An Experimental Study on the Performance of Haptic Data Transmission in Networked Haptic Collaboration

Yonghee You, Mee Young Sung, Nam-Joong Kim, Kyungkoo Jun

Abstract— **In this paper, we present preliminary results of our ongoing networked virtual reality project by discussing the implementation and performance of an experimental haptic collaboration system; a networked haptic basketball game. In this game, online players feel like handling a real basketball since they are able to feel the sense of touch by using haptic interfaces. One of challenging issues in this implementation is haptic data transmission over the Internet to allow online multi-user play. Since haptic information is extremely sensitive to delay, jitter, and loss, the provision of timely transmission is critical. We carry out some experiments to compare the performance of the haptic data transmission under various delays, jitters, and losses of packets for two models; one is the Position Transfer Model and the other is the Force Transfer Model. We observe that loss of packets may reduce the force feedback in the Position Transfer Model and jitters are more sensitive than delays for both models.**

***Index Terms*—Network, Haptics, Collaboration, Transmission, Delay, Jitter, Loss**

I. Introduction

THE emerging technology of haptics enables a realistic and immersive experience by artificial means through interactions with either computer generated or remote real environments [1]. Commercial haptic products let doctors train for simple procedures without endangering patients, designers sculpt digital clay figures to rapidly produce new product geometry, and museum visitors tactically feel previously inaccessible artifacts [2]. The recent development of sophisticated haptic algorithms allow users to experience virtual objects through the sense of touch in many exciting applications, including surgical simulations, virtual prototyping, military simulation, and immersive games [3], [4]. Haptics provides great promise to enrich the sensory interactions of virtual environments and enables realistic and immersive physical interaction with virtual or remote objects. For example, Basdogan et. al. utilized haptic interactions to verify the improved efficiency of cooperative tasks under the CVEs (Collaborative Virtual Environments) with haptics by comparing it with one only with visual feedbacks [5].

We can distinguish two types of haptic interactions; human-machine interactions and human-human interactions [1]. In general, single user VR applications involves the visualization of a scene and interaction with objects within the scene, However, the fundamental aspect of a collaborative experience is that the sensory communication between geographically separated users should enable them to display their actions to each other through a connected network. Recent hardware and software advances in haptic interfaces and faster network speeds have enabled us to integrate force feedback into networked CVEs over a network such as the Internet. Due to inaccessibility, remoteness, hazardousness, or cost-effectiveness, a human operator may not always be present in a work environment. Teleoperation has been proven a viable alternative for projecting human intelligence over networks. However, human-human haptic interaction is different from teleoperation. In a typical teleoperation setup, the master end controls the actions of the slave robot end, whereas both ends influence each other in human-human haptic interaction. Also, in teleoperation, an active user interacts with the real world; however, human-human haptic interaction involves interacting mostly with virtual worlds.

Although there have been several recent studies focused on the development of multimodal virtual environments to study haptics for human-machine haptic interactions, less attention has been paid to networked human-human haptic interactions for haptically enabled networked CVEs. Only recently have researchers paid any attention to haptic communication between people and the extent to which the addition of haptic communication would contribute to the collaborative experience.

We developed an experimental haptic collaboration system; a networked haptic basketball game. This paper presents our

This work was supported by the Brain Korea 21 Project in 2006, by grant No. RTI05-03-01 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy (MOCIE), and by the Multimedia Research Center at the University of Incheon.

M. Y. Sung is with the Computer Science & Engineering Department, University of Incheon, Incheon 402-749, South Korea (phone: 82-32-770-8496; fax: 82-32-766-6894; e-mail: mysung@incheon.ac.kr).

Y. H. Yoo is with the Computer Science & Engineering Department, University of Incheon, Incheon 402-749, South Korea (e-mail: yhinfuture@incheon.ac.kr).

N. J. Kim is with the Computer Science & Engineering Department, University of Incheon, Incheon 402-749, South Korea (e-mail: water09z@incheon.ac.kr).

K. K. Jun is with the Multimedia Systems Engineering Department, University of Incheon, Incheon 402-749, South Korea (e-mail: kjun@incheon.ac.kr).

experimental collaborative haptic game and the analysis of the characteristics of existing transmission protocols for haptic data transmission using our real system test bed.

II. Related Works

In this section, we briefly describe haptic rendering and some technologies such as OpenHaptics [6] and QUANTA [7], which are used for implementing our experiments.

A. Haptic Rendering

The goal of haptic rendering is to enable a user to touch, feel, and manipulate virtual objects through haptic interfaces as realistically as possible [8], [9]. A force-feedback device can generate kinesthetic information and temporal tactile information. By using these perceptual cues such as shape, stiffness, texture and friction, haptic rendering can render various properties of a virtual object. Unlike visual rendering, a minimum update rate to achieve realistic haptic rendering depends on the properties of virtual objects and a force-feedback device. Recommended update rates are 1 KHz and 5 KHz-10 KHz for a rigid surface and a textured surface respectively. For a transformable object, it is advised to keep the rate as fast as you can.

B. OpenHaptics

Figure 1 illustrates the structure of the OpenHaptics Toolkit from SensAble [10] which is an application that enables software developers to add haptics and true 3D navigation to a broad range of applications, including 3D design and modeling. OpenHaptics is patterned after OpenGL® API, making it familiar to graphics programmers and facilitating integration with new or existing OpenGL. This toolkit handles complex calculations and provides low-level device control for advanced developers. The architecture of OpenHaptics Toolkit is shown below.

HDAPI (Haptic Device API) is a low-level foundational layer for haptics. It is best suited for developers who are familiar with haptic paradigms and sending forces directly. This includes those interested in haptics research, telepresence, and remote manipulations. HLAPI (Haptic Library API) is designed for high-level haptics scene rendering. It is targeted at developers who are less familiar with haptics programming, but desire to quickly and easily add haptics to graphics applications. Utilities include mathematical and necessary functions such as vector and matrix calculations that are used for haptic devices.

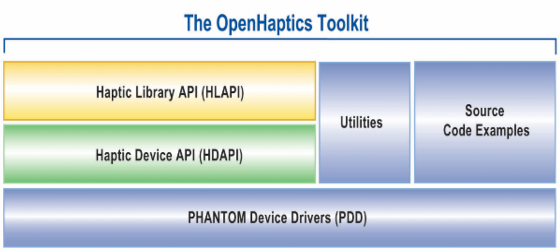

Figure 1. The OpenHaptics Toolkit

C. QUANTA Networking Library

QUANTA (The Quality of Service Adaptive Networking Toolkit) is a cross-platform adaptive networking toolkit for supporting the diverse networking requirements of latency-sensitive and bandwidth-intensive applications. It provides Reflector TCP/UDP, Parallel TCP and Reliable Blast UDP by using TCP and UDP. In addition, it supports the features such as IPv4, IPv6, thread and mutex. Since QUANTA inherits CAVERN (CAVE Automatic Virtual Environment Research Network) from CAVE (CAVE Automatic Virtual Environment) Systems, its structure is suitable for DVE (Distributed Virtual Environment) Systems. In this study, we developed a network module with the QUANTA Library.

III. Methods

We explain the development of a multi-user VR haptic collaboration that enables human-human haptic interaction over the Internet in this section. Details of hardware and software architecture are also described.

A. Experimental VR Haptic Collaboration

A virtual three-dimensional 'room' containing a sphere, a torus and two probes are displayed to each participant on their separate desktop system. In order to have every participant in the same environment, the application software is networked. Haptic devices with six spatial degrees of freedom (DOF) and three force DOF are attached to each probe. The users directly control the probe through the haptic feedback devices attached to the probes. Those probes can be moved and rotated independently. Through the manipulation of the probes with attached haptic devices rendering force feedback, the sphere may be moved around within the room. As illustrated in Figure 2, haptic interaction occurs at a haptic interface and that mechanically connects two symmetric dynamic systems. Each block in the diagram can contribute the perception by the human user.

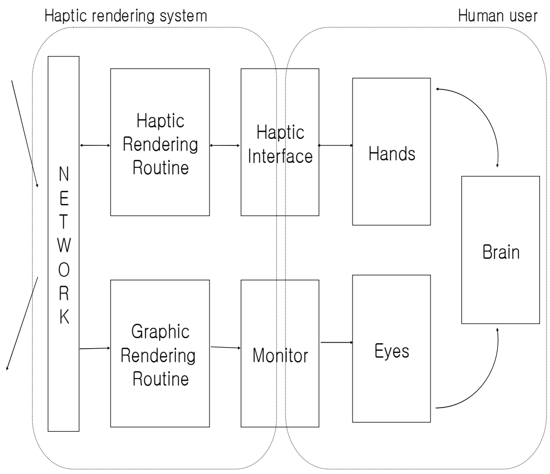

Figure 2. Basic architecture of the experimental haptic basketball game

A snapshot of the application can be seen in Figure 3. The walls of the room constrain the sphere.

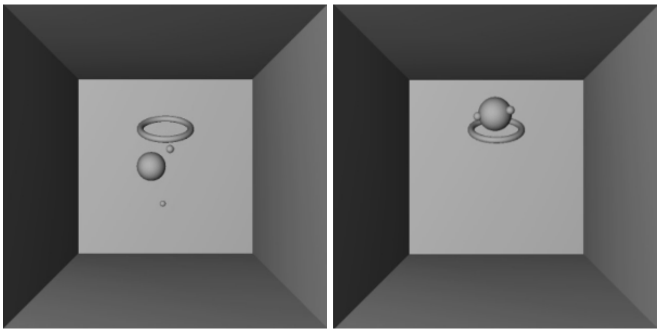

Figure 3. View of the experimental haptic basketball game

B. *Hardware Setup*

We used two pen-based PHANToM force-feedback devices from SensAble Technologies [10] at both sides of networked computers. These are robotic devices that allow the user to interact with remote and virtual objects. These devices have a stylus grip with which the users can touch and feel 3D objects. The update frequency of these devices is maintained at 500 Hz for stable haptic interactions (the general frequency of haptic devices is 1000Hz). Because of this sensitivity, effective force feedback needs to be updated at a rate of at least 1 *kHz* and within a latency of 60 *ms* [9]. However, providing consistent updates without any gap seems quite challenging over the currently QoS-deficient Internet. The network constraints in terms of delay, jitter, and loss are making critical impacts to the QoE (quality of experience) of haptic-based CVEs, as discussed in the remainder of this section [10]. The hardware setup of our haptic collaboration test bed is summarized in Figure 4.

Server:

- AMD Athlon™ 64 Processor 3500+ 2.21GHz, 1.00GB RAM
- OS : Microsoft Windows XP Professional Version 2002 Service Pack 2

Client:

- a SensAble PHANToM Omni haptic device
- Dell Precision PWS380 Intel(R) Pentium® 4 CPU 3.20GHz, 1.00GB RAM
- NVIDIA Quadro FX 1400graphics card
- OS : Microsoft Windows XP Professional Version 2002 Service Pack 2
- A 19” monitor

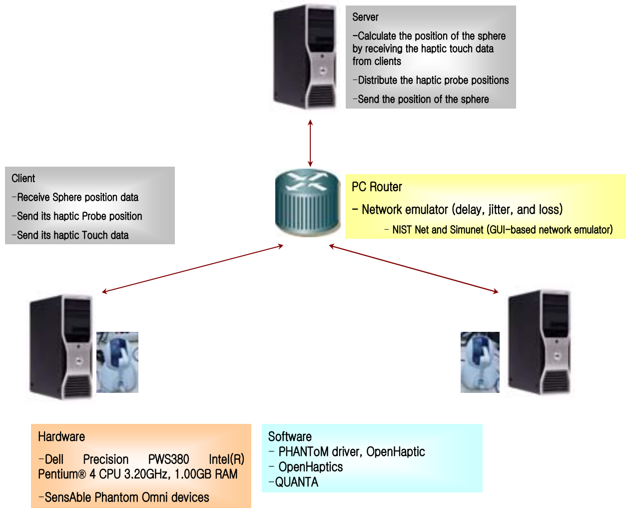

Figure 4. Hardware setup for haptic collaboration test bed

C. *Software Architecture*

OpenHaptics Toolkit(SDK) for haptic rendering from SensAble Technologies, OpenGL for graphical display, and QUANTA tool kit, a cross-platform adaptive networking toolkit are used to develop the application of our test bed. The application was written in the form of a multithreaded application which enabled the haptic subsystem to run concurrently.

As shown in Figure 5, the system has server-client architecture. This meant that more than two clients are able to participate in the system. In our model, all changes in the local application were sent to the server and after proper calculation, were distributed to every client. Two connections were used to synchronize each client as presented. The first connection carried the position vector of probes to the server and the server would bring it to the other client. It is called the ‘Haptic Probe channel’. The second connection is used to show the sphere at the same location in each of the clients’ desktops and it corresponds to the ‘Ball channel’.

The server initially receives all the data through the Probe channel and calculates the position of the sphere. Then it distributes the position of the sphere to each client through the Ball channel. The packets that carried data extracted from haptic device were categorized into two types; Probe Position and Sphere Position Packet. The first bit of each of the packets was used to distinguish a packet type. The Probe Position contained a packet type bit, client’s identifier and three double type variables. In contrast to the Probe Position, the Sphere Position Packet does not contain the client identifier because the position of the sphere was to be the same in every client’s desktop.

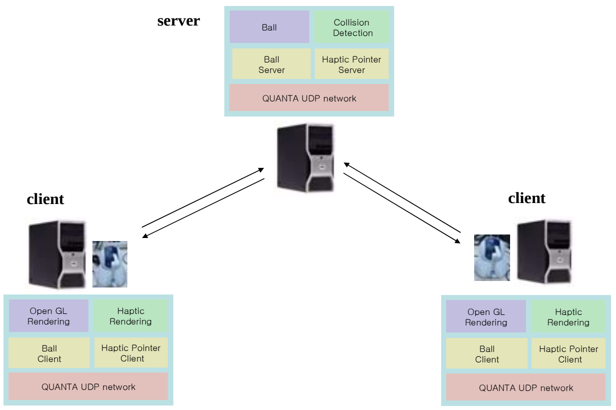

Figure 5. Software architecture of experimental haptic collaborative system

IV. EXPERIMENTS

A. Experiments Setup

We performed some experiments to examine the transmission efficiency of haptic data using the real test bed (presented in Figure 3). Note that we developed two versions of haptic basketball; one is implemented with position transfer model (shown in Figure 6), and the other version is implemented using force transfer (shown in Figure 7).

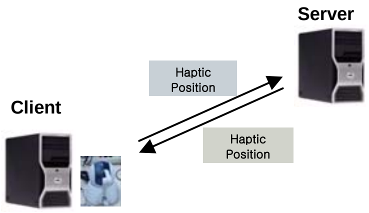

Figure 6. Position Transfer Model

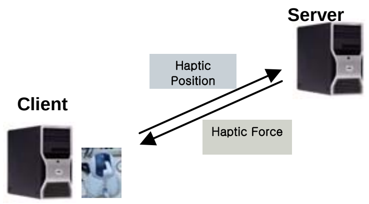

Figure 7. Force Transfer Model

For the more accurate experiments, we traced a sequence of haptic position movements of a simple hatic probe and apply the same position movements to the all experiments. Note that we only considered the force feedback of *X-dimension* in the virtual space for all the experiments in this paper. Note also that the unit of *x-axis* of all graphs in this paper is *millisecond* and the unit of *y-axis* of all graphs is *force value* for the PHAToM Omni haptic device.

B. Results

In the first experiment, we calculate the force feedback according to various losses of packets for two versions of models of our haptic basketball application. The results are presented in Figure 8 (a) Position Transfer Model and Figure 8 (b) Force Transfer Model. This experiment demonstrates that force feedback of the Position Transfer Model is reduced in the case of 5% losses, where the force feedback of Force Transfer Model is not reduced even with 10% losses. The magnified views around the beginning of loss experiments of two models are presented in Figure 8 (c) and Figure 8 (d). Note that the resulting line of force feedback in Force Transfer Model changes in steps, because the last value of force feedback is applied until the change occurs.

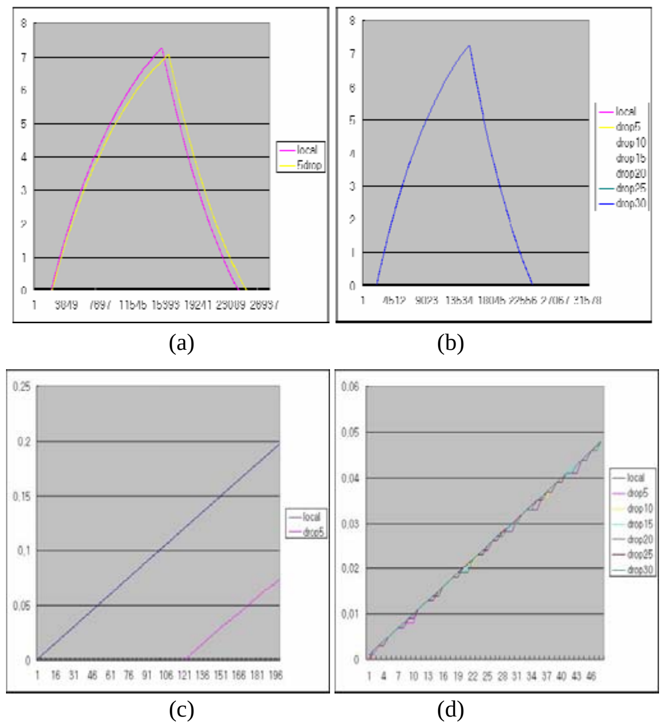

Figure 8. Force feedback according to various losses: (a) Position Transfer Model, (b) Force Transfer Model, and (c) Magnified view of Position Transfer Model around the beginning point (d) Magnified view of Force Transfer Model around the beginning point

In the second experiment, the force feedback according to various delays for two versions of models is evaluated. Figure 9 (a) and Figure 9 (b) illustrates that the pattern of force feedback of two models are very similar for various delays. Figure 9 (c) and Figure 9 (d) show the magnified views around the beginning of delay experiments of two models. We can find that the shape of force feedback is not changed and force feedback is regularly presented with given delay interval.

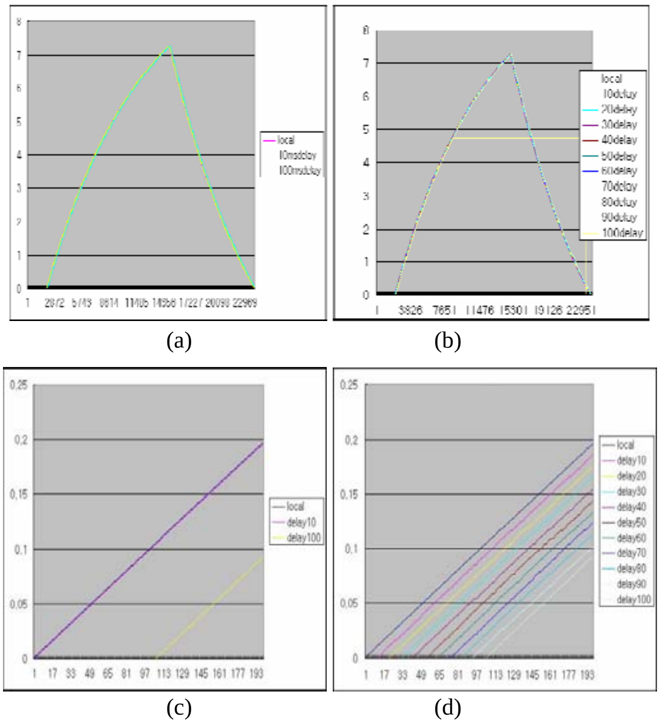

Figure 9. Force feedback according to various delays: (a) Position Transfer Model, (b) Force Transfer Model, and (c) Magnified view of Position Transfer Model around the beginning point (d) Magnified view of Force Transfer Model around the beginning point

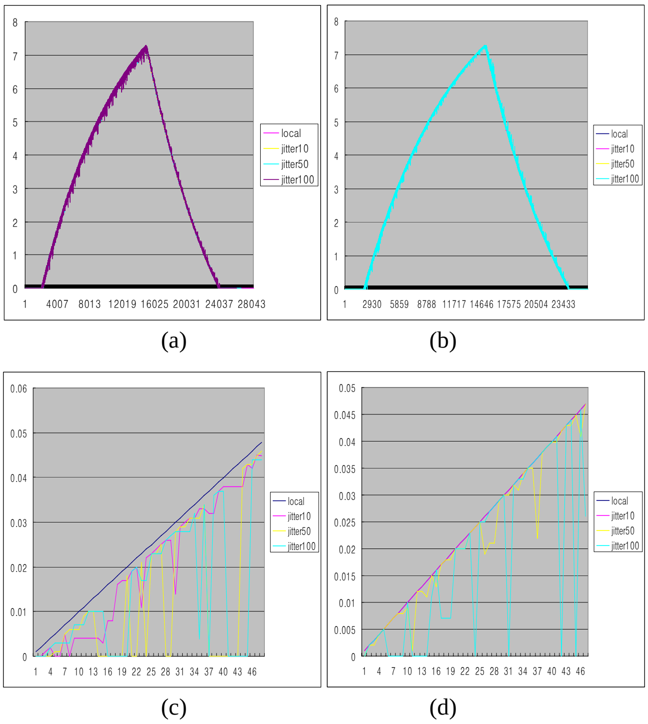

Figure 10. Force feedback according to various jitters: (a) Position Transfer Model, (b) Force Transfer Model, and (c) Magnified view of Position Transfer Model around the beginning point (d) Magnified view of Force Transfer Model around the beginning point

In the third experiment, we compute the force feedback of according to various jitters. The results are presented in Figure 10 (a) Position Transfer Model and Figure 10 (b) Force Transfer Model. The magnified views around the beginning of jitter experiments of two models are presented in Figure 10 (c) and Figure 10 (d). As illustrated in Figure 10, the patterns of force feedback with various jitters look almost the same. However, the force feedback changes very irregularly in contrast to the delay experiment. We also noticed that the variations of force with jitters are greater than those of delays and the force deviation due to jitters of the Position Transfer Model is stronger than that of the Force Transfer Model.

V. Conclusion and Future Work

The objective of our study was to mitigate the instability of the haptic interactions induced by network latency, jitter and loss that are presented under real network conditions. In order to achieve this goal, we developed an experimental haptic game and performed some experiments which allowed for analyzing the characteristics of haptic data transmission in real system according to various delays, jitters, and losses. We also examined which existing transmission model (Position Transfer Model and Force Transfer Model) was more adequate for haptic interactions.

We observe that loss of packets may reduce the force feedback in the Position Transfer Model and jitters are more sensitive than delays for both models. In fact, the loss of packets would affect the environment by reducing the force, and therefore desynchronize the touch of the objects in a shared environment.

In the future, we will study the QoS algorithm which will strongly work with significant delay, jitter and loss for haptic data transmission [11], [12], [13], [14], [15], [16], [17], [18], [19]. We will also investigate some of the adaptive transmission protocols for haptic interactions. In addition, we need to assess the subjective quality of the haptic interactions in an objective way. Later, we need to study the inter-client synchronization problem in haptic-based CVEs [20], [21], [22], [23], [24], in order to allow consistent collaboration among many participants.

References

[1] M. A. Srinivasan, and C. Basdogan, “Haptics in virtual environments: Taxonomy, research status, and challenges,” *Computers and Graphics*, 1997.

[2] T. Asano, and Y. Ishibashi, “Adaptive display control of exhibits in a distributed haptic museum, ” *Proc. the 3rd IEEE International Workshop on Haptic, Audio and Visual Environments and their Applications (HAVE'04)*, pp. 19-23, Oct. 2004.

[3] J. Kim, H. Kim, B. K. Tay, M. Muniyandi, M.A. Srinivasa, J. Jordan, , J. Mortensen, M. Oliveira, and M. Slater, “Transatlantic Touch: A Study of Haptic Collaboration over Long Distance,” *Presence*, Vol. 13. No.3, Massachusetts Institute of Technology, June 2004, pp. 218-337.

[4] S. Kunifuji, “An experimental study on the effects of network delay in cooperative shared haptic virtual environment,” *Computers and Graphics*, vol. 27, 2003, pp. 205-213.

[5] C. Basdogan, C. Ho, and M. Slater, M.A. Srinivasan, “An Experimental Study on the role of Touch in Shared Virtual Environments,” *ACM Transactions on Computer-Human Interaction*, ,Vol. 7, No. 4, December 2000, pp.443-460.

[6] OpenHaptics, http://www.sensable.com/products/phantom_ghost/OpenHapticsToolkit-intro.asp

[7] QUANTA, http://www.evl.uic.edu/cavern/quanta/
[8] K., Salisbury, F. Conti, and F. Barbagli, “Haptic Rendering: Introductory Concepts,” *IEEE Compute Graphics and Applications*, March/April 2004, pp.24-32.
[9] S. Choi, and H. Z. Tan, “Towards Realistic Haptic Rendering of Surface Textures,” *IEEE Compute Graphics and Applications*, March/April 2004, pp.40-47.
[10] SensAble technologies http://www.sensable.com/
[11] M. Fujimoto, Y. Ishibashi, “Packetization Interval of Haptic Media in Networked Virtual Environments”, ACM NetGames05, October 2005, 6 pages.
[12] K. Hikichi, H. Morino, Y. Yasuda, I. Arimoto, and K. Sezaki, “The evaluation of adaptive control for haptics collaboration over the internet,” *Proc. CQR (Communication Quality & Reliability) International Workshop*, 2002, pp. 218-222.
[13] K. Hikichi, H. Morino, I. Arimoto, I. Fukuda, S. Matsumoto, M. Iijima, K. Sezaki, and Y. Yasuda, “Architecture of haptics communication system for adaptation to network environments,” *Proc. IEEE ICME*, 2001.
[14] S. Matsumoto, I. Fukuda, H. Morino, K. Hikichi, K. Sezaki, and Y. Yasuda, “The influences of network issues on haptic collaboration in shared virtual environments,” *Proc. 5th PHANToM Users Group*, 2000.
[15] J. Marsh, M. Glencross, S. Pettifer, R. Hubbold, J. Cook, S. Daubrebet “Minimising latency and maintaining consistency in distributed virtual prototyping,” *ACM SIGGRAPH Conference on the Virtual Reality Continuum and its Applications in Industry (VRCAI)*, Singapore, June 2004, pp. 386–389.
[16] J. Marsh, M. Glencross, S. Pettifer, R. Hubbold, “A robust network architecture supporting rich behaviour in collaborative interactive applications,” *IEEE Transactions on Visualisation and Computer Graphics TVCG 12*, 3, May 2006, 405–416.
[17] M. O. Alhalabi, S. Horiguchi, “ Network latency issue in cooperative shared haptic virtual environment,” *SPIE Third International Conference on Virtual Reality and Its Application in Industry*, April 2003, Pan Z., Shi J., (Eds.), vol. 4756, pp. 199–205.
[18] D. Wang, K. Tuer, M. Rossi, L. NI, J. Shu, “The effect of time delays on tele-haptics,” *Second IEEE Internatioal Workshop on Haptic, Audio and Visual Environments and Their Applications HAVE*, 2003, pp. 7–12.
[19] R. S. Allison, J. E. Zacher, D. WANG, J. Shu, “ Effects of network delay on a collaborative motor task with telehaptic and televisual feedback,” *ACM SIGGRAPH International Conference on Virtual Reality Continuum and its Applications in Industry*, Singapore, 2004, ACM Press, pp. 375–381.
[20] B. Hannaford, J.-H. Ryu, Y. S. Kim, “Stable control of haptics. In *Touch in Virtual Environments*,” McLaughlin M. L., Hespanha J. P., Sukhatme G. S., (Eds.). Prentice Hall PTR, Upper Saddle River, NJ, 2002, ch. 3, pp. 47–70.
[21] C. Gunn, M. Hutchins, D. Stevenson, M. Adcock, “Using collaborative haptics in remote surgical training,” *worldHAPTICS First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, Pisa, Italy, March 2005, IEEE Computer Society, pp. 481–482.
[22] J. P Hespanha, M. Mclaughin, G. S. Sukhatme, M. Akbarian, R. Garg, W. Zhu, “Haptic collaboration over the internet,” *The Fifth PHANTOM Users Group Workshop, 2*000.
[23] M. Mclaughlin, G. Sukhatime, W. Peng, W. Zhu, J. Parks, “Performance and co-presence in heterogeneous haptic collaboration,” *IEEE Eleventh Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (HAPTICS)*, 2003.
[24] X. Shen, F. Bogsanyi, L. NI, N. D. Georganas, “A heterogeneous scalable architecture for collaborative haptics environments,” *IEEE International Workshop on Haptic Audio and Visual Environments (HAVE)*, September 2003, pp. 113–118.