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Evaluating the Effects of Haptics on Presence while Traveling in a Desktop Virtual Environment

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Abstract

Virtual reality applications seek to fully immerse participants into their virtual world experience. The investigation of how stimuli on the different senses influence the users is therefore crucial. As navigation is one of the most ubiquitous tasks in virtual environments, studying the influence of haptics on user presence is a necessity for future applications. This work presents an empirical study on the role of haptics during travel in a desktop virtual environment. Three techniques were compared in respect to task performance, perceived task performance, perceived presence and mental and physical workload. While our results indicate that haptics has a positive influence on participant's perceived presence and performance, his total workload remains constant. Furthermore, we show that these findings apply to both experienced and unexperienced virtual environment users.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interfaces]: Haptic I/O, Input devices and strategies, Evaluation/methodology I.3.7 [Three-Dimensional Graphics and Realism]: Virtual reality

1. Introduction

The major goal of Virtual Reality (VR) applications is to provide users with sensory information so that they feel the generated experience as a real one. Ideally, a VR application would stimulate all of the participant's senses. Unfortunately, we are still a long way from achieving this. Over the last decades a lot of effort has been spent on improving 3D audio and visual rendering. Hereby related, animation and physical simulation techniques have also received much interest. Physical simulation, however, is only recently finding its way into real-time virtual environments (VEs). Moreover, hardware support for calculating the physics behind these techniques are currently emerging in the forms of specialized physics processors , or can be processed by extensions available on new graphics hardware.

Haptics, enabling us to feel VEs and objects, has also been studied extensively over the last decades, resulting in several haptic I/O devices, collision detection techniques and interaction methods. However, most of the work in this area has remained limited to research projects and specialized setups, but have not yet reached a large audience. This is, at least partially, caused by the high requirements for haptic rendering calculations and the high costs involved with haptic devices. The prices of touch enabled I/O devices are decreasing, and new devices and applications arise frequently.

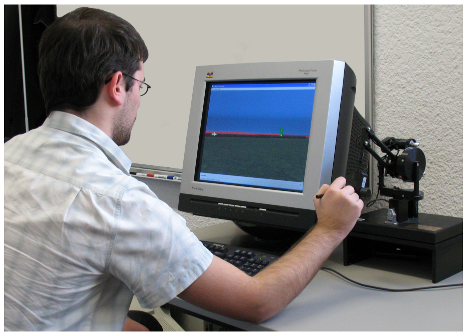

Figure 1: *A user navigating in the desktop virtual environment using the haptic travel technique.*

In previous work, we [JDBL06] showed how we used a rigid body simulator in the haptic rendering loop in order to create more dynamic haptic VEs. Since *navigation* is undoubtedly the most ubiquitous of the interaction tasks therein, we demonstrated our approach by creating a travel technique that allows users to feel the terrain and surrounding dynamic objects while navigating through a VE. As VR tries to immerse the participant as much as possible, it is crucial that we investigate how the stimuli on the different senses influence the user's perceived presence, the feeling of being there. Therefore, in this work we present an experimental study on the influence of haptics on the perceived presence during haptic travel. More specifically, we investigated how haptic force feedback affects travel in a VE: task performance, perceived task performance, perceived virtual presence, mental and physical workload. Furthermore, we investigated if this influence is larger on more experienced users than on VE novices. Section 2 discusses related work in the fields of haptic interaction and presence. Then, we describe the haptic travel technique. Section 4 introduces our research inquiries and is succeeded by a full description of the experiment. The results are discussed in section 6. Finally, we present our conclusions and give some future research directions.

2. Related Work

According to [BKH97] the task of navigating through a VR world can be split up in two phases: a cognitive component called *wayfinding* and a second named *viewpoint motion control*. In the wayfinding phase the user plans how he can reach the desired location, based upon an internal mental map of the environment together with several (mostly visual) cues from the environment. Viewpoint motion control or *travel*, on the other hand, is the physical component used to move one's viewpoint between different locations in the VE. Both phases are separate processes, although they can have an influence on each other. Since this work focuses on the traveling task, we will not go further into this discussion. Several traveling metaphors have been devised over the years [Min95, BKH97]. Probably the best known metaphor for exploring virtual worlds, is the 'flying vehicle', where the virtual camera is moved as if it is mounted on a vehicle or object that can be moved in space. Providing motion control with haptic feedback has not been applied in many real-time animation applications that involve physically simulated VEs. In [OTH02] Oore et. al. present a novel 3D input device for interactively controlling animations of a humanoid character. In [JWL05] the authors describe how 3D input in combination with *inverse kinematics* can be used to let an avatar perform hand interactions with objects in its immediate surroundings. Both approaches lack force feedback to limit the user's actions, causing several interaction issues. De Boeck et al. [DBC02] investigated navigation using the 'Camera In Hand' metaphor with a PHANToM and a spacemouse. This study, however, lacked an investigation on the user's presence and workload. Several other studies, such as [MRGSD02,NMS02] describe navigation and object recognition schemes in VEs for visually impaired people. The virtual worlds that are used, however, are fairly static and there are no dynamics or animations involved. Also, due to the severe haptic rendering requirements, the number of dynamic objects in a scene is usually limited.

Presence can in the context of interactions in 3D VEs be defined as a state of consciousness, the psychological state of being there [SW97]. Similarly, Witmer and Singer [WS98] define presence as the subjective experience of being in one place or environment, even when one is physically situated in another. Two psychological concepts are of interest concerning presence, those are *involvement* and *immersion* [WS98]. As users focus more attention on the virtual reality stimuli, their involvement in the virtual reality experience increases, resulting in an increasing sense of presence. Immersion, on the other hand, depends on the extent to which the stream of stimuli and experiences that the VE provides make people feel included in and able to interact with the environment. Factors which affect immersion include isolation from the real environment, perception of self-inclusion in the VE, natural interaction and control, and the sense of self-movement [WS98].

Investigating perceived presence is far from straightforward and a lot of research has been done in trying to determine a useful methodology for measuring it. Subjective methods rely on self-assessment by the participants and are usually performed after a task has been performed. The most employed questionaires are Witmer-Singer [WS98] and SUS [UCAS00]. The advantages of these questionnaires are that they are specifically tailored for what they want to measure. They are easy to use, validate and interpret and do not break the presence as they are conducted post-immersion. Presence with regard to VEs has mostly been investigated for immersion in setups in which only the visual and sometimes the auditory senses are presented to the participant [SW97, WS98, Mee01]. Sallnäs et al. [SRGS00] have investigated the presence in a haptic collaborative VE. They concluded that haptics improves task performance, perceived task performance, and perceived virtual presence in the collaborative distributed environment. Adding haptics to VEs does, however, not only influences presence, it can also influence the workload which a user experiences. Oakley et al. [OMBG00] investigated several haptic effects of which some had a higher workload than others. They used The NASA Task Load Index (TLX) questionnaire [HW90], a subjective workload assessment tool that allows users to perform subjective workload assessments on operator(s) working with various human-machine systems. NASA TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales: mental demand, physical demand, temporal demand, effort expended, performance level achieved, and frustration experienced. This work is an investigation on the travel technique that was proposed in [JDBL06] and the influence of the haptics on perceived presence and workload.

3. Haptic Travel

A complete description of the haptic travel technique can be found in [JDBL06]. In short, the method adopts a 'flying vehicle' metaphor where a rigid body simulator uses gravity to keep the 'vehicle' on the terrain. By generating a force feedback field, based on the user's input in combination with collision information provided by a rigid body simulator, the user is provided with information on what is

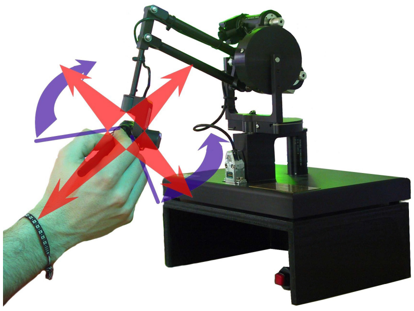

Figure 2: *The PHANToM's travel possibilities.*

happening to him in the VE. This includes information on the terrain (slope, sort of terrain) and collisions with objects.

In order to provide travel, two elements must be controlled [Min95]: *speed* and *direction of motion*. In this setup, a PHANToM device is used for registering 3D input and displaying haptic output. When the PHANToM is in the neutral position, which is specified at startup, no movement is applied in the VE. Thereafter, the viewpoint can be moved in a relative hand directed way, as shown in Figure 2. The speed and direction of movement is directly coupled to the users hand. When PHANToM's stylus is moved in front of the neutral position, the user's representation inside the VE moves forward. Similarly, he can also travel backwards, left and right. In order to rotate the viewpoint the user needs to rotate the PHANToM's stylus in the direction he wishes to turn (in this case limited to left and right). A spring force field directed toward the neutral position, constantly pushes the PHANTOM back to its rest state. The speed of the motion can be determined by the extent to which the hand movement is made. The further away the input device's end-effector is from the neutral position, the higher the avatar's velocity. As a result from the spring force and similar to the real world, faster movement will consequently require stronger force input. Similarly, the speed of the rotation is specified by the size of the angle that the stylus is rotated.

4. Hypotheses

we will investigate how perceived presence, perceived performance, workload as well as task performance are influenced by haptic feedback for the task of travel in a desktop VE. Our hypothesis include:

H1 Haptic force feedback improves task performance.
H2 Haptic force feedback increases perceived performance.
H3 Haptic force feedback increases perceived virtual presence.
H4 Haptic force feedback increases the physical demand.

5. Experiment

5.1. The Virtual Environment Setup

The test environment that was used for the experiment, was based on the framework described in [JDBL06]. It consist of a desktop VE wherein 3D scenes and objects can be loaded, and users can navigate. In order to increase realism, the object movements are physically simulated by a rigid body simulator. It is also this simulator that is used for calculating the haptic forces. The visualization of the virtual world is shown on a 19 inch monitor. Audio is provided through a set of speakers. The haptic display used is a PHANToM premium 1.0 (6 DOF) which is placed at the user's dominant hand. Figure 1 shows a user that is using the PHANToM to navigate through the VE.

Three input methods were provided, one employing the keyboard and two using the PHANToM, based on the haptic travel method as described in section 3. The keyboard method is used as a reference technique for the 3D input techniques, mainly in respect to task performance and workload. Since adding haptics to the keyboard is impossible, we cannot study the effect of that feedback on (perceived) presence. Another reason for using the keyboard as a reference is that, in contrast to the PHANToM, everyone is familiar with it, and it will thus give us a view of how efficient the 3D navigation techniques will perform. For traveling, it uses only the arrow keys and provides: forward and backward movement at constant speed and left and right turns. In order to be able to objectively compare the PHANToM-based techniques to the this, we had to adjust the PHANToM-based travel technique somewhat to make sure that all techniques provided the same functionality in terms of possible moves and speed. Therefore we disabled the left/right (strafe) movements, we switched to a constant turning speed and disabled the coupling of the traveling speed from the length of the displacement of the hand position from the neutral position. The final technique is exactly the same as the haptic travel technique, however the force feedback was left out. To summarize, we have 3 travel techniques allowing the same functionality: keyboard travel, (KT), PHANToM travel without haptic feedback (PT) and haptic travel (HT).

5.2. Task Description and Experiment Procedure

In order to compare the different traveling techniques described above, a navigation task was set up. The users were asked to travel through several virtual scenes from a starting position toward an end position as fast as possible. For this task, 10 scenes were created, 5 having a flat terrain and 5 with sloped terrains. These scenes consist of a start position, a goal position (indicated by a high green cylinder) and several physical barriers in the form of walls which, however, did not occlude the view of the goal position. The barriers were placed in order to coerce different travel patterns including e.g. moving in a straight line, moving through a narrow passage, and several combinations of short and long left and right turns. A schematic top down view of these scenes is shown in Figure 3. In order to eliminate the wayfinding component of the navigation task, large arrows were placed on the barriers showing the direction of travel at all times.

The design of the experiment was a within-participant de-

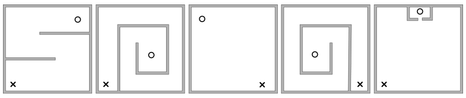

Figure 3: *The basic forms of the scenes,* **x** *marks the start position,* **o** *symbolizes the goal position.*

sign. The independent variables were the travel technique (TT) and the participant's VR experience (PE: experienced (EX) or unexperienced (UX)). The dependent variables were trial completion time, travel distance, total rotations performed, perceived presence and workload. The participants consisted of unpaid volunteers who were screened based on questions regarding their experience with VEs and 3D input devices. On this basis a group of 12 was selected, 9 male and 3 female, ranging in age from 21 to 59 (average 31). This included 6 experienced and 6 unexperienced VR application users. Participants, when ready, could initiate the travel task by a simple button press. Both the starting and finishing of a travel task were emphasized by playing a short sound. A flat scene with no obstacles was used for training. The travel techniques were fully counterbalanced across the 12 participants with one experienced and one unexperienced participant randomly assigned to each of the 6 unique orderings. The 9 scenes, remaining after 1 was used for training, were presented in random order. After testing each travel technique the participant filled out the workload and perceived presence questionnaire. When the participant had completed the entire test, another final questionnaire was presented in which he was asked to rank the travel techniques according to perceived performance and presence and was allowed to give other general remarks. Per participant, the experiment was performed in a single session, lasting about one hour.

6. Results

6.1. Trial Completion Time

The trial completion time, can be defined as the time it took the participants to navigate from the start to the goal position. The average trial completion times were calculated per technique by averaging the trial completion times for all users and scenes. For the KT, this resulted in an average time of 36.2s, for PT this was 40.3s and the HT averaged 40.5s.

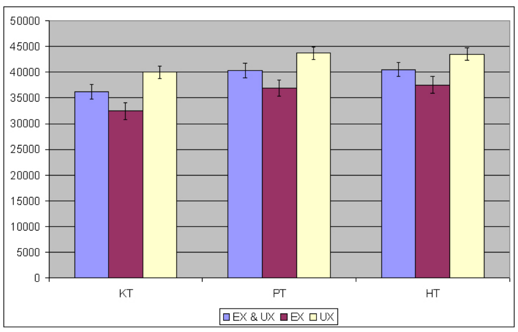

Figure 4: *Trial completion time by participants.*

Focusing on the PHANToM-based techniques, no significant performance difference is present, refuting H1. Post hoc comparisons showed that keyboard was significantly faster than both PHANToM-based techniques ($p < .05$) in terms of timing, the increase is around 11%. In order to explain this difference, we foremost took a look at the other dependent variables: the distance traveled and the amount of rotations a user made. Statistical analysis showed that there is no significant difference in distance traveled between the different travel techniques but we did see that using the PHANToM resulted in slightly longer distances traveled (4%). As a result of the constant speed, this difference in traveled distance can already partly explain the longer trial completion times. A further explanation can be found by looking at the amount of degrees rotated during the navigation task. There is a significant difference between the keyboard technique and the PHANToM techniques ($p < .01$). The (de)activation of the rotation with the PHANToM is slower compared to the keyboard since the user has to make a bigger gesture. This might also explain the larger difference in completion time as in distance traveled. In the original haptic travel technique the rotation with the PHANToM would happen gradually according to the amount of rotation, which we made constant in order to have a more fair comparison with the KT. We expect this problem of the tested technique to be removed if we would have tested the original technique.

We found that there was a significant interaction effect with PE ($F_{1,322} = 18.4$, $p < .0001$). By splitting up the users according to experience we see a significant difference in trial completion time. This interaction is illustrated in Figure 4. As expected experienced participants performed faster than unexperienced participant's but the performance with regard to the travel techniques has not been influenced significantly by participants experience. We found similar results for the other dependent variables.

6.2. Workload

The participant's workload was estimated by using the NASA-TLX questionnaire [HW90]. Figure 5 shows the resulting scores (scored on a scale of 100). The keyboard technique scored lower on all categories, which logically results in a lower total workload of 21. The PHANToM-based techniques had a significantly higher total workload ($p < .01$), 40 for the PT and 39 for HT. When we considered the difference between EX and UX, we found there was a small difference between them. Experienced participants had a smaller total workload than unexperienced participants.

Looking into the different subscales, we found that there is no significant difference between the PHANToM techniques for mental demand, temporal demand, performance and effort. Physical demand, on the other hand, is substantially higher in the case of HT. This is an expected result, since the user had to constantly push against a force field in the direction he wanted to travel. This was also hypothesized as H4. In contrast, the frustration level significantly

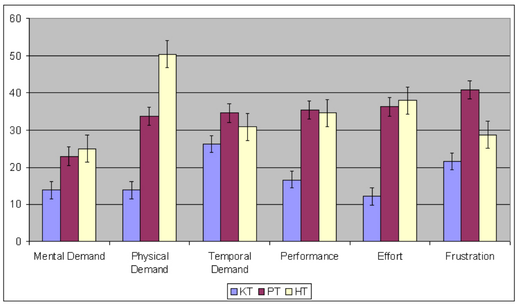

Figure 5: *Workload by travel technique.*

drops when haptic forces are present. We can contribute this to the fact that in case the user has feedback, that he can feel that he is moving. This is also present while navigating with the keyboard. The user just knows that he is moving when he presses a button (unless when he is colliding with an obstacle). When no haptics were present the user could only determine his movement visually. Also, in the PT users made larger hand movements up to the device's workspace limits and experienced more difficulty in finding the neutral position. This concurs with the findings of Mine [Min95] and Bowman [Bow] which state that many problems with 3D interaction techniques are caused by the lack of haptic feedback. Considering this in view of the total workload, we see that the decrease in frustration, caused by introducing feedback, is alleviated by an equally large increase in physical demand resulting in similar workloads for both techniques.

Figure 6 gives a more detailed overview of the workload for each travel technique taking into account participant's experience. When we compare EX with UX users we can diagnose that there was a higher mental demand. This was to be expected, since users that are familiar with traveling in VEs need to concentrate less on the actions they perform. While the EX indicate an important increase in physical demand for the HT with respect to PT, this was not supported by the results from the UX. Also, unexperienced users have a lower temporal demand than experienced users. This probably resulted from the constant speed condition, which was the same for all users. For experienced users the speed might not have been fast enough by which they felt more temporal demand. During observations, we also saw, especially with EX, that when the users had their final direction straight toward a sub/end goal position, they enlarged their hand movement, trying to speed up. We consider this to be a confirmation of our choice in the original technique, to allow users to define their virtual speed by the size of the displacement from the neutral position. For performance, effort and frustration there was a clear higher demand which can be assigned to them being less experienced.

6.3. Perceived Presence and Performance

In order to estimate the perceived presence, the user had to fill out the Witmer and Singer presence questionnaire (version 4.0) [WS98] and had to rank the travel techniques according the perceived presence and performance. This questionnaire is subdivided in 4 subscales: involvement, sensory fidelity, adaptation/immersion, interface quality. As this questionnaire is designed for total VR experiences, we could remove some questions that were irrelevant for our task, such as e.g.: "How closely were you able to examine objects?". As a result, all questions regarding sensory fidelity seemed to be dismissed. Therefore, we will discuss only the remaining three.

Considering the PHANToM-based techniques we can see that the addition of haptics gives a higher value for each of the 3 categories and especially for involvement, see Figure 7. Thus adding haptics to the travel technique gave the users a higher level of presence. The results are similar for both EX and UX. Comparing to the keyboard technique, the condition with the HT gives better results for involvement and adaptation/immersion but not for interface quality. This probably resulted from the fact that users judged the interface quality on the basis of the task that was given, in which they were asked to perform the task as fast as possible. They felt this to be the KT, which is enforced by their ranking of the navigation techniques according to perceived performance. All participants felt they were the fastest with the KT, which is sustained by the results described in section 6.1. The HT was ranked second and the PT last (χ^2 test: $p < .0001$) confirming H2. This is of course also due to the fact that all users were acquainted with the keyboard, while only 2 of them had prior experience with the PHANToM device. The ranking order for perceived presence is the HT, which was

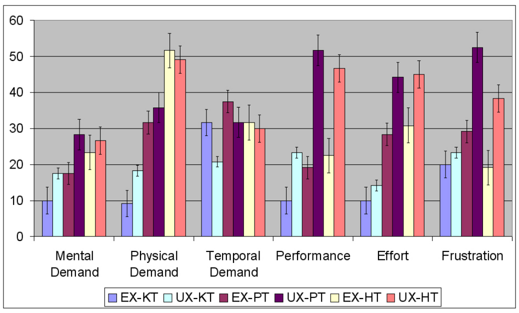

Figure 6: *Workload by travel technique and experience.*

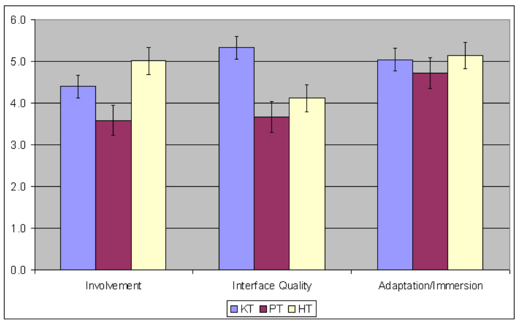

Figure 7: *The 3 perceived presence categories by travel technique.*

preferred by 9 participants, KT by 2 participants and the HT was preferred by 1 participant (χ^2 test: $p < .01$). The participant that stated to perceive more presence with the technique of the PHANToM without haptics, was an experienced VR user who had several years of experience with 3D input devices including the PHANToM and the non-haptic MicroScribe. This ordering of the TT by perceived presence, is affirmed by the results of the presence questionnaire and is an acknowledgement of H3.

7. Conclusions and Future Work

In this work we performed an empirical study on the addition of haptic force feedback to travel, and how this affects task performance, perceived task performance, perceived presence, mental and physical workload. A formal experiment was conducted comparing three travel techniques, a keyboard technique used as a benchmark and two PHANToM-based techniques, one with and one without haptic feedback. Our results demonstrate that, in terms of efficiency, the keyboard technique outperformed both PHANToM techniques, as expected. However, in terms of perceived user presence, involvement and satisfaction, haptic travel proved to be better. Comparison among the PHANTOM-based techniques showed that performance was not significantly improved although users perceived the haptic condition to be faster, allowing us to conclude that adding haptics has a positive influence on the task of travel. Also, we showed that these results apply to both experienced and unexperienced VR users.

In the future we would like to extend this study by investigating the complete haptic travel technique as it was originally designed in [JDBL06], with user specifiable travel and orientation speeds. Furthermore, it would be interesting to research the influence on wayfinding. Another logical next step would be to incorporate the haptic travel technique in contemporary games and virtual environments. This will hopefully, in correlation with the decrease in haptic device costs, lead to a more widespread use of haptics for VEs.

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