased softness is larger than or equal to about 0.9 N (= 1.6 N – 0.7 N). Similarly, we can fill out the pink range, in which the noticed difference rate is 100%, in Table 6.1. The increased softness of the other (white) range on the left hand side of the yellow range in Table 6.1 is smaller than that of the yellow range, and that of the white range on the right hand side is larger than around that of the yellow range and smaller than approximately that of the pink range. For visibility, the authors do not write the increased softness in the white range.

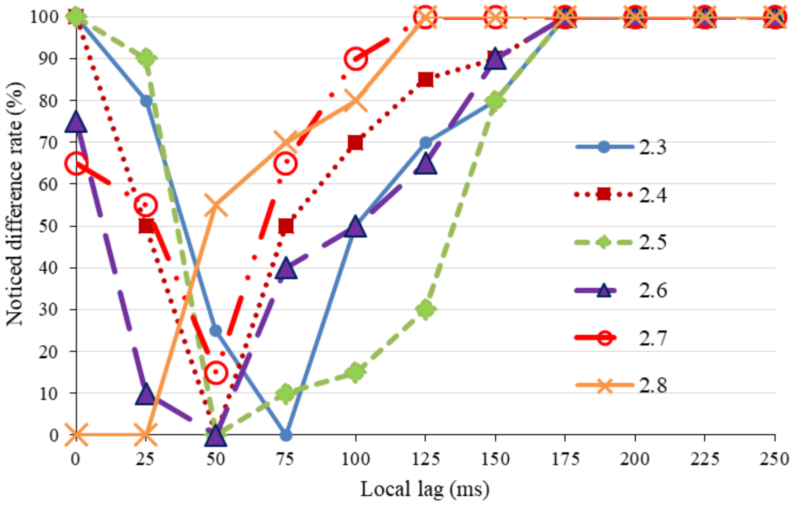
As the other softness increases, the pink range in of Tables 6.1 (a), (b), and (c), respectively, tends to get wider; the local lag in this range increases the softness by at least 0.4 N. The yellow range also tends to move to the left. This indicates that as humans can feel the difference in softness by the local lag more easily the difference becomes smaller. From Tables 6.1 (a), (b), and (c), it can be observed that the pink range gets wider as the standard softness increases. As well as, the yellow range tends to gets narrower as the standard softness become larger; the range has a tendency to move to the left. This shows that the local lag more easily as the standard softness become larger and then humans perceive the difference in softness.



(a) Standard softness 1.2 N



(b) Standard softness 2.0 N.



(c) Standard softness 2.8 N.

Figure 6.7. Noticed Difference Rate versus Local Lag

Table 6.1: Increased Softness (N) for Each other Softness.

(a) Standard softness: 1.2 N

		Local lag (ms)										
		0	25	50	75	100	125	150	175	200	225	250
Other softness (N)	0.7					0.4-0.6	0.4-0.6			≥0.9	≥0.9	≥0.9
	0.8					0.3-0.5	0.3-0.5			≥0.8	≥0.8	≥0.8
	0.9				0.2-0.4	0.2-0.4	0.2-0.4	0.2-0.4		≥0.7	≥0.7	≥0.7
	1.0			0.1- 0.3	0.1-0.3					≥0.6	≥0.6	≥0.6
	1.1			0-0.2	0-0.2			≥0.5	≥0.5	≥0.5	≥0.5	≥0.5
	1.2	-0.1-0.1					≥0.4	≥0.4	≥0.4	≥0.4	≥0.4	≥0.4

(b) Standard softness: 2.0 N

		Local lag (ms)										
		0	25	50	75	100	125	150	175	200	225	250
Other softness (N)	1.5					0.4-0.6	0.4-0.6		≥1.0	≥1.0	≥1.0	≥1.0
	1.6					0.3-0.5	0.3-0.5		≥0.9	≥0.9	≥0.9	≥0.9
	1.7				0.2-0.4	0.2-0.4	0.2-0.4			≥0.8	≥0.8	≥0.8
	1.8			0.1- 0.3	0.1-0.3					≥0.7	≥0.7	≥0.7
	1.9		0-0.2					≥0.6	≥0.6	≥0.6	≥0.6	≥0.6
	2.0	–0.1-0.1					≥0.5	≥0.5	≥0.5	≥0.5	≥0.5	≥0.5

(c) Standard softness: 2.8 N

		Local lag (ms)										
		0	25	50	75	100	125	150	175	200	225	250
Other softness (N)	2.3				0.5				≥0.9	≥0.9	≥0.9	≥0.9
	2.4			0.4					≥0.8	≥0.8	≥0.8	≥0.8
	2.5			0.3					≥0.7	≥0.7	≥0.7	≥0.7
	2.6			0.2					≥0.6	≥0.6	≥0.6	≥0.6
	2.7			0.1			≥0.5	≥0.5	≥0.5	≥0.5	≥0.5	≥0.5
	2.8	0	0				≥0.4	≥0.4	≥0.4	≥0.4	≥0.4	≥0.4

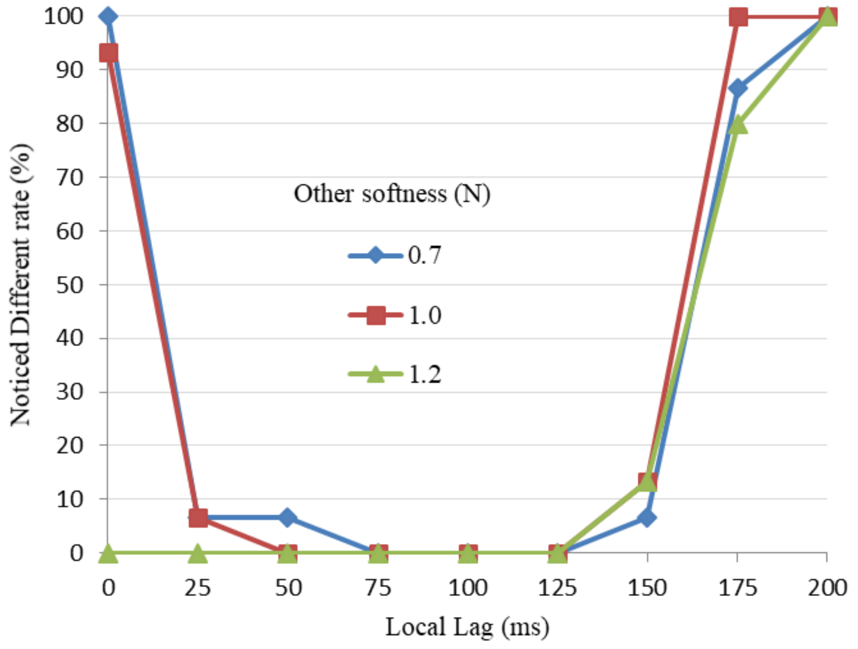
6.5 Effect of Adaptive Reaction Force Control on Human Perception

The noticeable difference rates versus the local lag for the three values of the standard softness (1.2 N, 2.0 N, and 2.8 N) are shown in Figures 3, 4 and 5. The noticeable difference rate is here defined as the ratio of the number of answers that there exists a difference between the standard softness (the pink balloon with the local lag of 0 ms) and the other softness (the green balloon with the various value of local lag) to the number of all the answers. In the figure, the noticed difference rate of 0% means that all the subjects answered "same." Also, the noticed difference rate for local lags on the left hand side of the noticed difference rate of 0% shows the ratio of the number of answers that the other softness is softer than the standard softness to the number of all the answers; on the right hand side, the rate represents the ratio of the number of answers that the other softness is harder.

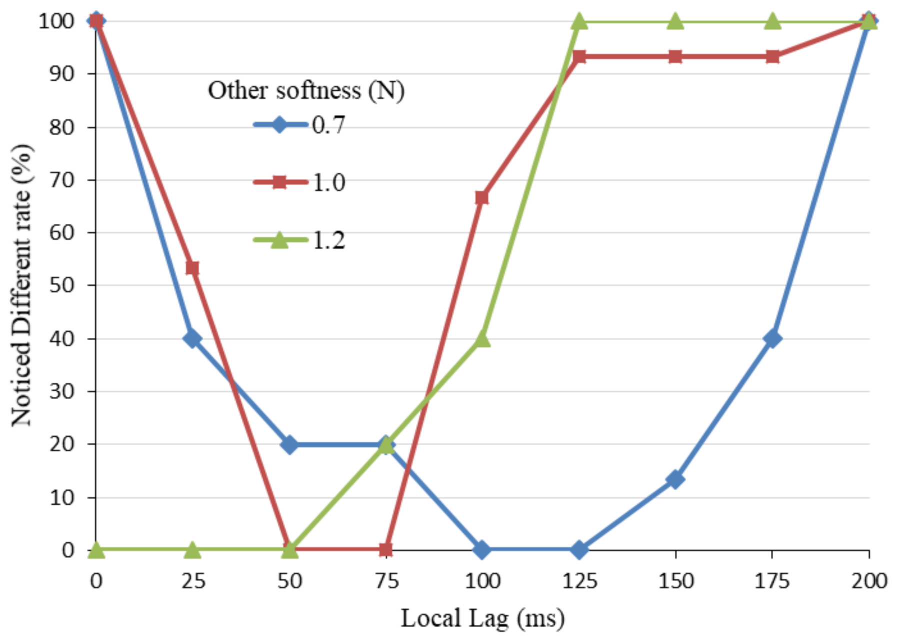
In Figures 6.8 (a), 6.9 (a), and 6.10 (a), it can be confirmed that when the difference between the standard softness and other softness is zero and local lag is 0 ms to around 150 ms, the noticed difference rate is 0%; all the subjects cannot perceive any difference. We also see when the difference between the standard softness and other softness is greater than 0.1 N and local lag is also greater than 0 ms to around 150ms, the noticed difference rate is still 0%; (Note that in [89], humans can hardly perceive the difference in softness when the other softness is almost the same as the standard softness; they start to perceive the absolute differences larger than or equal to about 0.1 N.) Therefore, the proposed control can keep the human perception of softness with different local lag. However, when the local lag is greater than 150 ms, the noticed difference rate is 100 %; all the subjects can perceive the difference between two balloons' softness. This is because when the local lag become larger, the adaptive reaction force control increases. In Figures 6.8 (a), 6.9 (a), and 6.10 (a), if the local lag is 0 ms, the softness difference is greater than 0.1 N and without adaptive reaction force control then the noticed difference rate is 100 %.

In Figures 6.8 (b), 6.9 (b) and 6.10 (b), it can be seen that when the difference between the standard softness and other softness is zero and the local lag is 0 ms, the noticed difference rate is 0%; all the subjects cannot perceive any difference. The author also sees that when the other softness is the same as the standard softness, the noticed difference rate becomes larger as the local lag increases up to around 125 ms.

When the other softness is not equal to the standard softness, the noticed difference rate first decreases down to almost zero and then increases as the local lag becomes larger. Furthermore, we observe that as the other softness becomes larger, the noticed difference rate tends to start to increase at a smaller local lag; the rate has a tendency to reach 100% earlier. From these considerations, the authors conclude that the local lag makes the balloon harder. To clarify how largely the local lag increases the softness, the hardening with delay is shown, which is here defined as the force which is increased when the local lag is changed, in Table 1. In Figure 3 (b), it can be noticed that for example, when the other softness is 0.7 N and the local lag is between about 100 ms and 125 ms, the noticed difference rate is 0%; then, the perceived softness should be between about 1.1 N and 1.3 N (= the standard softness (1.2 N) ± 0.1 N). This means that the increased softness is about 0.4 (= 1.1 N – 0.7 N) to 0.6 (= 1.3 N – 0.7 N). On the other hand, in Figure 3 (b), it can be found that for instance, when the other softness is 0.7 N and the local lag is larger than or equal to about 200 ms, the noticed difference rate is 100%; then, the perceived softness is larger than about 1.6 N (= the standard softness (1.2 N) + 0.4 N); this indicates that the increased softness is larger than or equal to about 0.9 N (= 1.6 N – 0.7 N).

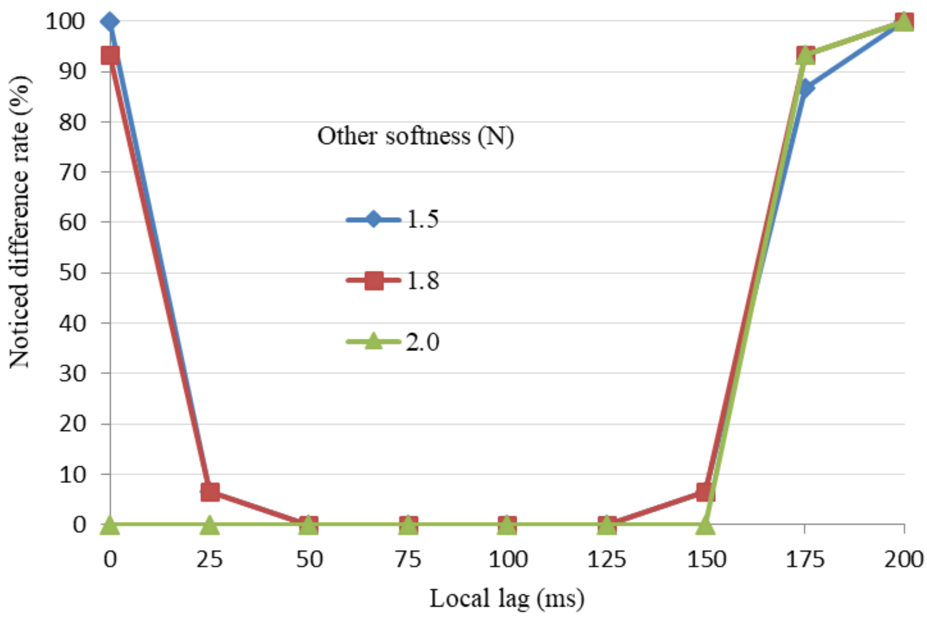


(a) With control

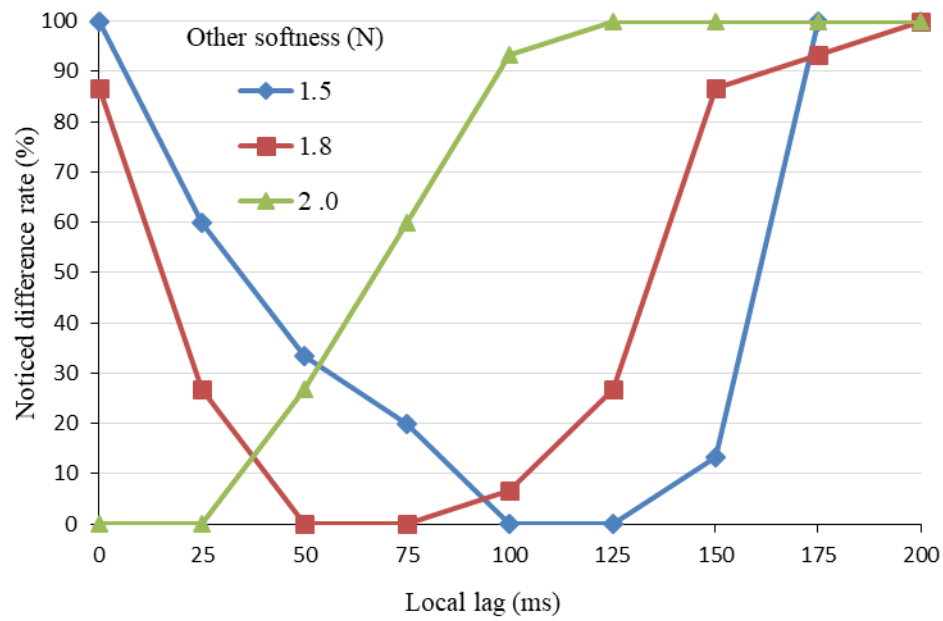


(b) Without control

Figure 6.8: Noticed Difference Rate for Standard Softness of 1.2 N

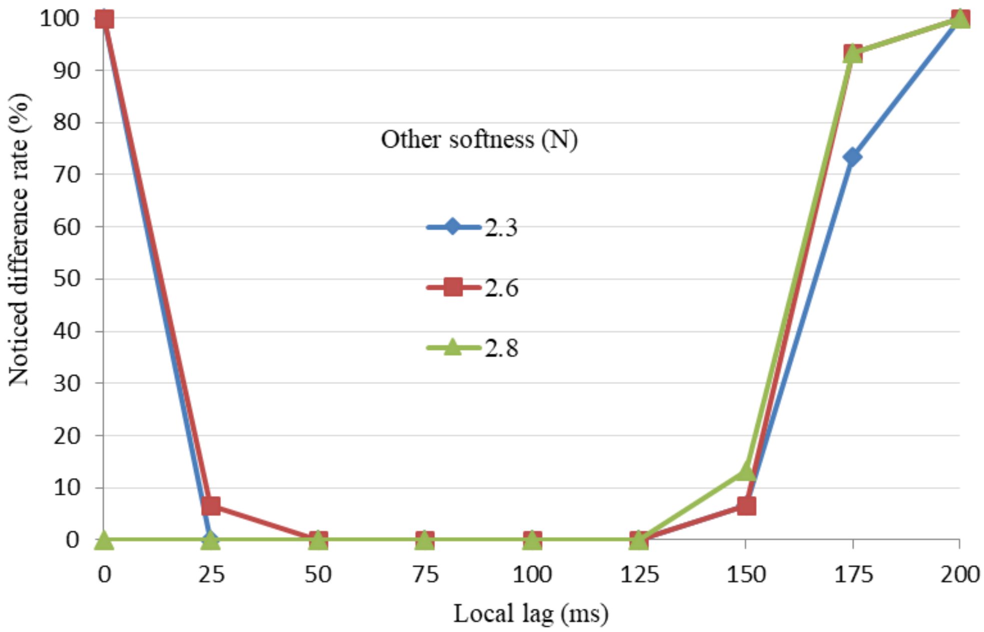


(a) With control

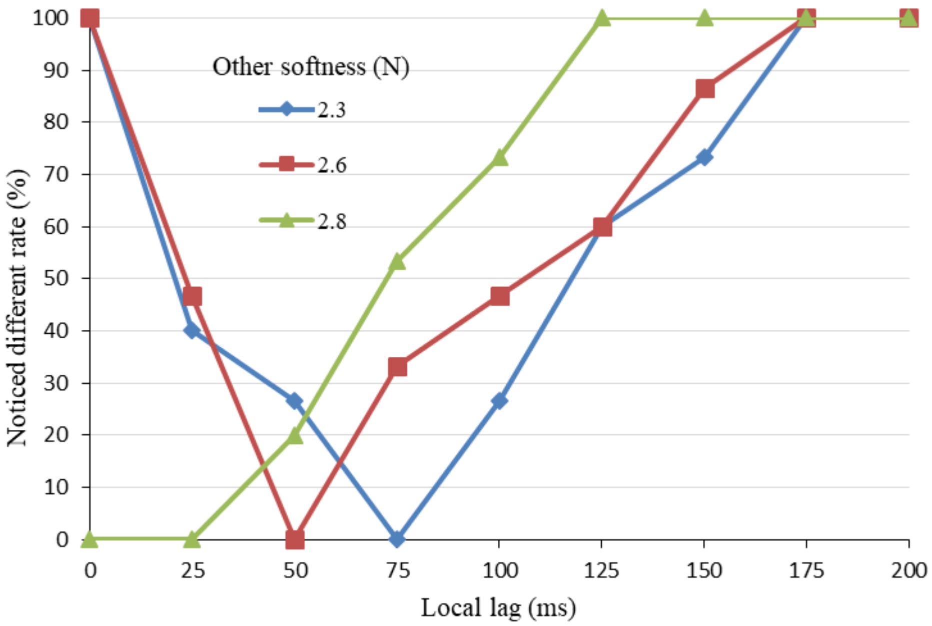


(b) Without control

Figure 6.9: Noticed Difference Rate for Standard Softness of 2.0 N



(a) With control



(b) Without control

Figure 6.10: Noticed Difference Rate for Standard Softness of 2.8 N

6.6 Summary

The authors consider the influences of the network delay and moving velocity to the efficiency of work in the weight balance system. The author examined the influence of the initial position of the ball also. According to experimental results, we found that it is possible to hold the ball around the middle of the stick when the network delay decreases. The authors also show that based on the network delay, the optimal moving velocity of the ball exists which depends on the additional delay.

The author illustrated how accurately each subject can perceive the difference of softness by QoE assessment with a networked haptic virtual space. When the softness is almost the same as the standard softness, subjects cannot easily perceive the difference in softness. Most of subjects start to perceive the absolute differences larger than about 0.1 N. For human perception of the softness, there is almost no difference between the case in which the softness is smaller than the standard softness and the case in which it is larger in the assessment.

By evaluating the quality of the experience, the author was able to understand more the impact of local lag on how softness is perceived by humans in a networked virtual environment. The author dealt with a networked haptic balloon bursting game that featured two balloons with various softness values. Therefore, the author discovered that the local lag can depend onto the human perception of softness. The author also defined how much the local lag increases the softness; for instance, when the local lag is greater than or equal to about 100 ms, the softness of 1.2 N increases by at least about 0.2 N.

CHAPTER 7
CONCLUSION AND FUTURE WORK

Through subjective and objective QoE evaluations in the context of networked balloon bursting games and networked weight balance systems, the investigation of the effects of network delay on quality of experience has been done in this study. In order to better understand how QoE is affected when media cannot be output simultaneously at all terminals or at different terminals due to a significant difference in network delay among the terminals, the two areas were chosen.

In the networked balance game, the author examined at the effects of network delay and moving velocity on the effectiveness of the work where two users collaboratively lift up a weighted ball with haptic sense in a virtual environment. Also, the author examined the influence of the initial position of the ball. As a result, the author found that it is possible to keep the ball around at the center when the network delay is small. Also, there exists the optimal moving velocity depending on the network delay.

With the use of haptic interface device in the networked balloon bursting game, we illustrated that how accurately each subject can perceive the difference of softness by QoE assessment in a networked virtual environment. As a result, the author found that subjects can hardly perceive the difference in softness when the softness is almost the same as the standard softness; they start to perceive the absolute differences larger than about 0.1 N. For human perception of the softness, there is almost no difference between the case in which the softness is smaller than the standard softness and the case in which it is larger in the assessment.

By evaluating the QoE (quality of experience), the author also looked into how local lag affected people's perceptions of softness with haptic sense in a networked virtual space. The author dealt with a networked balloon bursting game that featured two balloons with various softness values. In the assessment, the subjects determined whether the softness of the balloon is “same”, “softer” or “harder”. As a result, the author found that the human perception of softness is dependent on the local lag. The author also clarified how largely the local lag makes the softness harder; for instant, the softness of 1.2 N is increased by at least about 0.2 N when the local lag is larger than or equal to around 100 ms.

7.1. Discussion

It can be discovered that keeping the ball in the center is possible when the network delay is small as a result of the effects of network delay and moving velocity on virtual cooperative work with haptic sense. Additionally, depending on the network delay, there is a best moving speed.

According to the QoE assessment of human perception of softness in networked haptic virtual environment, we found that subjects cannot easily perceive the difference in softness when the softness is nearly identical to the standard softness. The subjects begin to perceive the absolute differences larger than about 0.1 N. Between the cases where the softness is smaller than the standard softness and the cases where it is larger in the assessment, there is essentially no difference in how softness is perceived by a human.

Human perception of softness with haptic sense in a networked virtual environments, where we discovered that human perception of softness is dependent on local lag. The auhtor also defined how much the local lag increases the softness; for instance, when the local lag is greater than or equal to about 100 ms, the softness of 1.2 N increases by at least about 0.2 N.

7.2 Advantages and Limitation of Proposed System

In order to create a constant delay (referred to in this study as the additional delay) for each packet transmitted between the two PCs, we used a network emulator (netem) in place of the actual network in our experiment system. Note that the author here handle constant delay for simplicity because media synchronization control absorbs the fluctuation of the network delay to some extent. In the experiment, the author handled two methods (called Methods 1 and 2). In Method 1, the users started to lift up the ball from the original position where the two cursors were on the ground and the weighted ball was positioned in the middle of the stick. The initial position of the ball in Method 2 is different from that in Method 1; the ball was placed at the far left of the stick. In both methods, in order to hold the ball at the middle of the stick and proceed at a constant speed, the users were instructed to raise up the ball to a height of 16.7 (in this study, we note that the diameter of the cursor is one). When each user raises the haptic's stylus in the vertical direction, the movement distance of 16.7 equates to 10 cm in actual space. In the experiment, in both methods, the combinations of the additional delay and moving velocity were selected in random order for each work. The experiment was conducted by two users (females) whose ages were 35. The experiment was run by ten times. The author examines the effects of network delay and moving velocity on work efficiency as they relate to the networked balance system with haptic sense. We also look at the impact of the ball's starting position.

In the networked haptic balloon-bursting game, two players each use a haptic interface device to burst balloons in a 3D virtual space. Fig. 4.3 shows the system configuration of balloon bursting game. The number of balloons that have burst is the point of competition between the two players. For simplicity in the virtual space, we use two balloons. The system is made up of two terminals, designated here as terminals 1 and 2, each of which has a PC with a display, haptic device (3D Systems Touch), and a headset. The virtual stylus is moved in the virtual space by each player using their own haptic interface device. The stylus's point corresponds to the haptic device's cursor (i.e., the point of contact with an object). The author judged the softness of a balloon by the force when the balloon is burst. Two balloons are set at the same time in the virtual space; one has constant values of softness (the balloon is called the standard balloon, and the softness of the standard balloon is referred to as the standard softness in this paper), and the other has various values of softness. The author prepared the following three different values as the standard softness: 1.2 N, 2.0 N, and 2.8 N (note that the haptic interface device's maximum response force is 3.3 N). In the virtual space of Fig. 4.4, the pink balloon on the left hand side has the standard softness, and the green one on the right hand side has other values of softness. With 15 participants, aged 25 to 35 (1 male and 14 female), the author conducted a QoE assessment. Each subject used the haptic interface device to practice popping a balloon for about two minutes prior to the test. As a result, the author discovered that subjects barely notice a difference in softness when it is nearly identical to the standard softness; instead, they begin to notice absolute differences greater than about 0.1 N. There is almost no difference between the cases where the softness is smaller than the standard softness and the cases where it is larger in the assessment for human perception of the softness.

With two balloons in a three dimensional virtual environment, one of them in the evaluation system has a standard softness value (referred to as the standard softness here), and the local lag is set to 0 ms (milliseconds). The other balloon (referred to as the other softness) has a different softness value, and the local lag is set to a particular amount. Then, each participant used a stylus from the haptic interface device to alternately burst both balloons while responding to which balloon was harder or softer. The three different values listed below are presented as the typical softness in a random order to each subject: The maximum reaction force of the haptic interface device in this study is 3.3 N, and the forces in this study were 1.2 N, 2.0 N, and 2.8 N (notice how the force is expressed in terms of softness) (newtons). The proportion of responses to all responses where there is a difference between the standard softness (the pink balloon with a local lag of 0 ms) and the other softness is known as the noticed difference rate (the green balloon with a local lag of a particular value). We found that people's perceptions of softness are influenced by the local lag. We also specified the amount by which the local lag raises the softness; for example, the softness of 1.2 N rises by at least 0.2 N when the local lag is more than or equal to roughly 100 ms.

7.3 Future Work

As the next step, the influences of other factors such as the weight and size of the ball will be examined on the work efficiency. It is also important to make a mathematical model of our system and to analyze the results in this research.

The authors will clarify in one of the upcoming research how much the delay jitter, packet loss and network delay influence how softness is perceived. To execute remote surgery operations and palpation in the medical area, for instance, this is crucial. The next phase of our research will focus on determining how QoS control can be used to reduce the impact of local lag on softness. The authors will also look at how to implement QoS control when network delay is unavoidably high in order to lessen its impact. It is also important to investigate how other haptic features are affected by delay jitter, packet loss, and network delay.

AUTHOR'S PUBLICATIONS

1. M. Z. Oo, Y. Ishibashi, and K. K. Wai, "Effect of Adaptive Reaction Force Control on Human Perception of Softness with Haptic Sense in Networked Virtual Environment," in Proc. 20th International Conference on Computer Applications (ICCA), Feb. 2023. (Accepted)
2. M. Z. Oo, Y. Ishibashi, and K. T. Mya, "Influence of local lag on human perception of softness in networked virtual environment with haptic sense," ITE Trans. on Media Technology and Applications (MTA), vol. 10, no. 1, pp. 18-25, Jan. 2022.
3. M. Z. Oo, Y. Ishibashi and K. T. Mya, "QoE Assessment of Human Perception of Softness in Networked Haptic Virtual Environment," 2021 3rd International Conference on Computer Communication and the Internet (ICCCI), pp. 27-31, Jun. 2021.
4. M. Z. Oo, Y. Ishibashi, and K. T. Mya, "Influences of network delay and moving velocity on virtual cooperative work with haptic sense," in Proc. The 12nd International Conference on Future Computer and Communication (ICFCC), pp. 108-113, Feb. 2020.

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APPENDICES

APPENDIX A: ASSESSMENT SHEET FOR INFLUENCE OF LOCAL LAG CONTROL

For example; the assessment of the influence of local lag to softness by human perception was done with 20 subjects (including 19 females and 1 male) whose ages were up 25 to 35. Each subject took around one hour including break time to carry out the assessment. The assessment sheets are also demonstrated as following Table:

(a) Standard softness 1.2 N

x	y	(x - y) = z	0 ms	25 ms	50 ms	75 ms	100 ms	125 ms	150 ms	175 ms	200 ms	225 ms	250 ms
1.2 N	0.7 N	0.5											
	0.8 N	0.4											
	0.9 N	0.3											
	1.0 N	0.2											
	1.1 N	0.1											
	1.2 N	0											

(b) Standard softness 2.0 N

x	y	(x - y) = z	0 ms	25 ms	50 ms	75 ms	100 ms	125 ms	150 ms	175 ms	200 ms	225 ms	250 ms
2.0 N	1.5 N	0.5											
	1.6 N	0.4											
	1.7 N	0.3											
	1.8 N	0.2											
	1.9 N	0.1											
	2.0 N	0											

(c) Standard softness 2.8 N

x	y	(x - y) = z	0 ms	25 ms	50 ms	75 ms	100 ms	125 ms	150 ms	175 ms	200 ms	225 ms	250 ms
2.8 N	2.3 N	0.5											
	2.4 N	0.4											
	2.5 N	0.3											
	2.6 N	0.2											
	2.7 N	0.1											
	2.8 N	0											

APPENDIX B: FUNCTION OF REACTION FORCE

```
hlGetShapeDoublev(b_effect, HL_REACTION_FORCE,reaction);
rcttmp = sqrt(reaction[0]*reaction[0] + reaction[1]*reaction[1]
+ reaction[2]*reaction[2]);

      if(rcttmp > 0){
                   exp_data_[exp_data_count_]    = rcttmp;
                   exp_data1_[exp_data_count_]    = burstflag;

                  SYSTEMTIME systime;
                  GetSystemTime(&systime);

            milisec[exp_data_count_]      =
systime.wMilliseconds;

cout<<exp_data_[exp_data_count_]<<","<<exp_data1_[exp_data_coun
t_]<<","<<milisec[exp_data_count_] <<endl;

                  exp_data_count_++;

                  }
```

APPENDIX C: THE COMMANDS TO ADD AND CHANGE THE VALUE OF DELAY

When the additional delay is added to the terminals, the command lines are used in the terminal of the Ubuntu (like as Network emulator; netem). The "add" command is used to add the additional delay to the terminals at first and "change" command is used to change the delay values to the terminals next time as following:

```
1. Sudo tc qdisc add dev enp3s0 root netem delay 100ms

2. Sudo tc qdisc change dev enp4s0 root netem delay 50ms
```