Supporting Object Handling and Hand Over Tasks in Haptic Collaborative Virtual Environments

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Abstract

This paper presents a user evaluation of a prototype of a haptic collaborative virtual environment (HCVE). The HCVE was designed in order to study the impact of haptic force feedback upon object handling and upon hand over tasks. Two different versions of the HCVE, free and controlled, were implemented and compared in order to study which was best suited for hand over tasks. The results indicate that visual feedback is dominant in relation to haptic feedback. They also indicate that additional supportive functions such as those added in the controlled version, should be known by the user in order to be useful.

1. Introduction

Supported by the development of the Internet, networked communication, coordination and collaboration has become an important issue in several organisations.

In command and control centres coordination of information plays a great role. Managing information efficiently is crucial for work performances that are often characterised by collaboration between several instances and a strong focus on the aim of the task. The work is often time critical and synchronous.

Only a few studies have been conducted concerning haptic collaborative virtual environments (HCVE). Earlier studies have shown that the haptic force feedback increases the sense of being together in shared virtual environments [1]. Other studies have also shown that haptic communication significantly increases perceived presence, improves usability and seems to facilitate collaboration in shared editors environments [11].

One study shows that haptic force feedback improves work efficiency and increases the feeling of intimacy between two participants performing a hand over task [5]. The same study indicates that haptic information prevented the participants from moving a shared virtual object in contradictory ways.

Another experimental study concerning collaborative manipulation of dynamic objects has shown that haptic force feedback significantly increases the virtual presence [12]. The study also showed that object manipulation was performed significantly faster and more precisely when haptic force feedback was provided.

One major issue in networked information handling systems is that the information handling should be conducted safely and securely, e.g. that the right information is delivered to the right person and that the information really is received. Subjectively perceived safety is often relative to trust, which is an important aspect of collaboration. Still there are only a few studies where trust between users in collaborative virtual environments has been investigated [6, 7]. The focus has been on the trust between the user and the system [10].

The over-all research question for this project has been: "How should a haptic collaborative virtual environment be designed in terms of visual feedback, haptic force feedback and functions in order to increase the perceived safety and the actual safety when handing over objects?" By perceived safety we mean the users' subjective feeling of having conducted e.g. a hand over task, successful and without losing the object. By actual safety we mean the measurable objective safety, e.g. if requirements for a successful hand over task really are fulfilled.

In this study, the impact that haptic force feedback has on people interacting with objects and handing over objects to each other is investigated. The aim of the study was twofold. First, we wanted to evaluate a prototype of a HCVE designed in order to support object handling and hand over tasks. Second, we wanted to compare two versions of the HCVE, a free version and a controlled version, in order to find out if one of them was best suitable for conducting hand over tasks safely.

2. User evaluation

The user evaluation consisted of collaborative tasks and was designed in order to study to what extent the users were able to use the functions provided in the environment, how the users experienced the feedback and if the interaction and collaboration were perceived as realistic,

intuitive, easy and fun. In order to decide which of the free or the controlled version was best suitable for a safe hand over, all tasks were conducted in both versions. The subjects were observed during, and interviewed after the evaluation.

2.1 Participants

To avoid a certain focus on the environment, e.g. technical, subjects with different education and occupation were recruited (Table 1). Ten persons, six men and four women, aged 23-60 participated. They collaborated two at a time in pairs.

Two pairs consisted of subjects already knowing each other, in two pairs they were unfamiliar to each other, and in one pair the collaborators worked at the same department but with different occupations.

None of the subjects had former experience of HCVEs and they were not rewarded for their participation.

Table 1. Participants' demography.

Pair	Sex	Age	Occupation	Relation
1	Female	25	BA student	Friends
	Female	24	BA student	
2	Female	36	MSc student	Unfamiliar to
	Male	31	System developer	each other
3	Female	60	Secretary	Work at same
	Female	27	PhD student	department
4	Male	28	Journalist	Unfamiliar to
	Female	27	Nurse	each other
5	Male	23	MSc student	Friends
	Male	24	MSc student	

2.2 Tasks

The collaborative tasks were of three different kinds. They were designed to investigate the perceived haptic feedback, the users' subjective experiences of interaction and collaboration and the users' ability to use the functions provided by the application. In order to compare free and controlled version, tasks from all three categories were solved in both versions. The three categories of collaborative tasks were:

1. Haptic object exploration tasks (tasks 1, 3, 7)
2. Placing and hand over tasks (tasks 2, 4, 8, 9)
3. Tasks requiring abstract thinking (tasks 5 and 10)

The first category consisted of deciding which object was heaviest among six blue and green shaded objects respectively, which object of twelve had smoothest and roughest surface respectively and finally, locate at least one pair of objects among twelve objects, with similar surface.

The objects were numbered 1 to 12 and the users were asked to note the number(s) of the decided object(s) in the problem statement. If the collaborators did not find the same object heaviest, smoothest etc., the two subjects were allowed to choose different objects.

Only the weight decision task was solved in both the free and the controlled version for each pair, as this was the only object exploration task requiring the user to lift the object. The subjects got no instruction in how to explore the objects.

The second category had to do with placing a certain number of objects on top of each other, and hand them over or receive them as one object. If the subjects lost the objects, they were instructed to start over again. Both users got the possibility to function as deliverer and receiver.

The last category of tasks was designed in order to force the subjects to collaborate and discuss. The users were asked to imagine that the objects were different kinds of information and that the number on the objects represented the objects value. They were asked to combine objects in order to obtain one object of a certain value, and hand this over to the collaborator (Figure 1). They were also asked to sort several objects in increasing or decreasing order.

Figure 1. Handing over an object of value 9.

2.3 Procedure

The collaborators were co-located in the same room during the evaluation and it was possible for them to talk to and to see each other (Figure 2). Both users had the same, static third person view of the environment.

Each participant got a written problem statement. This contained a short introduction and instructions for the ten tasks to solve. Task 6 was a demographic question, i.e. the participants solved nine collaborative tasks.

Each pair explored both the free and the controlled version. After task number five, the environment was changed from the free version to the controlled version or vice versa. Pair number 1, 3 and 5 started to solve problems in the free version and pair number 2 and 4 explored the controlled version first.

When the environment was changed the participants were only told they should explore a different environ-

ment. This was done in order to discover any perceived or noticeable differences between the two versions.

Figure 2. The evaluation set-up is shown to the left and a participant's view is shown to the right.

The participants did not train before the test session and were only instructed on how to hold the haptic device. They got no instructions on how to interact in the environment, in order to investigate if the interaction and collaboration were perceived as realistic, intuitive and easy.

In order to obtain spontaneous comments and reactions on the interaction and collaboration, the subjects were asked to talk aloud during the evaluation. They were also told to decide by themselves when a task was completed.

One test leader observed all participants during the evaluations and the interaction was video recorded in order for behaviour and dialogue to be analysed afterwards, if necessary. The main goal for the observation was to directly discover which problems occurred in the environment and to provoke the participants to talk aloud.

Finally, the same test leader interviewed the collaborators as a pair. The interview was based on questions concerning possible perceived differences between the versions, how the subjects experienced interaction and feedback, realism and intuitiveness, problem solving and collaboration. During the interview there was room for discussing other topics the subjects might bring up.

3. Interface design

The HCVE was developed in order to support the users in object handling and hand over tasks. The interface design was therefore focused on the hand over situation and the users interaction with the objects.

3.1 Visual and haptic feedback

The HCVE user interface (Figure 3) was designed as a room with shelves on top of which the objects were placed. The room did not contain any disturbing, personal objects as the environment was designed for formal meetings [9]. The ceiling and front wall was made transparent in order to make the interaction more visible for the user.

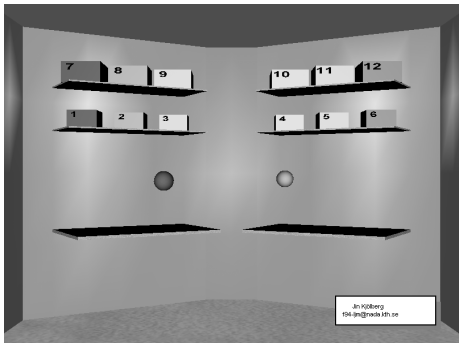

Figure 3. The visual user interface.

All surfaces in the environment, e.g. objects, shelves, walls etc. 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, collisions between objects etc.

The environment contained twelve objects (Table 2), placed on top of four shelves three by three. Two additional shelves, one to the left and one to the right were left empty.

Table 2. Object properties.

Visual texture	Haptic texture	Colour	Size [cm]	Mass [kg]
1		Dark blue	20x12x20	0,2
2		Blue	20x12x20	0,3
3		Light blue	20x12x20	0,2
4		Dark green	20x12x20	1,0
5		Green	20x12x20	0,5
6		Light green	20x12x20	0,3
7		Dark blue	26x14x26	0,5
8		Blue	26x14x26	0,2
9		Light blue	26x14x26	1,0
10		Dark green	26x14x26	0,5
11		Green	26x14x26	0,2
12		Light green	26x14x26	0,4

Objects to the left were coloured in shades of blue and objects to the right were coloured in shades of green. The objects were of two different sizes. There were one large and one small object in each colour shade. Each object had an image texture containing a number ranged

from 1 to 12. The objects were numbered from left to right, starting with the lower shelves.

The objects' haptic properties in addition to size, were mass, bump map texture and stiffness. Seven different haptic textures were attached to the twelve objects. The structures of the haptic textures were not visible in order to hide the haptic differences.

The avatars had the shape of a sphere, one coloured green and one coloured blue. The spherical form made the avatars neutral to rotation, i.e. they had no back or front and thus provided no directional information. The haptic device used (PHANTOM Desktop from SensAble Technologies) does only provide three degrees of freedom output. The user was therefore not able to feel rotational forces. In virtual environments it is important that the avatars do not afford properties the user do not have, e.g. the avatar has ears when the user cannot hear other users [2].

The users were able to feel and interact with each other through their avatars.

3.2 Functions

In the HCVE it was possible for the user to grasp an object by touching it with the avatar and then click and hold down the button on the haptic device. These operations made it possible to lift objects and place them at other locations. When the button was released so was the object. By pressing the avatar on to an object, the object moved in the pushed direction.

It was also possible to hand over an object to the other user and to hold the object together with the other user. By placing several objects on top of each other it was possible to create combined objects and hand them over by grasping the lower object.

3.3 Comparison of free and controlled version

A so-called free version of the environment was implemented in order to provide an intuitive and realistic interaction. The term "free" relates to the users' possibility to grasp and release objects freely in the environment.

In order to increase the support for the user in safe object handling and hand over tasks, a controlled version was implemented in addition to the free version. The term "control" relates to the system's control of when the users were able to grasp and release objects.

The controlled version was based on the free version, but some "controlling" functions or limitations were added. These were developed in order to prevent the user from losing an object (objective safety) and give the user additional feedback (subjective safety).

One such function was that when the user placed an object on top of another object, the user's object placed itself exactly above the other object. This gave the user a "snapping" or "clicking" feeling, and was meant as an additional haptic confirmation that the object was well placed on top of the other object.

Another limitation was that the users could only release an object when it was safely placed. If the user was lifting an object and then released the button, the avatar would still be connected to the object. In order to be able to release the object, the user had to place it on top of another object, on a shelf or give it to another user.

The consequences were that it was not possible to throw, release or lose an object in "open air". One specific user was therefore responsible for the object as long as it not was placed anywhere or handed over.

In the controlled version, it was also more difficult, i.e. it required a greater force, to push an object off a shelf, than in the free version.

3.4 Implementation

The HCVE was implemented using the Reachin API under Windows 2000. The haptic display systems used were two Reachin Displays (from Reachin Technologies) with two PHANTOM Desktops (from SensAble Technologies) as haptic devices. In order to avoid network delays and related problems, both devices ran on the same PC and were connected serially.

4. Results

The first aim of this study was to evaluate the HCVE and the second was to compare the free and the controlled version. All quantitative data of the object exploration tasks collected through the problem statement, are presented in Table 3 and commented in section 4.1. Users' subjective evaluation data collected through the interview are summarised in section 4.2 among with some of the test leader's observations. Results concerning the comparison of the two versions are presented in section 4.3.

No dialog transcription and analyse has been done due to time constraints and workload of this project.

4.1 Object exploration tasks

In the weight decision tasks only two subjects found the correct answer among the blue objects (task 1) and only one subject among the green ones (task 7). The correct answer was the object having the greatest mass (see Table 2). On the contrary, in task 1 there were seven subjects who believed the same wrong object to be the heaviest. This object was dark coloured, small and numbered 1.

All pairs succeeded in finding the object with the roughest (task 3a) and smoothest (task 3b) surface respectively. Only two pairs succeeded in finding two objects with the same smooth or rough surface respectively (task 3c).

When exploring the objects' weight and surface the test leader observed that participants used the haptic exploration principles (EP) described in [8], that is vertical movements when grasping the top of the object for weight exploration and lateral movement on the object surface for surface exploration. Several participants were not aware of the objects' surfaces until they were encouraged to explore them.

Table 3. Quantitative object exploration results. The numbers represent the number of the chosen object by each subject for each task. Shaded results were obtained in the free version.

Pair number	Task number				
	1	**3a**	**3b**	**3c**	**7**
1	1	7	5	2+3	5
	1	7	5	2+3	4
2	1	7	5	11+12	6
	9	7	5	11+12	6
3	1	7	5	2+4	6
	1	7	5	9+10	11
4	1	7	5	5+9, 7+12	6
	1	7	5	5+9, 7+12	5
5	9	7	5	3+10	11
	8	7	5	3+10	5
Correct answer	9	7	5	1+6, 2+3, 4+9, 8+10, 11+12	4

4.2 Users' subjective experiences

Primarily the subjects used visual feedback to ensure that the hand over was successful. The haptic feedback was used as a second control for the other user's impact on the object. Even the verbal communication was used as an additional feedback or control when handing over objects, even though the possibility to talk with each other was crucial for collaboration. The participants thought being at different locations with similar verbal communication possibilities would be comparable to the actual situation.

All participants found the interaction intuitive, easy, fun and quite realistic. There were only a few comments on the objects unrealistic behaviour, like the lack of rotation and lifting objects by touching them and press a button. Some participants got the impression that the objects were magnetic and thought that dark coloured, higher numbered or greater sized objects should be heavier than the opposite ones.

All subjects succeeded in handing over objects and were able to solve the tasks to their own satisfaction. Very rarely, participants losing the objects aborted the hand over. A few participants thought that it was the deliverer who was responsible for the handing over to succeed and therefore found it easier to act as receiver. Other subjects thought it was easier to deliver as they could feel when the receiver grasped the object, and therefore could release the object with less risk of losing it.

The most difficult task according to the participants was to locate the heaviest object. Even to locate two objects with similar surface was experienced as hard. The difficulties in solving these tasks were objectively confirmed by quantitative data (Table 3).

Only one participant expressed that the avatar provided small social presence, as there was no possibilities for the user to choose its properties. Other participants felt a strong identification with their avatar. They also thought that objects coloured in the same colour as their avatar belonged to them.

All participants had the feeling of being together with another person in the environment and thought that performing similar task in a single user environment would have been less stimulating.

The test leader observed that subjects were interested in trying to touch each other through the avatars, but only after a certain time of collaboration. There was also a tendency towards people already knowing each other, having more physical contact in the virtual environment. The avatars were often used as pointing devices in the environment.

4.3 Results from free vs. controlled version

In the beginning of the interview the subjects were asked if they discovered any differences in the two environments. Their spontaneous answers were "no", "was there two environments?" or "they looked the same".

During the interview it came clear that the participants found the interaction with the free version some easier than with the controlled one. One person believed that the difficulties were caused by a program bug, and not intentional. Still both versions were perceived as intuitive.

One couple (number 5) discovered the actual differences between the versions, but only after some reflection during the interview. This couple found the hand over tasks easier to conduct in the controlled version, since in that version it was impossible to lose the object.

The object exploration tasks showed no differences in task performance between the two versions.

5. Discussion and future work

An important result from the user evaluation was that visual feedback seems to override haptic feedback, especially in weight decision. This is indicated by the subjects' comments during evaluation and interview and even by task 1 (Table 3).

Charpentier showed already in 1891 that subjects report smaller objects as heavier, when objects of identical mass but different volume are lifted [3 referred to in 4]. Even when subjects are aware that objects are of

same mass, this result is preserved and is referred to as the size-weight illusion [4].

Similar studies have shown that there also exists a grasp-span weight illusion independent of visual feedback [4]. These studies have all been conducted in real physical environments. Our results indicate that at least the size-weight illusion can occur even in haptic virtual environments.

The difficulties in comparing haptic textures could be caused by the great difference in size between the avatar and the texture bump height. This could be compared to exploring surfaces with boxing gloves.

Based on this study it has not been possible to decide which version, free or controlled, provided the best properties for hand over tasks. As pointed out in the results both versions of the environment were experienced as intuitive. Still the subjects experienced some difficulties in the controlled version. These were in most cases related to how to and when it was possible to release objects. Only one couple found it easier to hand over objects in the controlled version. This couple was also the only one that was able to identify the differences between the versions.

This may indicate that the added functions could be supportive when the users are aware of them, but this has to be further investigated. One reason for the participants' inability to discover the differences may be that the visual interface was the same in both versions.

The observed tendency towards people knowing each other have more physical interaction, confirms what is pointed out in [11], i.e. touch is a very personal sense and use of haptic communication may be influenced by individual differences and social factors.

To further investigate the impact of haptic force feedback on hand over tasks, studies on the environment in a non-haptic condition will be conducted. Even studies where subjects are aware of additional functions or limitations like those in the controlled version, are necessary in order to decide which version is best suited for safely conducted hand over tasks.

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