Handing Over Objects in a Haptic Collaborative Virtual Environment

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Abstract

Co-located collaboration often involves joint object manipulation. Therefore, it is of interest to be able to manipulate objects in real time also in collaborative virtual environments. An experimental study was performed to investigate if haptic force feedback is advantageous when handing over objects in a three-dimensional virtual environment. In the collaborative haptic virtual environment used in the study, it was possible to feel the surface and the weight of the object that was handed over, and also the other surfaces in the environment. In the nonhaptic virtual environment the Phantom device functioned solely as a 3D mouse. Results showed that the haptic and the nonhaptic condition did not differ regarding the time it took to perform error free hand overs. However, when hand overs with errors were analysed, results showed that it took significantly longer time in the nonhaptic compared to the haptic condition. A significant learning effect was found in the haptic condition but not in the nonhaptic condition.

Keywords: Collaborative haptic environments, multimodal interaction and communication, hand over task, experiment.

1. Introduction

Object manipulation is an important activity in everyday life that can also be performed in virtual environments. In the study presented here the extent to which haptic force feedback improves performance when a person hands over a virtual object to another is investigated.

Joint manipulation of objects in collaborative virtual environments (CVE) has not been as well studied as single user manipulation.

Recently it has also become possible to add haptic force feedback in virtual environments in order to support perception of form, weight, surface friction, texture and softness or hardness of virtual objects.

A number of studies have shown that adding haptic force feedback improves single users performance when manipulating virtual objects. The added value of haptic force feedback lies in peoples´ ability to feel the object they manipulate, which makes interaction faster and more precise. One study showed that the effect of haptic force feedback shortened task completion times when the task was to put a peg in a hole simulating assembly work [4]. Hasser et al. [5] showed that the addition of force feedback to a computer mouse improved targeting performance and decreased targeting errors.

It has also been shown that if people get haptic force feedback from the context their performance is improved [11]. Results from that study showed that if a person gets haptic feedback from a table when sliding an object between two targets, performance is better than if moving the object through space without haptic feedback from the context.

In many cases people need to manipulate virtual objects jointly and would benefit from haptic force feedback when doing so. A few studies have investigated issues regarding joint manipulation of virtual objects in a haptic collaborative virtual environment [2; 6; 8; 9; 10].

In one study subjects were asked to play a collaborative game in virtual environments with one of the experimenters 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 such that contact between the wire and the ring was minimised or avoided. Results from this study showed that haptic communication enhanced perceived togetherness and improved task performance when pairs of people worked together [2].

In another study it was shown that subjects performed tasks significantly faster and more precisely when manipulating objects together in a haptic CVE compared to a nonhaptic CVE [9; 10]. One task required that subjects lifted cubes by pushing from each side of the object in order to build, two piles from eight cubes while another task was to build one cube out of the same eight cubes. Two other tasks required that subjects placed cubes in formations on the floor and in the last task subjects navigated, close together, around a formation. This study also showed that when haptic force feedback was provided, subjects´ perceived virtual presence was significantly improved.

Manipulation of objects can take many forms and one categorisation illustrates how diverse functions haptics fulfils in everyday life [7]. People use different strategies depending on the purpose of the tactile manipulation, like when investigating the weight, form, texture or softness of an object.

Joint manipulation of objects and indeed of objects in relation to contexts, can take just as many forms. One example is jointly grasping an object and moving it through an area that might have restrictions. Another example is moving an object by pushing from both sides and lifting the object together. In the experiment presented here "grasping" an object and handing it to another person in a virtual environment will be investigated.

Haptic force feedback might in the future be used for collaborative real-time manipulation of objects when for example constructing prototypes in three-dimensional CAD applications. Then it is essential to have knowledge about how collaborative motor events like lifting, handing over, guiding and so on, benefits from haptic force feedback.

The aimed movement paradigm advocated by Fitts [3] for evaluating performance in goal directed movements is well known. The classic task is a tapping task whereby a single person taps back and forth between two targets. In one study it was shown that a Fitts´ tapping task was performed significantly faster when haptic force feedback was provided [1]. Fitts´ law has been applied for many different navigation devices.

Traditionally one participant is asked to move a pointer to a stationary target. However, another possibility is that both the pointer and the target are mobile as when a person threads a needle. A third situation is when two people hand over an object from one person to the other, in order to move it between two targets.

The aim of the experimental study presented here is to determine if haptic force feedback is advantageous when handing over objects rapidly in order to move it between two targets in a three-dimensional virtual environment.

2. Method

2.1 Apparatus

The haptic and the nonhaptic virtual environment were implemented using the Reachin API at a Windows 2000 PC platform. The haptic display systems used in this project were two ReachIn Displays from ReachIn Technologies AB with two Desktop Phantoms from SensAble Technologies, Inc. (Figure 1). This system provides stereo vision by stereo glasses, CrystalEyes 3, from Stereographics.

Figure 1. A person collaborating in the haptic collaborative virtual environment using the ReachIn Display system.

In order to avoid network delays and related problems, both devices ran on the same PC, connected serially. Both users had the same, static third-person view of the environment.

The computer screen was video recorded for later analysis regarding task performance.

Subjects were not able to communicate with each other during the experiment. The experiment leader instructed one subject face to face and one subject by phone. This means that one subject had a headset.

2.2 The User Interface

The three-dimensional graphical user interface was designed as a room with two larger shelves, on top of which six cubes were placed, three by three. The room also contained two smaller shelves that served as target areas, underneath the two larger shelves.

The distance between the target shelves was fixed at 15,9 cm. Also the size of the target shelves was fixed.

The object size varied between 1,2 cm, 1,6 cm, 2,0 cm, 2,4 cm, 2,8 cm, and 3,2 cm in the shape of a cube. The avatars had the shape of spheres.

In both the haptic and the nonhaptic environment it was possible to grasp a cube by placing the avatar on the cube and then clicking the button on the haptic device. In this way it was possible to lift cubes. When the button was released so was the cube. It was in this way possible to hand over a cube to another user.

The haptic user interface was developed so that all surfaces in the environment were touchable and thus provided haptic force feedback. It was also possible to "feel" all events like in the physical world, e.g. gravity, other users impact on an object and collisions between cubes. The different haptic properties were texture, size, weight and stiffness. All other surfaces in the environment was also haptic with a certain friction and stiffness. The users were able to feel the other avatar that was represented by a sphere in the environment.

In the CVE condition without haptic force feedback, the user could neither feel the cubes, walls, floor, shelves or the other user in the environment. In that case, the Phantom functioned solely as a 3D mouse.

2.3 Subjects

Ten subjects participated in the experiment, with a mean age of 33 years. The subjects were nine students from Stockholm University and one administrative personnel from The Royal Institute of Technology. The subjects performed the experiment in five pairs, each consisting of one woman and one man. None of the subjects had prior experience with the collaborative desktop virtual interface used in this study. The subjects did not know each other before the experiment.

2.4 Task and Procedure

For this experiment a within group design was used. Each subject was seated in front of a haptic display system in separate rooms.

The experimenter took a cube from the upper shelves and placed the cube on one of the target shelves. Subjects were asked to alternately grasp a cube placed at a target shelf in the CVE, lift the cube and hand the cube to the other subject who tapped the cube at the second target shelf (Figure 2).

After the second subject has tapped the cube at the second target shelf, without letting go of it, she directly lifts it again and hand the cube over to the first subject and so on. Subjects used their dominant hand when doing the hand over task.

Subjects were asked to do the hand over task during a time period of 60 seconds. They were instructed to avoid dropping the cube. The subjects were told when to start and when to stop doing the task. The experimenter then placed the next cube at a target shelf and the subjects performed the hand over task for 60 seconds.

Subjects trained before the first haptic and before the first nonhaptic experimental trials until they could perform hand overs correctly and felt confident in doing so.

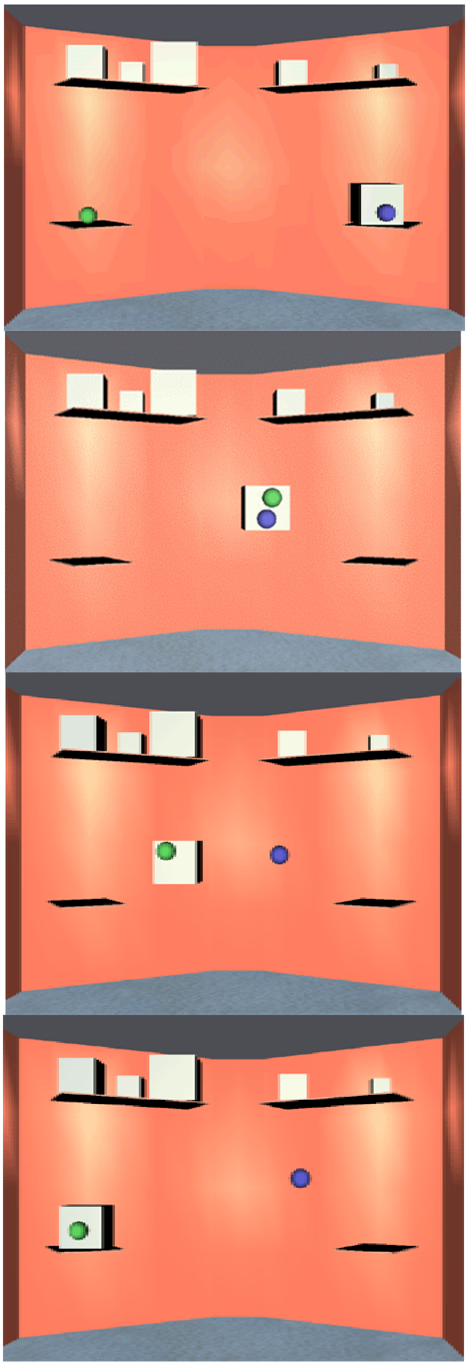

Figure 2. A sequence showing two subjects performing a hand over in the three-dimensional collaborative virtual environment.

Task difficulty was manipulated by changing cube sizes in randomised order, so that six differently sized cubes were handed over by each pair of subjects for each workload.

Workload was manipulated by providing haptic force feedback in one workload setting whereas in a second workload setting the Phantom functioned as a 3D-mouse without haptic force feedback.

Crossing these two experimental factors, task difficulty and workload, in a repeated measure design resulted in 12 experimental conditions. Two sessions were performed under each experimental condition, and so an experiment consisted of 24 trials run in randomised order.

3. Results

The aim of this experimental study was to investigate if haptic force feedback adds significantly to performance of a hand over task in a CVE.

The data are expressed as the total average time (t), in seconds. Data reflects the average time it took subjects to make one hand over with each of the six differently sized cubes added together as a total.

The analysis of subjects task performance was made in two ways. Firstly, total average time for performing error free hand overs was obtained. For this analysis two blocks of five error free hand overs on target shelves were recorded for each cube size in each session in both conditions.

Secondly, total average time for performing hand overs including errors was obtained. For this analysis one block of hand overs were recorded starting from the second tapping on a target shelf.

An error was recorded when subjects failed in coordinating a hand over and therefore dropped the cube. Subjects were asked to immediately pick up the dropped cube and continue the hand over task.

This was done for the two sessions in the haptic condition and for the two sessions in the nonhaptic condition. Mean time for intervals between tapping twice was obtained. The data was analysed using one-way repeated measures ANOVA.

3.1 Error Free Hand Overs

The result showed a significant main effect for treatments ($F = 4.764$, $p < 0.05$) regarding total average time for error free hand overs.

However, no significant differences were found between the haptic and the nonhaptic conditions regarding the total average time it took to perform error free hand overs neither in the first or the second trial.

The significant treatment effect, using Fisher's post hoc test, was due to a strong learning effect ($p < 0.05$) between the first and the second session in the haptic condition. A corresponding learning effect was not found between sessions in the nonhaptic condition.

The total mean time it took subjects to hand over a cube in each of the six sizes was longest for the first haptic session ($M = 16$ seconds, $s = 1$) and shortest for the second haptic session ($M = 13$ seconds, $s = 2$) (Table 1). The mean time was $M = 15$ seconds ($s = 2$) for the first nonhaptic session and $M = 14$ seconds ($s = 2$) for the second nonhaptic session (Table 1).

3.2 Hand Overs Including Errors

Results showed a significant main effect for treatments ($F = 3.747$, $p < 0.05$) regarding total average time for performing hand overs when errors were included. A significant difference was found, using Fisher's post hoc test, between the second haptic session and the second nonhaptic session ($p < 0.05$) regarding total average time for performing hand overs when errors were included. No significant differences were found between the first haptic and the first nonhaptic sessions.

A significant learning effect was found ($p < 0.05$) between the first and the second session in the haptic condition but a corresponding effect was not found between sessions in the nonhaptic condition.

Table 1. Mean times and standard deviations regarding time intervals for six differently sized cubes added together, in the analysis with errors and in the error free analysis for the haptic and nonhaptic CVE.

	Error free hand over	Hand over with errors
	$F(3, 12) = 4.764$ $p < 0.05$	$F(3, 12) = 3.747$ $p < 0.05$
	Mean (seconds), standard dev.	Mean (seconds), standard dev.
Haptic session 1.	$M = 16$ $s = 1$	$M = 17$ $s = 2$
Haptic session 2.	$M = 13$ $s = 2$	$M = 14$ $s = 2$
Nonhaptic session 1.	$M = 15$ $s = 2$	$M = 18$ $s = 3$
Nonhaptic session 2.	$M = 14$ $s = 2$	$M = 17$ $s = 4$

The total mean time it took subjects to hand over a cube in each of the six sizes was longest for the first nonhaptic session (M = 18 seconds, s = 3) and was (M = 17 seconds, s = 4) for the second nonhaptic session (Table 1). The mean time was M = 17 seconds (s = 2) for the first haptic session and shortest compared to all other sessions for the second haptic session M = 14 seconds (s = 2) (Table 1).

4. Conclusions and Discussion

The experiment presented in this paper aimed at investigating if haptic force feedback improves performance of a hand over task in a CVE. This was accomplished by applying Fitts´ law on performance of a collaboratively performed tapping task.

Results show that haptic force feedback significantly improves performance of a hand over task in a CVE when peoples´ errors are included in the analysis. A significant learning effect was also found between the haptic sessions.

If only error free hand overs are analysed there are no significant differences between the haptic or nonhaptic condition. However, results show a significant learning effect between the first and second haptic session.

The most difficult motor and perceptual event in a collaboratively performed Fitts´ tapping task is the actual hand over of the six differently sized cubes. The hand over event requires that the collaborators coordinate receiving and surrendering the cube. This means that the increasing task difficulty due to decreasing cube sizes is shared between collaborators and it is performing this motor task that produces errors. Coordinating hand overs in a nonhaptic environment requires that the decision that the subjects have to make about if the cube has been delivered or not is based on visual feedback only. If subjects get haptic feedback they can in fact communicate haptically, by testing if the other subject is holding on to the object by pulling it.

In summary, it is crucial to support this part of the collaboration that involves real time coordination of motor behaviour. Results from this study show that haptic force feedback successfully does that.

In future studies other kinds of low-level collaborative motor event should be investigated. Furthermore, more complex and realistic user scenarios needs to be studied like for example collaborative design work in CAD interfaces or in learning environments.

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