Effects of Sensory Feedback while Interacting with Graphical Menus in Virtual Environments

Nguyen-Thong Dang, Vincent Perrot, Daniel Mestre
Institute of Movement Sciences, CNRS and University of Aix-Marseille II

ABSTRACT

The present study investigates the effect of three types of sensory feedback (visual, auditory and passive haptic) in a context of two-handed interaction with graphical menus in virtual environments. Subjects controlled the position and orientation of a graphical menu using their non-dominant hand and interacted with menu items using their dominant index fingertip. An ISO 9241-9-based multi-tapping task and a sliding task were respectively used to evaluate subjects' performance in different feedback conditions. Adding passive haptic to visual feedback increased movement time and error rate, decreased throughput in the multi-tapping task, but outperformed visual only and visual-auditory feedback in the sliding task (in terms of movement time and number of times the contact between the finger and the pointer was lost). The results also showed that visual-auditory feedback, even if judged as useful by some subjects, decreased users' performance in the sliding task, as compared to visual-only feedback.

KEYWORDS: Target selection, pointing, tapping, sliding, two-handed interaction, 3D user interfaces, sensory feedback.

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – virtual reality. H.5.2: User Interfaces – input devices, interaction styles

1 INTRODUCTION

Graphical menus are frequently used for system control in Virtual Environments (VEs) in which users issue commands through interaction with menu items, in order to perform a particular function, to shift between interaction modes or to change the system state[1]. Using graphical menus presents certain advantages in virtual reality (VR) applications. An example of such an application is virtual prototyping, where users have to control a range of parameters, such as object color, object texture, intensity of different light sources, etc. While interaction with graphical menus placed at a distance can be carried out using three-dimensional (3D) pointers, such as a light ray [1] or a virtual hand [5], interaction with graphical menus placed within reach of users' hand, where the user's fingers can directly interact with menu items, has received somewhat less attention. Nevertheless, direct interaction with local objects and graphical menus to control objects' characteristic might provide users with intuitive and efficient interactions.

One of the problems with local interaction is the precision of the contact between the user's finger and virtual menus. Contact is used either in a discrete way, to validate an action, or in a continuous way, to modify or adjust a parameter in the VE. However, a simple apparent visual contact between the user's finger and the virtual object might not be enough to define a "valid" contact. In many cases, and for many reasons, users might erroneously think they touch the object. Such mismatch might lead to users' frustration after a series of failed attempts to perform an action. The main reason for this difficulty is the presence of an offset, inherent to a VR system, between the user's finger and the virtual menu item positions. A number of factors, from both the system's and the user's sides, contribute to form this offset. For example, the precision of the tracking system, user hand's jitter, user's visual perception of 3D objects in VEs, might all contribute to the offset.

In this context, in addition to additional visual feedback (e.g., a color change), a real contact can be added to achieve precise contact between the user's finger and the menu item. Real contact can be easily created through a tracked piece of plexiglass (co-localized with the virtual menu), which can be integrated to a typical 3D input device (for e.g., a wand) to facilitate both the user's handle and local interactions. In addition to haptic passive feedback provided by the plexiglass transparent sheet, sound can also be used to enhance the accurate perception of the visual contact between the user's finger and the menu item. Would those feedbacks have different effects on local interactions with menu items? Addressing this research question, we conducted an experimental study, investigating the effects of three types of additional sensory feedback on users' performance in a pointing task and in a sliding task in a virtual environment.

2 EXPERIMENTAL STUDY

2.1 Subjects and apparatus

Seven participants took part in the study. Two experimental tasks were randomly and sequentially assigned to them. Three different types of feedback (visual alone, visual + sound, visual + passive haptic) were tested. Subjects were presented with a virtual planar surface, projected in a 4-sided CAVE-like setup at the Mediterranean Virtual Reality Center (CRVM). Subjects controlled the position and orientation of the planar surface using their non-dominant hand and interacted with graphical elements displayed on the planar surface using their dominant index fingertip thanks to an ART® Fingertracking device. Passive haptic feedback was provided by co-locating a plexiglass sheet with the virtual planar surface. Auditory feedback consisted in a "beep" signaling the presence of the pointing fingertip inside a given menu item. Stereoscopic viewing was obtained using Infitec® technology. Real-time tracking of the subject's viewpoint, plexiglass sheet and fingers was obtained using an ART® system. Virtools® software was used to implement the experimental protocol.

2.2 Experimental Task I: Pointing

To evaluate pointing performance with there types of feedback, we adopted the methodology introduced in Part 9 of the ISO 9241 standard for non-keyboard input devices [4]. Performance was quantified by the throughput index (in bits per second (bps)), whose calculation is based on Fitts' law [3] and requires the measurement of effective index of difficulty (ID_e) and the average movement time (MT) (cf. Formula (1)). ID_e is defined as a function of the averaged actual movement distance (D_e) and effective target width (W_e) which captures the selection variability over a series of trials (cf. Formula (2)). SD_x is the standard deviation of the over/under-shoot projected onto the task axis for a given condition.

$$Throughput = \frac{ID_e}{MT} \quad (1)$$

$$ID_e = \log_2\left(\frac{D_e}{W_e}+1\right) \left(where\ W_e = 4.133 \times SD_x\right) \quad (2)$$

IEEE Virtual Reality 2011
19-23 March, Singapore
978-1-4577-0037-8/11/$26.00 ©2011 IEEE

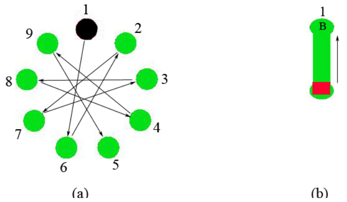

Figure 1. (a) Multi-tapping targets and (b) Sliding task

For this task, subjects were presented with 9 circular targets, arranged in a circle on the virtual planar surface. The order of presentation of the 9 targets was predefined as in Figure 1(a). Targets were highlighted in red (except target 1, which was highlighted in black, allowing the subject to rest) one at a time; subjects were asked to point to the highlighted target as quickly and accurately as possible using their index fingertip. Making a selection (whether a hit or a miss) ended the current trial.

We used a 3×2× 2× 6 within-subjects design for this task. The independent variables were feedback (visual (V), visual + auditory (VA) and visual + passive haptic (VH) feedback), target size (circle diameter 2.5cm and 4.0cm), distance between targets (11cm and 24cm), and block (1 to 6). The dependent variables were movement time (s), error rate (percent), and throughput (bps). Results were analyzed with repeated measures ANOVAs.

Average movement time was 0,528s (SD=0,139), 0,540s (SD=0,153) and 0,589s (SD=0,153) in the V, VA and VH conditions respectively. The difference was significant ($F(2,432) = 7{,}724$, $p=0{,}001$). Post-hoc comparisons using Tukey test revealed significant differences between the VH and V conditions ($p<0.001$), and between the VH and VA conditions ($p=0.003$). The difference between the V and VA conditions was not significant. The average error rate was 7,43%, (SD=12,44%), 5,68% (SD=10,20%) and 9,38% (SD=13,54%) for the V, VA and VH conditions respectively. The difference was significant ($F(2,432) = 4{,}289$, $p = 0{,}014$). Post-hoc comparisons (Tukey test) revealed a significant difference in error rate between the VH and VA conditions ($p = 0.004$). The difference in throughput, which incorporates both speed and accuracy, was also significant ($F(2,432)=20{,}414$, $p<0{,}001$). The average throughput was 4,92bps (SD=1,51), 4,84bps (SD=1,43) and 4,11bps (SD=1,37) respectively for the V, VA and VH conditions. Post-hoc comparisons using Tukey test revealed significant differences in throughput between the VH and V conditions ($p<0.001$), and between the VH and VA conditions ($p<0.001$).

The longer movement time in the condition of visual and passive haptic feedback (i.e., the VH condition) was surprising, since the visual feedback was the main indicator for subjects to plan their pointing gesture and we expected equivalent performance in the three conditions. A possible explanation is that the presence of a physical plexiglass surface might have forced subjects to slow down their hand movement at the end of the pointing movement, in order to avoid painful contact with the plexiglass. It was not the case in the other two conditions since the user's finger could pass through the virtual planar surface. An analysis of speed profiles on times-series data might test this hypothesis.

2.3 Experimental Task II: Sliding

Subjects pointed to a red circle target at the centre of a virtual planar surface to start a trial. A green bar linking the centre of the planar surface to one of the 9 positions as presented in Figure 1(a) (depending on trials) and a red cursor were presented at the centre of the planar surface (cf. Figure 1(b)). Subjects had to move the cursor to the other end (i.e., the end B in Figure 1(b)), of the green bar to finish a trial. Subjects could only move the cursor when the index fingertip touched the cursor. In the VA condition, the subject could hear a "ding" when touching the red target at the beginning and a continuous sound feedback when moving the cursor.

A 3×2×2×3 within-subjects design was used for this task. The independent variables were feedback (visual (V), visual + auditory (VA) and visual + passive haptic (VH) feedback), bar size (2.5cm, 4.0 cm), bar length (10cm, 12cm), and block (1 to 3). The dependent variables were movement time (s) and number of contact losses (times) between the index fingertip and the cursor. Results were analyzed with repeated measures ANOVAs.

The average movement time was 1,124s (SD=0,380) in the V condition, 1,277s (SD=0,512) in the VA condition and 0,929s (SD=0,212) in the VH condition. The difference was significant ($F(2,216) = 16{,}639$, $p<0{,}001$). Post-hoc comparisons using Tukey test revealed significant differences between the VH and V conditions ($p=0.002$), between the VH and VA conditions ($p<0.001$) and between the V and VA conditions ($p=0.011$). The number of contact losses varied in accord with the movement time: 1,185 times (SD=0,787) in the V condition, 1,485 times (SD=0,913) in the VA condition and 0,667 times (SD=0,595) in the VH condition. The difference was significant ($F(2,216) = 22{,}368$, $p<0{,}001$). Post-hoc comparisons using Tukey test revealed significant differences between the VA and V conditions ($p=0.015$), between the VH and V conditions ($p<0.001$) and between the VH and VA conditions ($p<0.001$).

Increased users' performance in the condition with passive haptic feedback was expected since the plexiglass sheet constrained the user finger's movement on the slider's surface, leading to reduced contact losses and movement time. However, it was surprising to see longer movement time and more contact losses with continuous auditory feedback, as compared to visual feedback only. The continuous auditory feedback might have attracted subjects' attention, forcing them to make more corrective movements, resulting in longer movement time and more errors.

3 Conclusion

We have presented here a preliminary study, evaluating the effect of three types of sensory feedback during a sliding and a pointing task, in a context of interaction with graphical menus. Auditory feedback appeared to be more efficient than passive haptic feedback (in terms of movement time, errors and throughput) in the pointing task which required rapid aiming movements, but less efficient than both visual/passive haptic feedback and visual feedback alone in the sliding task. Results obtained with the pointing task raise a number of issues. The ending condition for the pointing task, which was defined as a surface contact between the fingertip and the target, might not be enough to address questions regarding pointing precision in VEs. Adding spatial constraints to the ending condition (e.g., the end points of pointing having to be in a given 3D zone) might help to gain more insight on the effect of auditory and passive haptic sensory feedbacks.

Acknowledgment

The authors wish to thank Jean-Marie Pergandi, Pierre Mallet, Cédric Goulon and all the subjects. This work was carried out in the framework of the VIRTU'ART project, approved by the Pole PEGASE, funded by the PACA region and the French DGCIS.

References

[1] Bowman, D. and Hodges, L., An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments, SI3D '97, 35-38, 1997.

[2] Bowman, D., Kruijff E., LaViola J.J., and Poupyrev I. 3D user interfaces: theory and practice. Reading, MA: Addison-Wesley; 2004.

[3] Fitts, P. M., The information capacity of the human motor system in controlling the amplitude of movement, J. Exp. Psychol., 47, 1954, 381-391.

[4] ISO 9241-9 Ergonomic requirements for office work with visual display terminals (VDTs) - Part 9: Requirements for non-keyboard input devices. International Organization for Standardization, 2000.

[5] Sturman, D.J., Zeltzer, D. and Pieper, S. Hands-on interaction with virtual environments. In Proceedings of UIST '89, 19-24, 1989.