Tactile Communication | Haptic Communication | Network Delay

Collaboration Projects

Evaluation of Five-finger Haptic Communication with Network Delay

To realize tactile communication, we clarify some issues regarding how delay affects human perception, haptic displays and their control systems when stiffness data is transmitted over a network. This research was conducted jointly with the Iwata-Yano Laboratory (Professor Hiroo Iwata and Associate Professor Hiroaki Yano), Graduate School of Systems and Information Engineering, University of Tsukuba.

Takayuki Tamura, Kouki Hayashi and Minoru Takahata

1. Introduction

During the past several decades, it has become easy to transmit sounds (audio data) and videos (visual data) using the Internet and mobile terminals. In order to realize communication with highly realistic sensation, we need to expand communication media [1].

In addition to sounds and videos, we are undertaking research on the tactile senses, like forces and skin sensation. By transmitting tactile information, people can, for example, feel the softness of a cushion, the weight of a bag, or the texture of the material in a piece of clothing from a remote location. As a result, people can experience Internet shopping that is more like actually visiting a shop. In this way, communication of tactile information can be used to create various new styles of communication.

Tactile sensation can be divided into two major classifications: cutaneous sensation and haptic sensation (deep sensation) [2]. Cutaneous sensation refers to the perception of the physical surface, smooth or harsh, warm or cold. Haptic sensation refers to perception of properties such as stiffness, weight, and shape.

In tactile communication, tactile information is measured at a remote location, transmitted back, and reproduced for the user at their location. There are various issues to be solved in realizing tactile communication, including development of display devices to reproduce the tactile sensations, sensors to detect the tactile sensations, and communication technologies to transmit tactile information. Further issues include miniaturizing and improving the output capabilities of the display device's actuators[*1] and improving the accuracy of the sensors. Also, designing the network architecture for tactile communication must take into consideration the characteristics of tactile sense, that it requires wide bandwidth.

Previous research has evaluated the effects of network delay on task performance using tactile communication [3]. However, there is very little research into human perception through tactile communication with network delay. By measuring how tactile information is perceived by humans in an environment with network delay, it should be possible to determine the network architecture requirements, such as maximum delay or packet loss rate[*2] on the network. In this research, we focus on these communication-technology issues with haptic communication, and evaluate some effects of network delay on haptic perception. This result will provide basic knowledge required to design a network supporting tactile communication.

Also, in consideration of the types

*1 **Actuator**: A mechanical element which produces a physical force using the energy applied. For example, motors and hydraulic cylinders.

*2 **Packet loss rate**: The proportion of the total number of packets transmitted to the packets that do not arrive normally because of interference, packet collision, etc. in a wireless cell.

of actions and objects that people touch every day, we developed a new haptic display using five fingers, which could present a broad range of reaction forces accurately, from soft to hard objects. This research was conducted jointly with the Iwata-Yano Laboratory, University of Tsukuba to acquire a highly reliable evaluation result for the newly developed display. The Iwata-Yano Laboratory has already conducted a large number of studies using the tactile display and has broad experience in tactile research.

In this article, we describe the experimental results of the effects of network delay on human perception after explaining how our tactile communication was realized.

2. Implementation of Tactile Communication

Tactile communication can be separated into three components: the haptic sensor, the haptic display (the display device) and the communications network. The haptic sensor sends the haptic information obtained when it touches the object to the haptic display via the communications network. The haptic display reproduces the haptic sensation based on the haptic information it receives. The subject can then sense the reaction force from the haptic display, as though he/she was directly touching the physical object.

When we touch an object, there is an action-reaction relationship between our hand and the object. That is, as we are being touched by the object, we feel a reaction force from it. In the same way, with tactile communication, it is necessary for the display to present tactile information at the same time as the tactile sensor is acquiring the information.

To realize haptic communication, one can use either a bilateral control method in which an actual, physical object is touched by a robotic arm with sensors at a remote location, or a virtual environment in which a virtual object defined within a server machine is touched virtually. In this research, a virtual environment was used, allowing physical characteristics such as stiffness, weight and shape to be configured easily, and allowing the same conditions to be presented repeatedly.

An example of how to build such a virtual environment is shown in **Figure 1**. It is composed of the remote server that constructs the virtual environment, and the haptic display and haptic display control machine which allows the subject to perceive the haptic information. In the virtual environment constructed by a server, the virtual objects are defined by size, stiffness, weight, and surface texture. In addition to these objects, a virtual hand is defined based on its positioning relative to the haptic display. The virtual objects can be touched by manipulating the virtual hand through the haptic display. The haptic information for a virtual object can be either recorded by sensing a real object, or defined manually. The user can operate the haptic display directly with his/her hand. The position data of the haptic display sent to the server is used to update the position of the virtual hand within the virtual environment. The server calculates the contact status between the virtual objects and the virtual hand, as well as corresponding reaction forces to be applied. The reaction forces are sent to the haptic display control machine. The haptic display control machine controls the haptic display to present the reaction forces so that the subject experiences the reaction forces from touching the virtual objects in the virtual environment through the

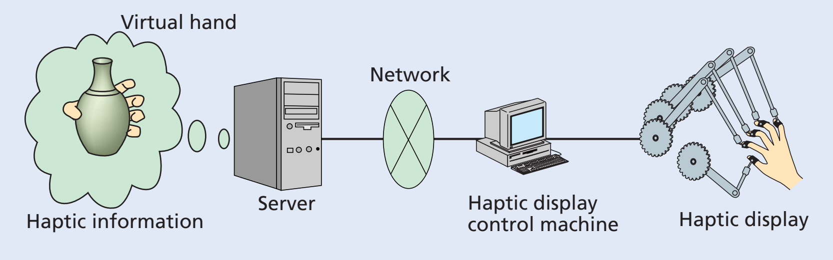

Figure 1 Haptic communication using a virtual environment

haptic display.

3. Evaluation of the Perception of Stiffness with Network Delay

3.1 Experiment Overview

We have described that manipulation of the object and presentation of the haptic information are carried out simultaneously. However, with haptic communication, the network delays occurring on the haptic communication may interfere with the simultaneity between manipulation and presentation. This may result in the subject perceiving the haptic information differently than if he/she was holding the actual object.

There has already been some research into how subjects perceive the haptic information with network delay [4]. These experiments used a pen-based haptic display, presenting the haptic information for only a single point. Further, in these experiments the subjects perceive the haptic information through the pen mainly with their arm. However, we manipulate objects and perceive most of the reaction forces mainly using five fingers in our daily lives. When an object is grasped with the fingers, the reaction force is felt just by the fingers, so the sensation produced may be different than if only the arm is used. We perform complex manipulations – pinching, grasping and rotating – using multiple fingers in combination. With tactile communication, using five fingers also enables performing all of these manipulations the same as usual.

Accordingly, we developed a new five-finger haptic display for this research and conducted experiments presenting haptic sensation to all five fingers simultaneously. Subjects can grasp virtual objects with all five fingers, and perceive the stiffness of the objects. Using the new haptic display, we investigated the effects of network delay on human perception and on the control system for the haptic display.

The experimental system consisted of the five-finger haptic display, the haptic display control machine, and the server which constructs the virtual environment. The five-finger haptic display is connected to the control machine. The server and the five-finger haptic display control machine are connected via a LAN. The virtual objects presented in the experiments were 4-cm-thick, infinite flat surfaces, and the reaction forces were calculated using a spring-damper model[*3]. The network delay was simulated by inserting a wait time at the server between the time of receiving the position data from the haptic display, and sending back the reaction force data to the haptic display. The subjects grasped the virtual object with five fingers of one hand, and attempted to perceive the stiffness of the object.

We used Scheffe's method of paired comparisons[*4] in the experiment. First, the subjects were presented with two objects with differing delay times through the five-finger haptic display, a standard and a comparison stimulus. The subjects evaluated the comparison object as "harder", "the same", or "softer" than the standard object. In the evaluation process, the subjects were able to switch freely back and forth between the standard and comparison objects to ensure that an adequate comparison could be made. A total of six adult subjects, three types of virtual elastic objects with varying stiffness, and six levels of simulated network delay for each object on the server were used.

3.2 Five-finger Haptic Display

The five-finger haptic display is composed of five units (five small haptic displays) mounted on a pedestal (**Photo 1**). The link of each unit is affixed to a finger on the right hand, allowing independent haptic information to be presented to each finger. The units were arranged to allow measurement of finger movements as they grasp objects, not to hinder finger motion, and to prevent interference between the units.

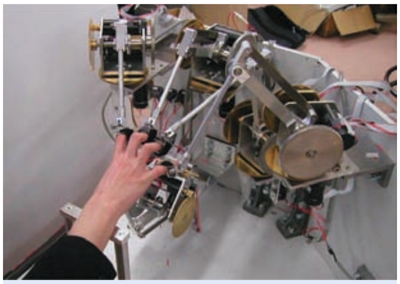

Photo 1 Five-finger haptic display

*3 **Spring-damper model**: A type of physical model used to express stiffness of virtual objects. It is expressed by combining a spring component (a force related to the amount of penetration) and a damper component (a force related to the speed of the penetrating object). If the spring component is large, the object will be stiff, and if the damper component is large, the object will be viscous.

3.3 Experimental Results

A part of the results of the experiment is shown in **Figure 2**. The horizontal axis shows the amount of network delay added at the server, and the vertical axis shows the perceived hardness on a psychological scale. To derive the linear value on a psychological scale, the responses from the subjects were converted to a score with “harder” mapping to 1, “the same” to 0 and “softer” to – 1. Then, a score for each stimulus was calculated totaling the results from all subjects. For each presented stimulus, the linear value is calculated by dividing the total by 2SN, where S is the number of the additional delay levels, and N is the number of subjects. A more-positive value indicates that the subjects perceived the object as harder. The graph shows that when the delay was 0 ms, the subjects perceived the object as harder, and as the delay increased, they began to perceive the object as softer. The similar tendencies were observed with other virtual objects as well. Analysis of variance showed that compared to when the delay was 0 ms, delays of 16 ms or more resulted in a significant difference for the object. The subjects clearly perceived the object in the experiment presented with delays of 16 ms and above as softer than they should have felt.

The experimental results clearly show that objects feel softer when delay is added than without delay, and the perception of stiffness using five fingers shows the same tendency as when using the pen-type haptic display. Further, we observed that as the amount of added delay is increased, the control of haptic display became unstable, in some cases making it impossible to even touch the virtual object.

In this system, a spring-damper model is used to calculate the reaction forces. A spring-damper model calculates the reaction forces based on the amount and the speed with which the virtual hand penetrates the virtual object. Therefore, when the virtual hand penetrates the virtual object by a large amount during a single sampling time period in an environment with network delay, the user will suddenly feel a very large reaction force presented after the delay time. Repeated occurrence of this effect is likely what leads to instability in the control system.

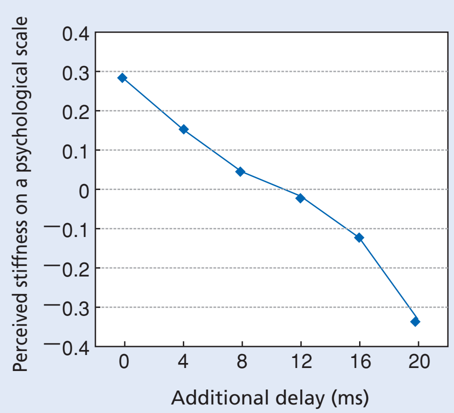

Figure 2 Perception of stiffness differences of an elastic object with network delay

4. Conclusion

In this research we examined the effects of network delay on the perception of stiffness when grasping objects with five fingers. The knowledge obtained through the experiments will be used as a guideline for designing network architectures supporting tactile communication.

However, the experimental conditions were quite limited, further experiments are needed to examine perception of weight and shape as well as different haptic displays in order to identify network requirements for tactile communication.

In future work, we also plan to eliminate the control instabilities occurring when network delays become large.

By accumulating more basic knowledge about human perception, we aim to make communication with highly realistic sensation and construction of highly effective networks possible.

*4 **Scheffe’s method of paired comparisons**: An experimental method used in psychophysical experiments. Pairs of stimuli are selected to be compared from among the set of stimuli, one to be the standard, and one to be compared with it. The method is to then determine how the compared stimulus feels relative to the standard stimulus. Rather than simply selecting one of two alternatives, as in a regular one-to-one comparison, this method enables a more detailed determination.

References

[1] Ministry of Internal Affairs and Communications: "Study Group on Communication Technology of Five senses' " http://www.soumu.go.jp/ joho_tsusin/ policyreports/chousa/gokan/pdf/060922_2.pdf, 2001 (In Japanese).

[2] Y.Iwamura: "Neuropsychology Collection: Touch," First edition, Igaku-Shoin Ltd., Mar. 2001 (In Japanese).

[3] D. Wang, K. Tuer, M. Rossi, L. Ni and J. Shu: "The Effect of Time Delays on Telehaptics," Haptic, Audio and Visual Environments and their Applications, IEEE, pp.7-12, Sep. 2003.

[4] H.Ohnishi, S.Yamazaki, K.Mochizuki, N.Nakamura and K.Yuki: "Psychophysical Evaluation of a Haptic Display: Effect of Delay on Perception of Elasticity," IEICE Technical report, Vol.105, No.17, pp.5-10, Apr. 2005 (In Japanese).