Difficulties Using Passive Haptic Augmentation in the Interaction within a Virtual Environment

R. Viciana-Abad, A. Reyes-Lecuona, F.J. Cañadas-Quesada
Department of Electronic Technology
University of Málaga
ETSI Telecomunicación, Campus de Teatinos, CP. 29071
Málaga, Spain.
{ viciana@uma.es, areyes@uma.es, fjcq@uma.es }

Abstract

In this paper, the evaluation of an interaction technique based on the metaphor of the natural hand in a virtual environment (VE) is presented. The aim of this study is the analysis of how the inclusion of passive haptic feedback affects the interaction within a VE.

With this purpose an experiment with 18 subjects was conducted. The pilot design of this experiment and the implemented system used as a testbed are described.

The evaluation of this interaction has been developed taking into account both, objective and subjective factors. A pilot experiment was conducted to study the relationship among haptic feedback, presence and task performance, and the obtained results are discussed.

A new objective estimation of presence is also presented.

1. Introduction

Applications based on immersive VE are complex because of the interaction within the environment. Over recent years, there has been some research into 3D interaction aimed at the development of new interaction techniques and at the study of their evaluation. Moreover, the sense of presence has proved to be highly influenced by interaction mechanisms [1].

Lombard [2] interprets presence as "a perceptual illusion of non-mediation"; presence is what happens when the participant forgets that his perceptions are mediated by technology. In this sense the effect the implemented passive touch mechanism has on the illusion of non-mediation is evaluated within this testbed.

Many research studies [3] suggest that multimodal interaction compensates some constraints of interaction mechanisms. In this sense the haptic modality is being included in a wide variety of forms in Virtual Reality systems and via different devices. On the other hand, multimodality has to be carefully used because mismatches between the different sensorial sources can lead to negative effects for the user [4] [5]. Furthermore, the economical cost of devices that provide force feedback is sometimes a drawback.

In this paper we propose the use of passive force feedback as an alternative to complex, active devices for some specific applications. Moreover, the constraints of using this passive force feedback instead of active devices are discussed.

The performance assessment of the interaction techniques is difficult, mainly because its definition is unclear. A possibility is the measurement of the task completion time, the accuracy or the error rate. Nevertheless, certain applications based on VE usually treat a broad definition of performance, in which cybersickness or presence can be considered [6]. So, in this paper we propose a testbed to evaluate a passive force feedback mechanism by measuring the task performance and its relationship with presence.

In section 2, a discussion of the prior work is presented. The testbed description and the experiment design are shown in sections 3 and 4. In section 5, the results obtained from the experiment are presented. We conclude, in sections 6 and 7, with a discussion and some conclusions about the results. Finally, in section 8 we describe some ideas about further research.

2. Prior work

In recent years, a number of researchers ([7] [8]) have explored the use of new interaction techniques to enhance human performance, using objective metrics.

The use of haptic in a VE is implemented in several systems. McLean [9] discusses the use of haptic feedback as a design element for human computer interaction. Moreover different investigations measure the effectiveness of passive haptic feedback by objective and subjective metrics. Meehan [10] uses the concept of passive haptics to elicit presence. Rossember [11] shows, in a pilot study, that both active and passive force feedback can be effective in decreasing the task completion time. Hoffman [12] provides the subjective analysis of a technique based on tactile augmentation.

Furthermore, regarding the relationship between interactivity and presence and its consequences, some studies have determined that interactivity of VEs is an important cause of presence [13].

3. The testbed system

The system used as a testbed reproduces a virtual version of the "Simon says" game (Figure 1). This game is

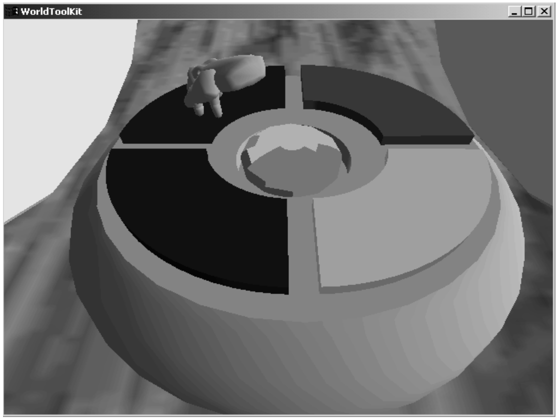

Figure 1 "Simon says" game shown to the subjects

a simple device that consists of four differently coloured buttons.

The system shows a sequence (by lighting the buttons and emitting a sound) and the user must then try to reproduce the sequence correctly. When the reproduced sequence is correct, the system increases the sequence length by adding one new step. Hence, the task grows in complexity as the sequence length increases. When the sequence is not well reproduced an error sound is emitted and two lateral plates (see Figure 1) are suddenly closed, grabbing the user's virtual hand.

The interaction with the virtual game consists in pushing buttons. Therefore, it is simply a selection task of objects within a close range. This selection is implemented as a natural mechanism by merely touching the buttons with the fingers of the virtual hand.

To do this, we need to track the position of the user's hand with a tracker (Flock of Bird by Ascension) and a VR glove (cyberglove by VTi). Furthermore the user sees the VE through a HMD (Head Mounted Display (VR8 by IIS)) with another tracker attached in order to sense the orientation of the head.

The system detects when a button is pressed by testing when an intersection between one of the user's fingers and a button occurs. This intersection is checked in two ways: by testing the fingertips bounding-box, and with a ray originating from the fingertip and normal to the button surface. The button goes off when all the fingertips are removed and separated by a minimum distance threshold.

The passive force feedback is implemented in the system by means of a real surface placed under the participant's hand. Furthermore, the tracking control system is calibrated in such a way that the real fingers touch the real surface when the virtual hand presses a button. This calibration procedure includes a slight rotation of the reference system. This allows us to reduce certain distortion of the magnetic tracker attached to the user's hand and match the real horizontal plane with the virtual one.

4. Pilot experiment

We have conducted a pilot experiment to explore the influence of using passive force feedback in the task performance and presence achieved during the interaction with the testbed system.

4.1. Participants

Eighteen subjects (10 males, 8 females) participated in the experiment. All of them were undergraduate first year telecommunication engineering students at the University of Málaga, aged between 17 and 19. No reward was given to them for their collaboration.

4.2. Experimental conditions and procedures

In this experiment, the independent variable was the existence or absence of passive haptic feedback when the participant presses a button. The experiment has a within-subject design. This means that every subject interacts with the system under two conditions: "haptic feedback" (FB) and "no haptic feedback" (NFB) (See Figure 2). Moreover, to eliminate the possible effect the order of the two conditions has, a counterbalanced design was made. Thus, the participants were randomly assigned into two groups. In one group, FB condition was used before NFB condition (FB-NFB), and in the other group the opposite order was used (NFB-FB).

The dependent variables considered in this experiment are the subjects' sense of presence within the VE and the task performance when interacting with the system.

a)

b)

Figure 2 a) FB condition b) NFB condition

The experiment took place in a research laboratory. Upon arrival, participants completed consent forms and then they received all the task instructions. Every trial lasted 6 minutes; the first two minutes being devoted to training. The difference between these two periods is that in the training phase, there is no *virtual grabbing* of the hand when an error is committed.

4.3. Measurement mechanisms

The sense of presence was operationalized by means of a subjective measurement based on questionnaires, and an objective one, based on user behaviour. The task performance was operationalized via some different measurements.

4.3.1. Presence measurements. The subjective measurement of presence was calculated by using two presence questionnaires; Presence Questionnaire (PQ), proposed by Witmer et al. [14], and the questionnaire proposed by Slater et al. [15].

In order to evaluate the subject behaviour when an error is made we record his/her hand position, for two seconds from the moment this error is made. With this data, a two-dimensional graph can be plotted representing the averaged trajectory of the hand. In order to compute this average, we consider that the hand is in the origin of coordinates (0,0,0) when an error is committed. Then, the average position for each time *t* after an error is computed as follows:

$$\left(\overline{X}(t), \overline{Y}(t), \overline{Z}(t)\right) = \left(\frac{\sum_{i=1}^{N} x_i(t)}{N}, \frac{\sum_{i=1}^{N} y_i(t)}{N}, \frac{\sum_{i=1}^{N} z_i(t)}{N} \right)$$

where $x_i(t)$, $y_i(t)$ and $z(t)$ are x, y, z coordinates respectively of the hand at the time *t* after the *i*-th error is committed. N is the total amount of errors. A linear interpolation is used to compute the average trajectory in certain temporal positions where no data is recorded.

So, every time an error occurs, two seconds of hand position are recorded, and we can follow the evolution over time of the user's hand movement. Note that following an error the game triggers the closing of the lateral plates and a sound is emitted. Therefore, differences in the trajectories made by the hand in response to this virtual event are expected to be related to different levels of presence.

4.3.2. Task performance measurements. During the trials, the score, the number of errors committed during the game, the spurious actions and the elapsed time between button pressings are recorded. The score is considered as the maximum sequence length reached by the user during the game. Spurious actions are evaluated registering the number of times the central button in the game is pressed when the user is trying to reproduce a sequence.

Furthermore, the subjects were asked how long they thought the trials lasted. The subjective estimation of time is considered to be an indication of the difficulty related to the provided interaction mechanism [16].

5. Results

5.1. Presence measurements

Regarding the sense of presence, the presence factor proposed by Slater et al. (**SF** in Figure 3) showed a slight difference between the two conditions within both groups. Moreover no differences were noted when analyzing the participants' answers without considering the order.

The PQ questionnaire showed certain significant differences between the two experimental conditions. The factors evaluated were: Presence **P**, Control/Involvement **C**/I, Natural **N**, Interface Quality **IQ**, Auditory **A**, Haptic **H** and Resolution **R**.

No dependence to the order of the two conditions (FB/NFB) was found for any of these factors. So, the difference in the factors between the two conditions in the 18 subjects is analysed, without taking into account the order.

In Figure 3, differences in the mean factors for each condition and their significance are shown. These factor values are always higher in the NFB condition in the two groups except in R (with no significance).

In Figure 4, the averaged trajectories of the users' hands in three dimensions (a, b) and their projections in the horizontal plane (c, d) under the two conditions are shown.

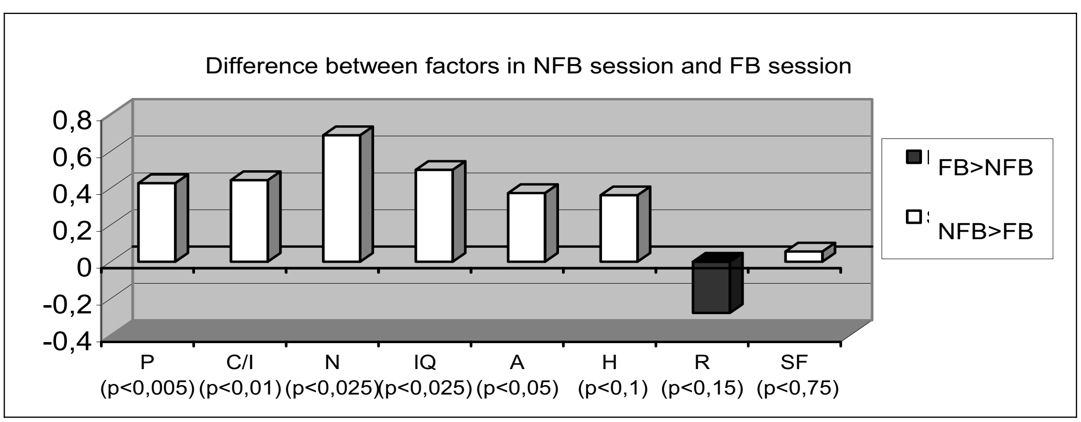

Figure 3 Differences found for each factor

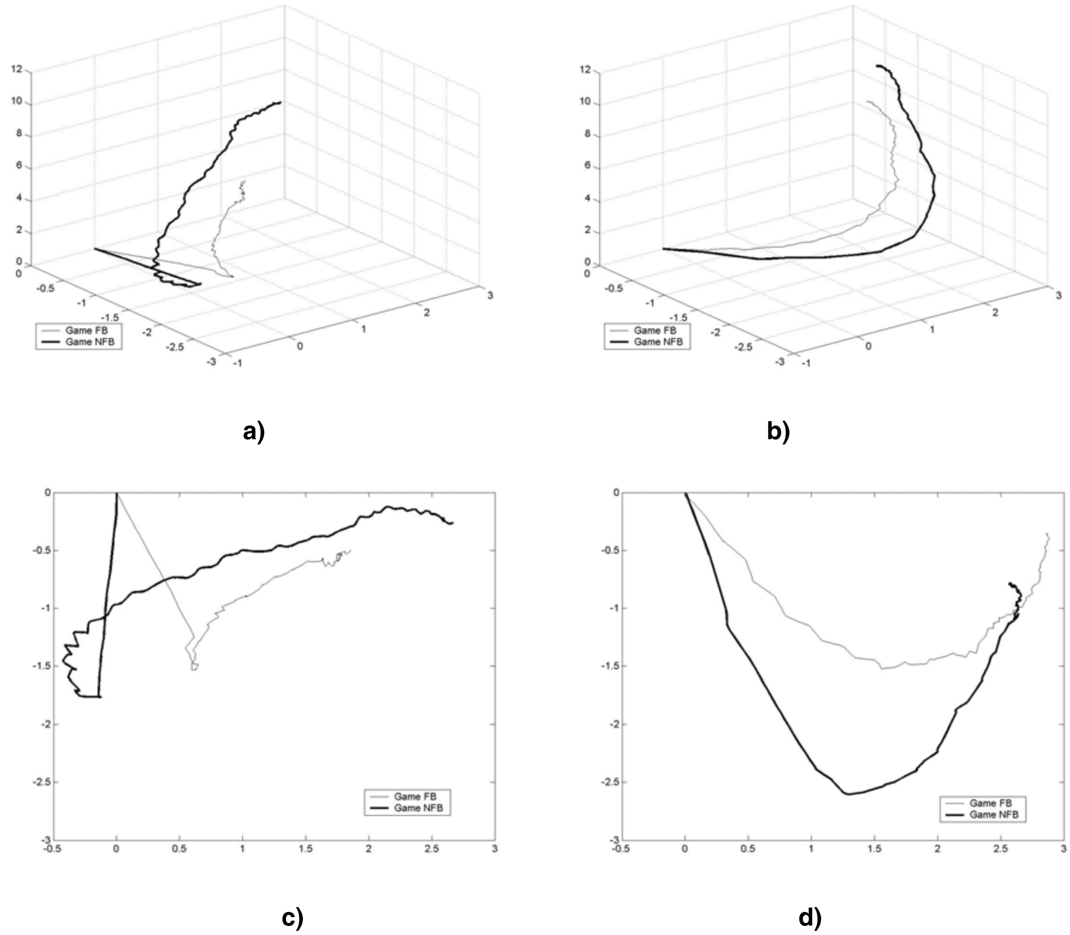

Figure 4 a) c) Averaged trajectory of the users' hand during two seconds following an error. b) d) Averaged trajectory of the users' hand during two seconds from when the highest scores are reached just before an error is made.

Subfigures a) and c) show the average trajectories during two seconds following an error and its consequences. Subfigures b) and d) show the average trajectories during two seconds after users reach their highest score just before an error is made. When no error is made the graphics show the normal movement needed in order to clearly view the next sequence. So, they move their hand back closer to their bodies. When an error occurs this movement is the response to the clashing plates. As can be seen in this figure, a sharper change in the users' hand trajectory occurs when an error is made. In both cases the users' hand is moved over a wider range in NFB condition.

5.2. Task performance measurements

The highest score is achieved within the NFB condition. The difference in the length of the sequence between the two conditions on average is 1.72 ($p<0.025$).

Regarding spurious actions, a dependence with the order of administration of the two conditions was found. Better values are taken in the first condition, whether being FB or NFB, (difference of 2.83 $p<0.025$).

The average time elapsed between button pressings, is shorter in the NFB condition. However, it is a small non-significant difference of 166 ms.

The subjective estimation of the average time spent in each condition, was higher in FB condition. These averaged values are 6.27 min. (NFB) and 7.35 min (FB), but no significant differences were found ($p <0.25$).

6. Discussion

In this paper, a study on how passive haptic feedback affects the sense of presence and task performance within a VE is presented. In accordance with previous works, we expected haptic feedback to enhance the sense of presence and task performance [10] [11] [17].

However, our results show that, surprisingly, this passive haptic feedback diminishes the sense of presence and task performance. This could be explained by the fact that slight mismatches were detected between the position of the virtual object and the prop arranged to provide the passive haptic feedback. These mismatches can hinder the interaction because the rigid surface which can become an obstacle. In these situations, passive haptic feedback produces a sense of mediation that decreases the sense of presence. This idea is in accordance with the subjective estimation of time reported by the subjects. Subjects in the FB session reported a longer time, although the experiment duration was the same for both conditions. According to some studies [16] that relate higher time estimation with interaction difficulties, it seems that the interaction task in FB condition was more complex.

Although passive haptic feedback presents some advantages over active ([18], [19]), special care must be taken with the spatial synchronism. This kind of non-intelligent feedback might become an obstacle to the interaction when slight mismatches in that synchronism are present.

7. Conclusions

The presented testbed and pilot study have shown the importance of the spatial synchronism between real and virtual worlds for interaction. These findings indicate that further research should include techniques that improve the spatial synchronism.

We have also proposed a new objective technique to estimate presence, based on the users' reaction when an event takes place (in this case the clashing plates) via detecting changes in the hand trajectory. Our results indicate a relationship between the objective and subjective measures of presence, based on questionnaires. Furthermore, in this interaction experiment, task performance is also related to presence. In both cases, it seems that the sense of presence of the subject is higher in the NFB condition. Moreover better performance is found in the NFB condition considering the score, precision and elapsed time between button pressings.

The experiment developed for this research shows how the improvement that is expected by providing a new source of sensorial information might become a new interaction difficulty. Nevertheless, we still think that haptic feedback should improve the interaction, but we suggest that passive haptic feedback presents difficulties of implementation regarding spatial matching. Moreover, adding a new source of information requires a major effort in order for this new source to coherently join with the other sensorial sources present. In this sense, passive haptic mechanisms, whilst easier to supply than active ones, require more effort in order to overcome the lack of accuracy derived from tracking systems and the virtual reality glove.

One of the major problem sources is that there are individual differences among users. It is difficult to provide an interaction mechanism appropriate for each individual user, with different hands and different interaction and cognitive styles.

8. Further works

Further research should include techniques that improve the spatial synchronism between real objects and virtual ones. Due to the lack of accuracy of the tracking system used for the fingers (virtual reality glove) and the hand (tracker), the passive haptic feedback should be made via using a soft surface. This would provide a certain error margin that could facilitate the interaction between user and virtual environment

In order to overcome individual differences, some facilities should be provided allowing the configuration of the virtual hand in such a way that it is adapted to some physical features of the real hand. In addition, the calibration procedures should be improved.

Acknowledgements

This work has been partially supported by Spanish Ministry of Education & Science and ERDF funds through the project TIC2002-4348-C20-01.

References

[1] W.I. Jsselsteijn. Elements of a multi-level theory of presence: Phenomenology, mental processing and neural correlates. In *Proceedings of PRESENCE 2002,* 245-259. October 2002.

[2] M. Lombard, T. Ditton. At the heart of it all: the concept of presence. *Journal of Computer-Mediated Communication*, 3(2). September, 1997.

[3] F. Biocca, J. Kin, Y. Choi. Visual touch in virtual environments: an exploratory study of presence, multimodal interfaces, and cross-modal sensory illusions. Pr*esence: Teleoperators and Virtual Environments*, 10 (3), 247-265. 2001.

[4] F. Biocca. Will simulator sickness slow down the diffusion of virtual environment technology?. *Presence: Teleoperators and Virtual Environments*, 1 (3), 334-343. 1992.

[5] K. Stanney. Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda. *International Journal of Human-Computer Interaction*, 10 (2), 135–187. 1998.

[6] R.S., Kalawsky, S.T. Bee, S.P. Nee. Human factors evaluation techniques to aid understanding of virtual interfaces. *BT Technology Journal*, 17 (1), 128-141, 1999.

[7] S. Poupyrev, M. Billinghurst, T. Ichikawa. Egocentric object manipulation in virtual environments: empirical evaluation of interaction techniques. In *Proceedings EUROGRAPHICS'98,* 17 (3) , 41-52. 1998.

[8] D.A. Bowman, D.B. Johnson, L.F. Hodges. Testbed evaluation of virtual environment interaction techniques. *Presence: Teleoperators and Virtual Environments*, 10, 75-95. 2001.

[9] K.E. MacLean. Designing with haptic feedback. In *Proceedings of IEEE Robotics and Automation*, 783-788. 2000.

[10] M.Meehan, B. Insko, M.Whitton, F.P. Brooks. Physiological measures of presence in virtual environments. In *Proceedings of 4th International Workshop on Presence*. May 2001.

[11] L. Rosenberg, S. Brave. Using force feedback to enhance human performance in graphical user interfaces. In *Proceedings of CHI 96*, 291-292. 1996.

[12] H.G. Hoffman, A. Hollandera, K. Schrodera, S. Rousseaua, T. Furnessn. Physically touching and tasting virtual objects

enhances the realism of virtual experiences. In *Proceedings Virtual Reality* 3, 226-234. 1998.

[13] M.J. Schuemie, C.A.P.G. van der Mast. Presence: Interacting in VR?. In *Proceedings of Twente Workshop on Language Technology* 15, 213-217. 1999.

[14] B.G. Witmer, M.J. Singer. Measuring presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3), 225–240. 1998.

[15] D. Nunez. A connectionist explanation of presence in virtual environments. M. Phil Thesis. Dep. of Computer Science, University of Cape Town. 2003.

[16] A. Haston, A. Kingstone. Time estimation: The effect of cortically mediated attention. *Brain and Cognition*, 55 (2), 286-289. 2004.

[17] E.L. Sallnäs, K. Rassmus-Gröhn, C. Sjöström. Supporting Presence in Collaborative Environments by Haptic Force Feedback. In *Proceedings of CHI 2000*, 7 (4), 461-476. December 2000.

[18] B.E. Insko. Passive haptics significantly enhances virtual environments. Doctoral Thesis. Department of Computing Science, UNC Chape0. 2001.

[19] M.R. McGee. Investigating a multimodal solution for improving force feedback generated textures. Doctoral Thesis. Department of Computing Science, University of Glasgow. 2003.