Collaborative Haptic Environment Assessment

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ABSTRACT

Collaborative virtual environments (CVE) allow users from different geographical locations to execute a shared task by acting upon the same entities in the virtual world. Most of these environments rely on visual and auditory senses. The advances in haptic technology have opened a path for the sense of touch to be integrated into CVE. The main issue in a haptic CVE is maintaining state consistency despite the existence of network delays. We focus this research on studying the effects of network latency on task performance and we report our preliminary results.

KEYWORDS: Haptics, Collaborative Haptics

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces - Haptic I/O; C.2.1 [Computer-Communication Networks]: Network Architecture and Design - Network Communications

1 INTRODUCTION

Haptic, derived from the Greek word *haptesthai* (meaning 'contact' or 'touch'), is an emerging technology that simulates the sense of touch in computing. From research and education to entertainment, the opportunity for the use of haptic technology is growing fast. Recent advancements in haptic technology have significantly reduced the cost of haptic hardware, making them more affordable and widespread.

As an emerging technology, the performance of force feedback over different media has not been thoroughly investigated. Visually and auditory mediated distributed environments (i.e. tele-collaborations) have been investigated extensively in the last decade through a set of distributed virtual environments and distributed interactive simulations. However, haptic mediated distributed environments have been the subject of a relatively small set of studies. This is mainly due to the lack of availability and the difficulty of integrating haptic rendering devices. In recent years, a few research groups investigated haptics for distributed environments [1-3].

An inherent negative characteristic of the collaborative virtual environments is network delays. The integration of haptic interfaces with visual and audio becomes challenging. Solutions were proposed to cope with delays for sensory modalities (visual, auditory, and haptic), from a technical perspective, but from a perceptual perspective, multimodal distributed CVE design must take into consideration the behavioral and neurological patterns specific to its human users. An efficient distributed multimodal CVE must provide an excellent "perceptual integration", which is not only task dependent but might be even more difficult to attain than the technical integration [4, 5].

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In this paper we report on our investigation of the effects of network delay and jitter on task performance, in a CVE utilizing visual and haptic simulation over IP networks. Delays in a small Local Area Network (LAN) are negligible, but will grow as the size of the network increase. To investigate network latency on the LAN, we incorporate randomly simulated delays in the CVE. To facilitate data collection, we deployed Wireshark® [6] to monitor and record packets transmitted across the LAN. Between the CVE output and Wireshark, we are able to determine if there are any real delays, packet loss or jitter and, how they affect the collaborative task performance.

2 EXPERIMENTAL DESIGN

We developed a 3D scene where, two remote users can manipulate four cubes (Figure 1). The goal of the task is to stack all four cubes onto a central stacking pedestal by lifting the cubes with haptic devices and maneuvering them into place. The design includes boundaries (such that the cubes do not leave the range of motion of the haptic devices), simulated gravity to provide mass to the cubes, friction to enable the lifting of cubes, collision detection, and shadows for depth perception. We employ Sensable's H3D API, which combines numerous open-source standards into one software development platform, to implement the simulation. The 3D scenes graphics are implemented using X3D. The Python scripting language is used to define the behavior of the haptic devices.

Figure 1. Two users collaborating with each other in the cube staking task, using haptic devices

We conducted the experiments using voluntary student participants from various departments. The participants performed six warm-up trials before they started ten test trials. The warm-up trials were used to familiarize the participants with the haptic equipment and the task. There were no simulated delays in the warm-up trials. During the test trials, the CVE generated simulated delays as in the previous experiments. Delays of 25, 50, 100 and 200 milliseconds were randomly introduced during the test trials. The 0 delay (*"default"* delay) was used as the base case. For each trial, the cubes were positioned randomly in the scene to prevent habitual performance through repetition.

Shadows were implemented to give the users additional depth cues. They were implemented as black squares that followed the cubes along the floor, with lengths and widths equal to the cubes they represented, and positions defined by the x and z coordinates of the object.

To implement the network side, we used a generic client-server architecture. The client side provided the user interface and user-centric logic for haptic interaction. The client sent streaming data to the server using the User Datagram Protocol (UDP). The packets contained pointer coordinates and forces. The server processed the information received by the client and sent streaming data back to the clients, providing continuous synchronization.

We utilized three computers located in our research lab and a 5-port gigabit Ethernet switch to build up a LAN. The two clients were installed on comparable desktop. The server and the Wireshark software were installed on a laptop used also to monitor and collect data. The computers were coupled together using Cat 5e Ethernet cables ranging from 15 to 20 feet and configured in a Class C Network.

3 Assessment

We established a set of objective parameters for the experiment to determine the effectiveness of the task performance and compare performances between trials with different network delays.

1. Time for task completion: is a measure of how well the users worked together to complete the task.
2. Number of broken cubes: is a measure on how well the users responded to each other during the task.
3. Quality of stacking: is a measure of how well the users worked together and responded to each other.

We defined a single subjective parameter to help us gauge the quality of the user's interaction with each other in the CVE. Togetherness: A sense of togetherness may improve collaboration if users can perceive each other.

4 Results

Our first assessment showed that the mean time to complete the task with 25, 50, 100, and 200 ms delays was 82, 95, 138, and 171 seconds respectively as illustrated in Figure 2. This data formed a quadratic trend, demonstrating that as the network delay increased, the time to complete the task increased. The results for the second assessment showed a strong correlation with the first assessment, where the mean number of cubes broken were 1, 3, 4, and 6 for the same delays (Figure 3). The final assessment yielded unexpected results. The data formed a cubic trend with a small variance between network delays with a mean distance of 3.3, 3.8, 3.9, and 3.7 cm (Figure 4). The base case ("default" delay) is highlighted with a bold horizontal line.

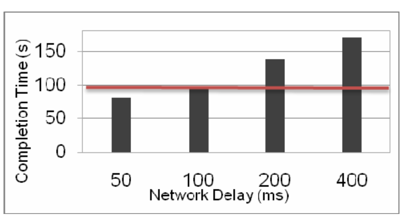

Figure 2. Mean time to complete task

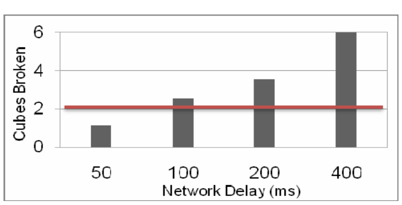

Figure 3. Mean number of cubes broken

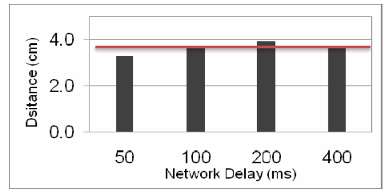

Figure 4. Mean distance from center

Following the experiment, we presented each participant with a survey asking them to rate how well they perceived the other user visually and tactilely, and to indicate which sense they felt the most helpful in completing the task. The results showed that 21 of 22 participants felt that they perceived the other participants through the use of haptics. However, only 5 of the 22 participants selected the tactile sense as the most useful. The visual sense had the highest selection at 14; the auditory sense at 3 (as users were allowed to talk with each other).

5 Conclusions

We setup a preliminary experiment in which remotely located users cooperate in the virtual environment each of them manipulating one haptic device in order to achieve a shared goal. We simulate networks delay in a client-server architecture deployed over the LAN in order to investigate the latency effect on task performance. Preliminary results suggest that delays negatively affect reaction time and task completion time, but has little affect on the user's accuracy. Seemingly, there is a delay threshold (of about 200ms) for this task. Passing this threshold will negatively and substantially impact task completion. Future work will attempt to clearly delineate the delay threshold for a generic human task and assess the effect of delay and delay variation on collaborative task performance to determine parameters critical to the use of haptic devices in cooperative tasks.

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