Interaction with haptic feedback and co-location in virtual reality

David Swapp, Vijay Pawar and Céline Loscos
University College London
d.swapp@cs.ucl.ac.uk, vijaympawar@hotmail.com, c.loscos@cs.ucl.ac.uk

Abstract

This paper outlines a study into the effects of co-location[1] of haptic and visual sensory modes in VR simulations. The study hypothesis is that co-location of these sensory modes will lead to improved task performance and enhanced sense of presence within a VR environment. Experiments were conducted to evaluate the effect on user performance of co-located haptic feedback. Results show that co-location is an important factor, and when coupled with haptic feedback the performance of the user is greatly improved.

Keywords--- **Haptic interaction, virtual environment systems, visual-haptic co-location**

1. Introduction

Presence is likely to be enhanced by multi-modal input: in a VR environment, the addition of sensory modes should consolidate our sense of presence, although conflicting sensory cues are liable to degrade the sense of presence. At the moment, research in VR is dominated by simulation for the visual and audio sensory modes. In many application areas it is likely that touch can also be a compelling factor in presence [1] [2] , and other studies show that the addition of haptics can lead to improved task performance[3] [4] .

Precise co-location of haptics is technically hard to achieve. A commonly-implemented compromise is the use of visual markers to represent the haptic contact points. Because the markers are visually rendered by the same graphics system as the virtual environment, spatial correspondence is guaranteed. In the current study, such a setup is referred to as non-colocated haptics.

1.1 Implementation issues for co-location

- **Occlusion:** For screen-projection systems (as opposed to HMDs), occlusion problems arise when we reach behind a displayed graphical object: instead of our hand being occluded by the object, the reverse is the case.
- **Accommodation:** Accommodation (focus) of the eyes on a virtual object is determined by the distance from the eyes to the projection surface. However, if we are trying to view a real object (e.g. the haptic contact point) that is co-located in space with a virtual object, this gives rise to a perceptual dissonance –we can feel the object at our fingertip via haptic feedback, but we cannot visually focus on both virtual object and fingertip simultaneously.
- **Calibration:** The co-ordinate systems for both visual and haptic rendering must be aligned. Discrepancies between haptic positioning (which typically can be calibrated to a very high degree of accuracy) and head tracking will lead to a decoupling of the visual and haptic renderings. Additionally, CRT nonlinearities can distort stereo disparities and disrupt co-location.

[1] The term 'co-location' is used throughout to refer to the co-location of haptic and visual sensory modes, except where otherwise specified.

2. Design of experiments

In order to evaluate the effect of co-location on user performance, we designed 3 experiments to test users' interaction accuracy, ease of manipulation, and agility. The experiments were run on a PC with NVidia Quadro FX1100 graphics, displayed on a CRT monitor. The user wore shutter glasses for stereo viewing. Haptic interaction was provided with a Phantom Desktop from Sensable technology[5] The Phantom was positioned to allow co-location and the full workspace of the device. The interaction workspace was between the screen and the user, the support being on the right hand side of the user.

For each task there are 2 independent variables: co-location and haptic feedback. For co-location, the Phantom is carefully positioned such that the point of interaction on the Phantom coincides visually with the point of contact in the 3D scene. For non-co-location, visual markers indicate this point of contact. When haptic feedback is turned off, the Phantom is used as a 3D joystick. Thus there are 4 classes of interaction:

- co-located haptics
- non-colocated haptics
- co-location with no haptic feedback
- non-colocation, no haptic feedback

2.1 Task design

The first task tests spatial accuracy. The user needs to touch, one by one in a given sequence, a set of objects distributed in 3D space. A screenshot is shown in Figure 1.

Figure 1 Spatial accuracy test

The second task tests spatial manipulation. It involves manipulating a ball through an environment consisting of a sequence of objects, akin to moving it through a maze.

The third task tests spatial response. Gravity is simulated and the user must juggle objects in the environment. The task stops when an object drops.

For all tasks, there are 3 levels of difficulty, with increasing numbers of objects, more complex spatial arrangement, and decreasing object size. For each trial, the time taken to complete the task is measured**.**

2.2 Experiment procedure

A within-groups design was employed on a set of 6 users. Each user was given a description of the tasks, after which the system was calibrated for stereo adaptation and co-location. Users were asked to keep their head as still as possible to maintain correct stereo and co-location. A training period of a few minutes followed. The tasks were then presented in the following order: spatial accuracy, spatial manipulation, then spatial response. Each task was performed using the 4 interaction classes in order: co-located haptics; non-colocated haptics; co-located with no haptic feedback; non-co-located with no haptic feedback.

3. Results

All users completed the set of tasks and times were recorded. The results are shown in Figures 2, 3 and 4. For Figures 2 and 3 shorter time indicates better performance. For Figure 4, longer time indicates better performance.

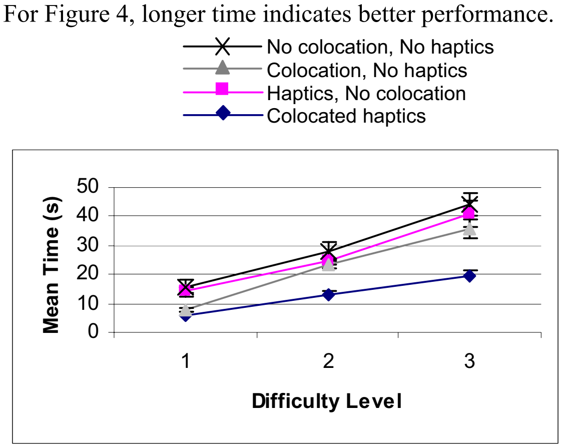

Figure 2 Results for spatial accuracy.

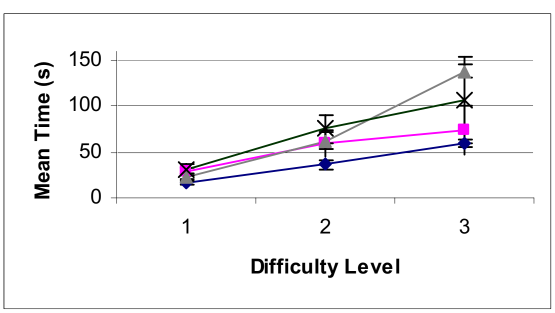

Figure 3 Results for spatial manipulation.

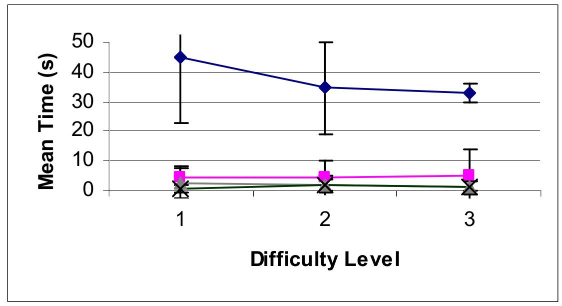

Figure 4 Results for spatial response.

The most salient results are summarised below:

- Interaction with co-located haptic feedback leads to better user performance for all tasks.
- For the spatial accuracy task, co-location is of greater benefit than haptic feedback in task performance.
- The spatial response task is almost impossible to perform without co-located haptic feedback.
- Users' comments reflect the quantitative findings, with preferences for both haptic feedback and co-location.

4. Conclusions

This study indicates not only that haptic feedback assists interaction performance in a 3D environment, but also that co-location is a significant factor. The next step for this research is to extend it to a fully immersive VE system equipped with a larger haptic device[1] [2] [6] Head-tracking and a larger haptic workspace will allow us to investigate more fully some of the implementation problems described earlier. A more immersive system will also enable a broader investigation of the impact of multi-sensory co-location on presence.

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