Design of a Collaborative System for Real Time Haptic Feedback in Distributed Virtual Environments over IP Networks

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***Abstract* – This paper presents an investigation into system architectures for real time haptic feedback in distributed virtual environments over IP switched network. Network impairments such as time delay, jitter and packet loss have a different impact on remote haptic collaborations than the traditional master-slave tele-operation. A hybrid architecture has been proposed and developed to address the challenges in the new use scenario. Experiments have been conducted to show the performance of this architecture in comparison with the currently available time delay compensation algorithms, i.e. dead reckoning. A set of network Quality of Service (QoS) parameters for these types of haptic collaborative systems is obtained. Findings of the study are presented in the paper with recommendations for developing systems that support haptic collaboration.**

Keywords- Distributed virtual environments, haptic interactions, QoS, peer-to-peer, network impairments.

I. INTRODUCTION

The future Internet will have to carry a wide range of applications, and many of these will incorporate new type of traffic. There has been recent interest in the transmission of multimodal information over the internet [1], and in particular the transmission of haptic information [2][3]. Therefore, it is important to know the QoS requirements for transmitting haptic traffic over packet switched networks such as the Internet.

Effectively transmitting haptic data in Distributed Haptic Virtual Environments (DHVEs) is a promising research area for a wide range of new applications. The architecture of the DHVE for each application is important, and while peer-to-peer systems offer the benefits of scalability and decentralized control, there are a number of significant challenges associated with synchronizing the virtual environments across a network. Network impairments can have severe (and different) impacts on the user's haptic experience and while the basic network QoS parameters for haptic interaction have now been established [3], to date there has been no consideration of the specific network impairment parameters for peer-to-peer distributed virtual environments that require force and positional synchronization. The effect of network impairments has a direct impact on the sense of human perception during DHVE interactions. Each network impairment affects the sense of force feedback in a particular way. Studies have shown that the haptic experience is especially sensitive to jitter, and deteriorates as network-induced packet delay beyond 30ms and packet jitter beyond 2ms [1].

The contributions of the work presented in this paper are: (i) a new peer-to-peer architecture and an associated algorithm for supporting force collaboration and position synchronization in networked haptic applications, (ii) an empirical investigation of the QoS parameters for haptic collaboration with our proposed algorithm, which is considered together with the well-known dead reckoning position prediction algorithm [5], and a proprietary delay compensation algorithm: TiDeC™ [6] respectively, (iii) we also show the effect of network impairments i.e. delay and jitter, on collaborative force with our proposed algorithm together with either TiDeC™ or dead reckoning.

II. EXISTING RESEARCH IN NETWORKED HAPTICS

Kim and Jordon [7] present a study of transatlantic network latency. The experiment concerns a collaborative method in which both users lift a virtual cube. Questionnaires were used to report the ease with which they could perform the task and the subjective levels of presence and co-presence experienced. Hikichi

[8] have designed a client and server system in which two clients are connected to one server. Dead reckoning and media synchronization are used. Delay jitter between 10 and 40ms adversely affects their system. The packet transmission of their system is only 20 packets per second.

Cheong [9] uses motion synchronization control with a shared virtual environment. This type of control can be used effectively when the round trip delay is less than 300ms. However, there is no study of jitter or packet loss which are major problems in DVHE applications. Dead reckoning and pre-reckoning [10][11] are used in distributed virtual environments to predict the trajectory of an entity. The aim of dead reckoning is to reduce network bandwidth utilization. In operation, update packets are only issued to notify peer hosts of a change in status when a preset error threshold has been exceeded [10][12].

The majority of the preceding works have concentrated on synchronization of positions (haptic device or virtual objects). The work presented here further extends this to study the force interaction between two users. We have developed an experimental platform based on the peer-to-peer network architecture in order to study network impairments for haptic feedback in distributed virtual environments. We transmit the haptic interface point (HIP) position, the virtual objects' positions, timestamp and force to the remote environment.

III. METHODOLOGY

Our system employs a peer-to-peer architecture whereby each peer has its own copy of the virtual environment database. When there is a change of local status, this update is sent directly to the remote peer without going through any server. The transmission of force is important when the virtual object is being touched by two subjects at the same time. Both subjects are able to feel a reaction force when pushing a virtual object against each other. Therefore, when two forces push the virtual object at the same time, the stronger force will decide in which direction the virtual object should move. Position synchronization is effected by the transmission of the position difference which is calculated from current and previous position. The position difference of the local peer is transmitted to the remote peer. The pseudo-code for our haptic interaction algorithm is given below.

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Local position displacement, Δp_l ← previous position (t-1) – current position (t)

Remote position displacement, Δp_r ← previous position (t-1) – current position (t)

if (local_force_flag == true)
        final_position, p = local position + Δp_l
        final_force, f = local_force + Δf
else
        final_position, p = local position + Δp_r
        final_force, f = 0
```

The algorithm can also be represented by a time events diagram as shown in Fig. 1. The concept of the algorithm in Fig.1 is the same as the pseudo-code. The differences in position, force and time at local peer are sent to remote peer and vice versa. Fig. 2. shows the concept of the forces calculation in which we will have a local force calculation for each peer. The resultant force is the summation of the local force and remote force.

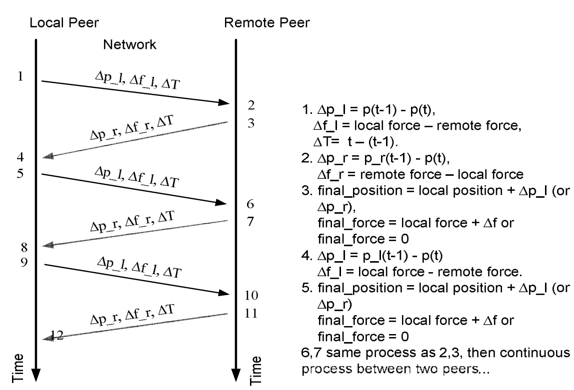


Fig. 1. Position, force and time events on local and remote peers

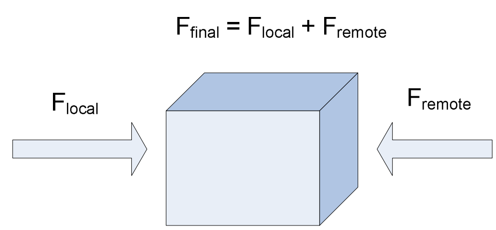


Fig. 2. Calculation of interactive forces on a virtual cube at local and remote peers

IV. EXPERIMENTAL TESTBED

In the test system, two PCs are used to carry out the tasks. A network emulator called NetDisturb [13] is used in order to create the network impairments to the traffic flowing between the two peers. Each peer in Fig. 3 transmits device (HIP) position, virtual object position, timestamp and force to the remote peer. The packet rate between the two peers is 1000 packets/second.

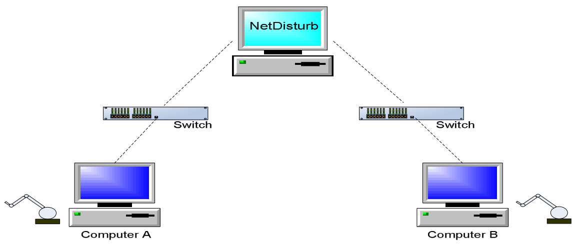
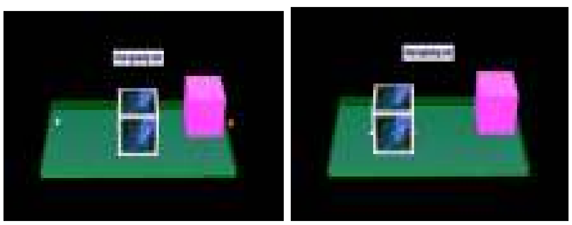


Fig. 3. Experiment platform of peer-to-peer system with NetDisturb



(a) (b)

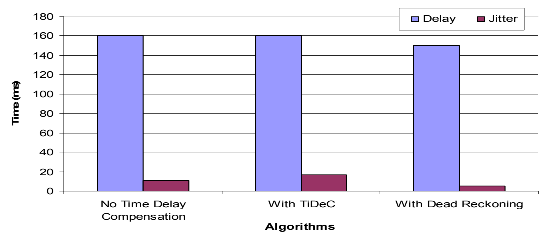
Fig. 4. Local & remote views of the collaborative virtual environment with one moving cube and one static cube

The peer-to-peer system of our haptic environment consists of a work platform, one moving cube, one static cube and two ball spheres which represent local and remote PHANToM Omni [14] cursors (HIPs). Subjects are able to feel the two virtual cubes but not the work platform. The blue cube in the middle of Fig. 4 is movable and whereas the pink cube on the right hand side of screen shot is static. Subjects are able to push the moving blue cube by using two PHANToM devices and feel the momentum, force, and velocity of the virtual cube. A collaborative task is a task whereby subjects are taking turns to perform a task at different time. A co-operative task is the time that two users are in fact manipulating a virtual object at the same time, as shown in Fig. 5.

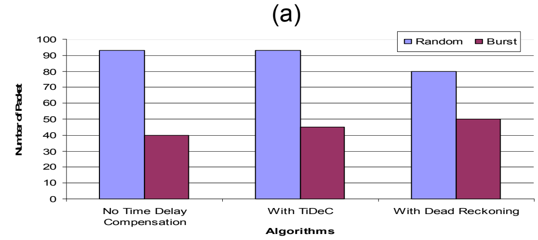
Fig. 5. Photo shows subjects doing tasks within a DVHE

V. EXPERIMENTAL RESULTS

Fig. 6 shows evaluation of time delay compensation algorithms in force collaboration when two subjects push the virtual cube together under the influence of delay, jitter and packet losses. In Fig. 6a, the system was able to accept about 160ms delay before the force collaboration became unacceptable. At this point, the virtual cubes appeared to feel "soft" when touched with the HIP. This is because the position of virtual object had not been updated yet due to the delay. Incorporating dead reckoning reduced this delay tolerance by a small amount to 150 ms, while TiDeC™ did not make any difference.



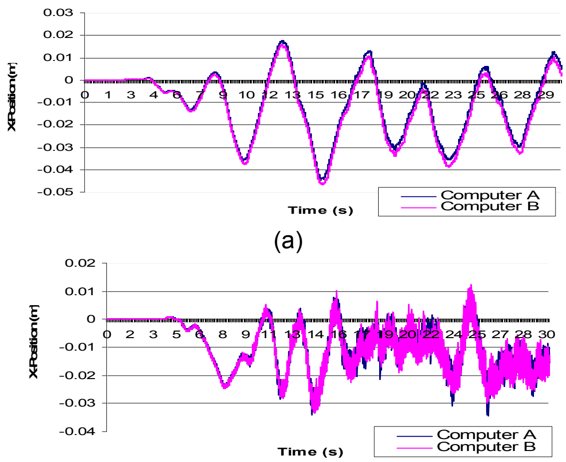
(a)



(b)

Fig. 6. Evaluation of different types of algorithms with (a) delay and jitter, (b) random and burst packet loss in force collaboration

Fig. 6b shows the size of packet loss for different compensation algorithms. Our basic system without time delay compensation algorithms was able to sustain good force collaboration with random packet losses at the rate of 93 packet loss out of 100 packets and burst packet loss at the rate of 40 packets. TiDeC™ was able to accept the same amount of random packet loss but tolerated a higher burst loss of 45 packets. However, the dead reckoning algorithm only tolerated a random packet loss of 80. This is because dead reckoning is based on prediction; any loss of next states can severely affect the calculation. This is especially true for random packet loss. However, dead reckoning works better if the packet lost is predicted and continuous. This is shown in Fig. 6b which is burst loss of 50 packets.



(a)

(b)

Fig.7. X-Position discrepancies of the virtual cube under 15ms jitter with (a) TiDeC™, (b) Dead Reckoning

Fig. 7 shows the x-position discrepancy against jitter between the two peers with TiDeC™ and dead reckoning when two subjects pushed the virtual cube together. Fig. 7(a) shows that TiDeC™ maintained the position of the virtual cube. We can still see the trajectory of the virtual cube position. The trajectory of x-position follows a curve with lapse of time. Fig. 7(b) shows that dead reckoning made the system totally unusable because virtual cube's position moved vigorously and its trajectory was not able to follow the curve of the virtual cube position. This is due to the fact that dead reckoning calculates the velocity for use in position prediction by using the current and previous data packets. Jitter makes the velocity varies thus the predicted position is varying. The variation of velocity caused by jitter is more severe than constant delay because the arrival time of data packet is changing. Our basic algorithm responds with jitter has the similar effect as TiDeC™.

Table 1 summarizes our findings with average, minimum, maximum and standard deviation of x-position between both peers under 160ms delay. The results in Table 1 show that standard deviations of our basic algorithm and TiDeC™ are higher than dead reckoning technique. This is because our algorithm and TiDeC™ don't predict virtual cube position under delay. In our algorithms and TiDeC™ with 160ms delay, the virtual cube at the two peers is moving in opposite direction when two subjects push the virtual cube together. This effect is because the cube position of remote peer has not arrived at local peer yet due to delay. In dead reckoning, the standard deviation is lower because of prediction algorithm. In Table 1, dead reckoning reduces the x-position discrepancy but it also creates deviation from the original trajectory as similar to the case of jitter.

Table 1. X-Position discrepancy between local and remote peer with constant delay = 160ms

Network Impairment	X-Position Discrepancy (mm)		
Algorithms	No Time Delay Compensation	TiDeC	Dead Reckoning
Average	13.78864	13.99095	3.34105
Minimum	0	0	0
Maximum	46.01366	50.12439	58.8545
Std Dev.	10.98565	10.80822	3.840116

VI. CONCLUSION AND FUTURE WORK

In this paper, we have presented a prototype system for networked haptic interactions and proposed a force collaboration and position synchronization algorithm. A set of network QoS parameters for these types of haptic collaborative systems is also obtained. The experimental results show that the system achieves acceptable force collaborations up to delays of 160ms. Meanwhile, jitter is a main problem for dead reckoning algorithm in which it allows only 5ms. From experiment results, it is more difficult to perform force collaboration under the influence of burst packet loss than random packet loss. TiDeC™ does not have much effect on virtual objects position when they are pushed by HIP. For collaborative system with force feedback, the position prediction type of algorithm such as dead reckoning is not suitable in a peer-to-peer haptic application because of the way we make contact with virtual objects (force collaboration).

It remains a challenge to designing DVHE type of application under network impairments. While we have defined a set of network QoS parameters for real time haptic feedback, enhanced compensation algorithms is required to provide the haptic collaborations under large network delay, jitter and loss. Later, we need to investigate the possibility of a system that allows consistency force and position collaboration among multiple users.

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