Supporting Collaboration in Distributed Environments by Haptic Force Feedback.

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ABSTRACT
The extent that haptic force feedback affects peoples ability to collaborate in a distributed way or how it affects their perception of the collaborative environment has not been investigated much. In this paper an experiment is presented where collaboration in a distributed desktop virtual environment with haptic force feedback was studied. A video analysis of the frequency of failures to lift cubes collaboratively in a haptic condition compared to a condition with no haptic force feedback was conducted. The frequency of failures to lift cubes collaboratively is in this study a measure of precision in task performance. The statistical analysis of the data shows that it is significantly more difficult to lift objects collaboratively in a three-dimensional desktop virtual environment without haptic force feedback.

INTRODUCTION

In this paper results are presented from an experimental study of interaction in a collaborative desktop virtual environment, where the independent variable was haptic force feedback. The PHANToM, a one-point haptic device was used for the haptic force feedback, and a program especially developed for the purpose provided the collaborative virtual environment. The program enables for two individuals placed in different locations to simultaneously feel and manipulate dynamic objects in a shared desktop virtual environment. The main aim of this paper is to present results from an analysis of the video recordings of the collaboration between subjects. The focus of the analysis was to investigate how haptic force feedback affected the precision in manipulating objects collaboratively in the desktop virtual environment.

In an earlier analysis of data from the experiment it was shown (Sallnäs et al in press) that haptic force feedback significantly increases task performance, which meant that the tasks were completed in less time in the haptic force feedback condition. All pairs of subjects succeeded in completing all tasks, which means that it was possible to manipulate the PHANToM satisfactorily in both conditions. Results from a questionnaire that measured perceived performance showed that the subjects in the haptic feedback condition perceived themselves as performing tasks significantly better. Results also showed that haptic force feedback significantly improves perceived virtual presence in the collaborative distributed environment, measured by a questionnaire. Virtual presence was in this experimental study defined as the subjective experience of being in one place or environment, even when one is physically situated in another. Finally the results showed that haptic force feedback did not increase perceived social presence significantly, also measured by a questionnaire. The definition of social presence in this experimental study was "feeling that one is socially present with another person at a remote location".

BACKGROUND

A small number of studies have investigated interaction with haptic force feedback interfaces. The result in one study suggests that if people have the opportunity to "feel" the interface they are collaborating in, they manipulate the interface faster and more precisely (Ishii et al, 1994). In a study by Gupta et al (1997) that investigated the effect of haptic force feedback, results indicated shortened task completion times when the task was to put a peg in a hole simulating assembly work (Gupta et al. 1997). Also, Hasser et al. (1998) showed that the addition of force feedback to a computer mouse improved targeting performance and decreased targeting errors. In another study the subject's performance was improved significantly when the task consisted of drawing in an interface (Hurmuzlu et al., 1998). These studies did not investigate collaborative performance but single human computer interaction. However, in one study, subjects were asked to play a collaborative game in virtual environments with one experimenter who was an "expert" player. The players could feel objects in the common environment. They were asked to move a ring on a wire in collaboration with each other in such a way that contact between the wire and the ring was minimised or avoided. Results from this study indicate that haptic communication could enhance perceived "togetherness" and improve task performance in pairs working together (Basdogan, 1998; Durlach & Slater, 1998).

METHOD

Subjects

Twenty-eight subjects participated in the experiment. The subjects performed the experiment in pairs. There were 14 pairs, - each consisting of one woman and one man (figure 1). The subjects were students from Lund University in Sweden. The subjects were between 20-31 years old and the mean age was 23 years.

Figure 1. Subjects are doing tasks using two versions of the PHANToM, on the left a "T" model and on the right an "A" model.

Independent Variable

The independent variable in the experiment was the collaborative desktop interface with two conditions, one three-dimensional visual /audio/haptic interface and one three-dimensional visual/audio interface. The variable feature was haptic force feedback. The environment exists in two different versions, one with haptic force feedback and one without haptic force feedback. The haptic environment consists of a room with constraining walls, ceiling and floor, containing eight dynamic cubes that initially are placed on the floor (figure 2).

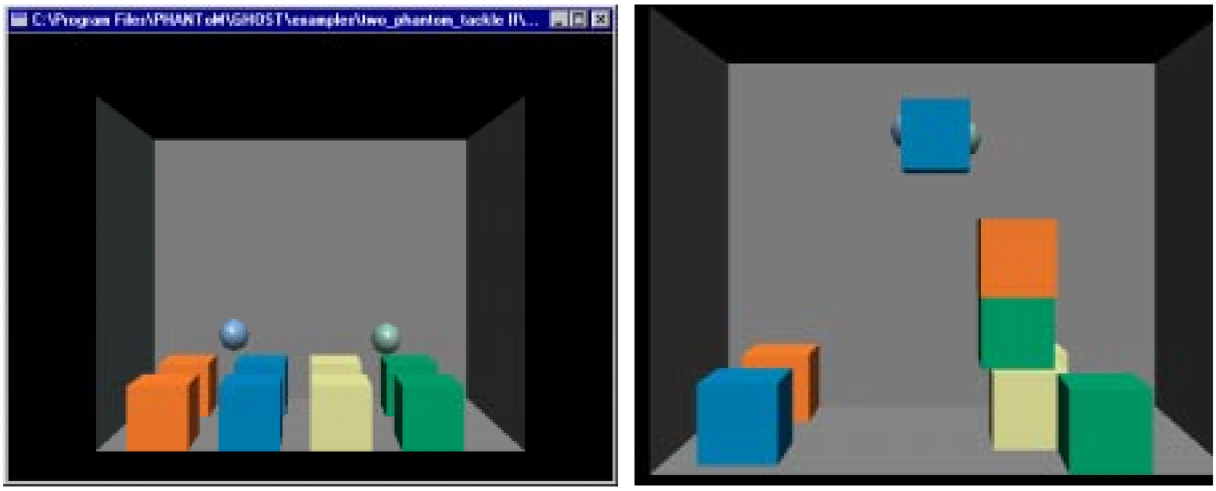

Figure 2. Two views of the collaborative virtual environment with eight dynamic cubes placed in the room and representations of the users in the form of one green and one blue sphere. The right picture shows two subjects lifting a cube together.

The cubes are modelled to simulate simplified cubes with form, mass, damping and surface friction, but lack e.g. the ability to rotate. The cubes are of four different colours (green, blue, yellow and orange, two of each) to make them easily distinguishable, but are identical in dynamic behaviour, form and mass. Furthermore, the users can hold on to each other - a feature originally implemented to enable the users to virtually "shake hands". Lifting the cubes can be done in two different ways. Either the users collaborate in lifting the cubes by pressing into the cube from opposite sides and lift it upwards simultaneously, or a single user lifts a cube by pressing it against the wall and pushing it upwards. Spheres with a diameter of 12 mm represent the users. In the graphical version they are distinguishable by colour (one is blue, the other green). In the version without haptic force feedback, the user can feel neither the cubes, nor the walls, nor the other user in the environment, and the users cannot hold on to each other. In that case, the PHANToM functions solely as a 3D mouse.

Apparatus

The haptic display system used in this investigation was a PHANToM (figure 1) from SensAble Technologies Inc. of Boston, MA. Two PHANToMs, placed in two different rooms linked to a single host computer, were used for the experiment. Both PHANToMs were identical in operation, but were of different models. One was attached to the table (the "A" model) and the other was attached hanging upside down (an older "T" model). Two 21-inch computer screens were used to display the graphical information to the users, one for each user in the different locations. The screens, attached via a video splitter to the host computer, showed identical views of the virtual environment. Headsets (GN Netcom) provided audio communication via a telephone connection. The headsets had two earpieces and one microphone each. One video camera was used to record the interaction from one of the locations and a tape recorder recorded the sound at the other location. The angle of video recording was from behind the subject and slightly from the side so that the computer screen and the hand with which the person was controlling the PHANToM were visible.

Tasks

Each collaborating pair of subjects was presented with five tasks (A- E). Task A-C consisted of lifting and moving eight cubes together in order to build: one cube without an illustration (task A), two lines (task B, fig. 5), and two piles (task C, fig. 6). Task D required the subjects to explain one half of a whole pattern to the other subject, as each subject had only one half of an illustration each, and then build the whole pattern (fig. 7-8). The instructions for task E were to navigate together around the pattern that the subjects had built in task D (fig. 9).

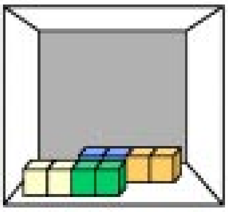

Figure 5. Task B

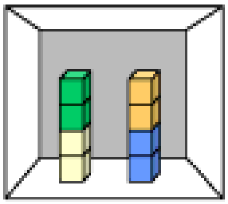

Figure 6. Task C

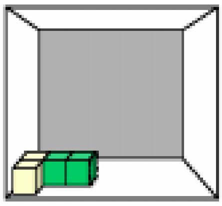

Figure 7. Task D, person 1

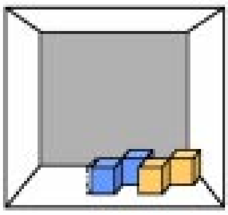

Figure 8. Task D, person 2

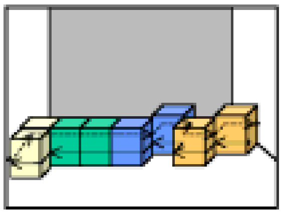

Figure 9. Task E

Video analysis

The video recordings generate reliable data about the navigation and manipulation of cubes of both subjects in the virtual desktop environment, as one computer screen is videotaped. Subjects' behaviour in the environment can thus be studied. In both conditions but especially in the condition without haptic force feedback, the subjects did not always manage to lift or transport the cubes because they did not position their representations (with their PHANToM) correctly. In this study the video recordings were analysed in order to collect the frequency of failures to lift the cubes collaboratively as a measure of precision in task performance. The operational definition of failure to lift a cube was, that two subjects positioned their representations beside one cube and tried to lift it, but failed to lift or transport the cube in order to proceed one step in performing the task. Data on the frequency of failures to lift the cubes collaboratively were collected for two of the five tasks. These were tasks A and C that required subjects to lift cubes in order to complete the tasks.

RESULTS

Frequencies of failures to lift cubes together were analysed with ANOVA. Results show that there is a significant difference between conditions regarding subjects´ ability to lift cubes in task A (p=0.003) and in task C (p=0.011). In the haptic force feedback condition subjects failed to lift cubes on average 4 times in task A and 7 times in task C. In the condition without haptic force feedback subjects failed to lift cubes on average 12 times in task A and 30 times in task C. This should be compared to the results that show that there was no significant difference between conditions regarding how many successful lifts the subjects performed in order to complete task A (p=0.32) and task C (p=0.67).

Failure to lift cubes together				Haptic feedback	No haptic feedback
Task A	(n=14)	F=15	p= 0.003 **	M=4	M=12
Task C	(n=14)	F=9	p=0.011*	M=7	M=30

* = significant at 95% level
** = significant at 99% level

CONCLUSIONS

The results of this study are consistent with the earlier results that show that haptic force feedback improve performance. The earlier results suggested that it took significantly longer time to perform tasks in the condition without haptic force feedback. In the earlier analysis subjects also reported significantly higher perception of their own performance in the haptic environment. The analysis that is presented in this paper show that it is significantly more difficult to coordinate actions with the aim of lifting objects in a three-dimensional desktop virtual environment without haptic force feedback. These results show that at least a major part of the difference regarding time to perform tasks can be explained by the fact that subjects' precision when moving cubes without haptic force feedback is significantly lower.

It should be noted that even in the haptic condition manipulation of virtual cubes were not effortless and subjects did fail a number of times even with haptic force feedback. But subjects performed the actions that they had planned more consistently and they did not shift focus as often because of failure to lift a cube.

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