Object Manipulation in Virtual Environments: Effects of Visual and Haptic Feedback

A.C. Boud, C. Baber, & S.J. Steiner

The School of Manufacturing and Mechanical Engineering,
The University of Birmingham, Egbaston, Birmingham, B15 2TT, UK
a.c.boud@bham.ac.uk

Abstract

This paper investigates performance times for object manipulation tasks in virtual environments (VEs). The study presents a 'novel' interaction technique where Instrumented Objects (IOs) are used as an interaction device that provide participants with encompassing haptic information. Comparative experiments were undertaken, where participants used a number of different interaction techniques to solve the Tower of Hanoi problem. Performance times were monitored for each interaction technique, with the study demonstrating that superior performance times were achieved when 3D immersive virtual reality (VR) with IOs are used. The relevance of this technique is discussed.

Key words: Virtual Environments, Haptic Feedback, Object Manipulation.

1. Introduction

A growing amount of research is being undertaken amongst virtual reality (VR) practitioners concerning the ability of users to interact in a virtual environment (VE) in a natural and realistic manner. In fact, this is of vital importance if VR is to achieve its potential in a number of applications. In certain areas this is possible; but in an increasing number of complex applications (including areas such as operator training and design for assembly), technological limitations are being encountered. One area receiving significant interest is that of interacting with virtual objects, due to the task's influence on a wide range of applications.

Conventional interaction techniques with computer generated data are based on a 'point and click' paradigm. However, VR technology has provided a whole new approach to visualisation and interaction. Rather than 'point, select, click', VR allows 'reach, grasp, carry'. Although VR offers significant benefits, it also presents a number of problems. This paper seeks to present an overview of haptic technology, describing the advantages, and highlighting a number of limitations. The importance of achieving a realistic interaction technique for the manipulation of virtual objects is described, and different VR interaction techniques are investigated. Performance times are compared for completing the Tower of Hanoi problem using (i) 2D desktop VR with a conventional mouse, (ii) 3D immersive VR with a '3D' mouse, and (iii) 3D immersive VR with instrumented objects (IOs), results are presented, and the relevance of using IOs is discussed.

2. Haptic feedback

With input devices such as the '3D' mouse, a user can be immersed in a VE and can interact with components in three dimensional space. However, when a user moves their hand to grasp an object, as no haptic feedback is provided, there is no indication to the user if the object has been grasped. Therefore, it is possible for the user's hand to pass straight through the object, which presents a totally different form of interaction to that of the real world. Visual and auditory cues can be applied in the VE indicating that a collision has occurred between the geometry of the user's hand and the geometry of the object, but this is far from replicating the physical action in the real world. Hence, to maximise the realism of the environment, and to improve the 'naturalness' of an object manipulation task in a VE, it has been proposed that haptic feedback will improve performance times, and reduce error rates (Richard, et al, 1996).

The human haptic system is described by Ellis (Ellis, *et al*, 1996) as "the sensory system which includes proprioceptive sensing of muscle/tendon states as well as tactile sensing of skin deformation" (p. 321). Haptic feedback is the term generally used to encompass tactile, force, and kinaesthetic feedback. Tactile feedback generates a sense of touch to the skin of the user, force feedback provides a sensation of weight or resistance to an object, and kinaesthetic feedback provides a sensation of muscles and tendons through body movements. One of the main reasons we have not seen a device fully capable of supporting the haptic system, is the complicated structure of the underlying physiology of these processes. (For a more in-depth overview of the physiological system concerned with human sensation and perception, see Matlin (Matlin, 1988).)

Haptic devices were originally used for telerobotic applications, such as nuclear, space or underwater environments, where it was hazardous or impractical for a human operator to enter. Telerobotic devices are based around a master/slave system, where the operator controls a master device remotely located from the slave robot. Existing teleoperated devices and their haptic principles have been adopted for use with VEs.

Burdea (Burdea, 1996) has categorised feedback devices for VR applications into force and tactile devices.

2.1 Force Feedback

Force feedback devices form the majority of devices currently available, and these are further categorised into portable and non-portable devices.

The most common form of force feedback devices are non-portable, desk-grounded devices, based upon a joystick or pen design. These systems tend to be comparatively cheap; however, the limitation of their movement can pose problems when used in immersive systems, as the device is always fixed in the same location, and hence limits the movement of the operator in the VE. Ceiling or ground based devices tend to offer improved functionality; however, the associated cost is also higher, limiting their use to large research laboratories (Burdea, 1996).

Portable feedback systems provide an improved method of haptic feedback for immersive VR systems, as the device is usually attached to the operator (either in the form of arm exoskeletons, or hand masters), and the device therefore moves with the user, offering a more natural interface. However, this presents a number of problems. To present the user with a good freedom of movement, using either the arm or the hand, the design of the haptic device needs to incorporate a number of degrees of freedom. This therefore requires a number of actuators and complex mechanical structures to apply the resultant forces. Portable force feedback devices therefore tend to be heavy, and can limit the users operational time due to the onset of fatigue.

2.2. Tactile Feedback

Simoga (Simoga, 1993) categorises tactile feedback into:-

- Visual or audible display: does not provide a sense of tactile feedback through the tactile senses, but rather indicates that an object has been grasped through visual or auditory cues. However, it is arguable if this can be categorised as a tactile feedback device, as no feedback is applied through the tactile senses.
- Pneumatic stimulation: utilises air pockets (usually located inside an instrumented glove) that inflate once an object has been grasped.
- Vibro-tactile stimulation: uses a number of blunt pins that activate once an object has been grasped. The pins operate with variable frequency and amplitude depending upon the object touched.
- Electro-tactile stimulation: uses a number of electrodes to emit electrical pulses to various parts of the hand.
- Functional neuro-muscular stimulation: this method of tactile feedback is still at a very early stage of research, but may offer the greatest potential of all the devices discussed. Functional neuro-musular stimulation uses neurological signals, interpreted by the brain as tactile responses.

2.3 Summary of force and tactile feedback

From the preceding discussion it should be apparent that the devices are currently poor at presenting some of the essential haptic feedback. For example, stimulation of the receptors in the skin is problematic. One could use a dataglove but it is difficult to have precise correspondence between stimulation and receptor (particularly with different sized hands in the same sized glove). Kinaesthetic feedback can be obtained from a 3D mouse, but the movements used to move the mouse are not necessarily the same type as those used to move the real object.

To summarise, a number of haptic devices have been developed which do offer a good degree of tactile feedback, but fail to provide significant force feedback, and vice versa. The selection of a feedback device is therefore dependant upon the application. There are a considerable number of devices currently under development or on the market, and the functionality offered by these devices is vastly different. For certain applications, using just a force feedback device may provide the necessary haptic information. However, if a device were required to provide encompassing haptic information, a force, tactile and kinaesthetic feedback device would be required for each of these modalities.

3. Interaction in VEs

VR can be defined as a three dimensional computer generated environment, updating in real time, and allowing human interaction through various input/output devices. By allowing a variety of representations, e.g. 2D or 3D, desktop or immersive, VR can offer users the opportunity to explore virtual objects at levels of detail appropriate to work activity. It is a fundamental point as to whether immersive, 3D VR is superior to other forms of representation for object manipulation tasks. This highlights one of the main advantages of VR, namely it enables visualisation and interaction with 3D objects in a 3D manner. Although desktop based VR systems allow visualisation of 3D objects, it is not possible to fully interact with these objects in a natural and realistic way. We note that work is needed on how best to relate representation to user requirements.

VR permits different interaction strategies (although the predominant form is through some type of pointing device). Efforts to improve the 'naturalness' of interaction, e.g. through haptic feedback, have met with a variety of problems (Burdea, 1996). One issue of concern is if the technical problems of haptic feedback are solved, there still remain human factors which lead to impaired overall performance (Gupta, *et al.*, 1997). In this paper we present a method of providing haptic feedback using real IOs, where the user can grasp, pick up, and manipulate objects, providing the user with tactile, force and kinaesthetic feedback.

A simple classification of visual and haptic feedback can be made on the basis of whether the domain of the feedback is real or virtual, i.e. see Table 1.

Table 1: Feedback classification

		Visual Feedback	
		Real	Virtual
Haptic Feedback	Real	A	D
	Virtual	B	C

Reading counter-clockwise, A = real-task performance, B = telemanipulation (often performed with mediated visual display), C = conventional VR, and D = haptic augmentation of VR. Our interest is two fold, (i) to compare the effects of these different configurations on user performance, and (ii) to examine D in more detail.

Hand (Hand, 1997) states "providing feedback by manipulating physical input devices which closely correspond to virtual objects is an important step towards bridging the gap between knowing what we want to do and knowing how to do it" (p. 272). Examples of research into these physical input devices include Murakami's (Murakami, *et al*, 1994) use of deformable shapes to interact with virtual space; Hinckley's (Hinckley, *et al*, 1994, 1997) use of an instrumented cutting plane to inspect brain scans; and Taylor's (Taylor, 1995) investigation into the use of surrogate objects for object manipulation in VEs. Thus, the idea of considering real objects to manipulate virtual representations is receiving growing support.

4. Experimentation

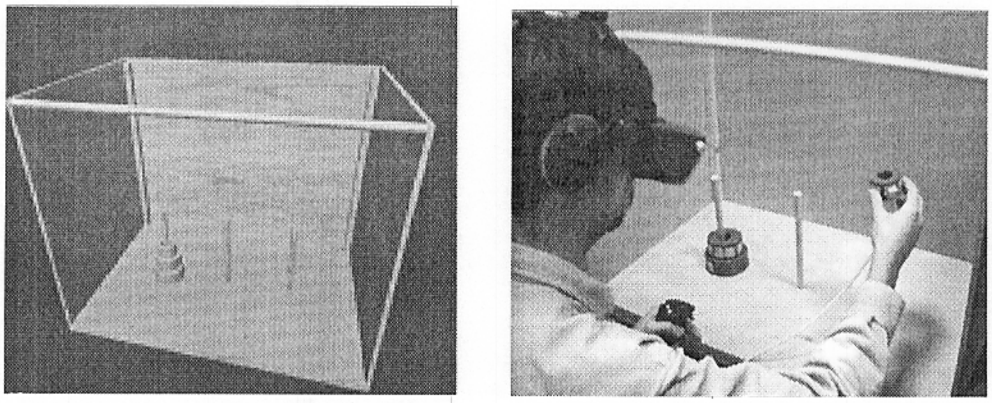
Previous work has compared cell A with cell C from Table 1, e.g. Gupta (Gupta, *et al*, 1997) compares part handling and insertion performance times for a 'peg in hole' task. The task is performed using either a PHANToM force feedback device to manipulate a virtual peg into a hole or a physical peg to be inserted into a hole, where the real and simulated tasks have the same sizes, weights, frictional characteristics, and index of difficulty as defined by Fitts law (Fitts, 1954). The results indicated that performance times in the multimodal VE were twice as long as in the real world, but trends in the variation in assembly times with parameters such as friction, chamfer, clearance, and handling distances were the same. However, the authors noted that provision of force feedback tended to improve performance (assembly completion times were found to increase by a factor of 1.3 with the absence of force feedback), particularly in the insertion phase. While the authors note several possible explanations of the differences in performance, we will draw upon two for our discussion: (i) dissociation between visual and haptic displays meant that it was difficult for the users to match physical actions to space; (ii) object manipulation using the PHANToM differed to that using the real object, e.g., the point of contact at the fingertip differed in the two modes. In our research we have sought to match visual and haptic information and to allow object manipulation to follow the activity used in real tasks. Also, Richard (Richard, *et al*, 1993) conducted studies using the Rutgers Master feedback device for object manipulation performance in VEs. They found that task performance was improved by 50% and learning times were reduced by 50% with the provision of haptic feedback. Our intention in this experiment is simply to compare cells A, C and D in order to determine the utility of D, i.e., to compare real and VE performance with that of a hybrid haptic augmented VR. For this purpose, The Tower of Hanoi problem was selected as it allowed us to investigate performance of a sequence of actions, rather than single movements (see Figure 1).

Method

Participants used (i) 2D, (ii) 3D immersive VR with a 3D mouse, or (iii) 3D immersive VR using IOs interaction techniques to solve the Tower of Hanoi problem. Four experienced VR users (with in excess of 6 months experience of immersive VR systems) were employed for the study. Each task was completed 10 times, under; (i) desktop VR and conventional 2D mouse; (ii) immersive VR and 3D mouse; (iii) immersive VR and IOs; (iv) real environment with real objects, and (v) the real environment, but with the participants blindfolded.

Equipment

In this study, we employed IOs as the interaction devices for VR. The objects were wooden discs fitted with a magnetic position sensor, which could be used (in much the same fashion as a 3D mouse) to move a



a) VE for Tower of Hanoi problem

b) Task performance using IOs and HMD

Figure 1. Object manipulation in VEs

graphical representation of the object in a VE.\ In this way, the properties of real objects will be used for manipulating virtual objects.

The model was generated using 3D Studio Max, and converted with texture maps to improve the realism of the model. The model contained approximately 1000 polygons, and was maintained at a constant frame rate above 25 fps. The study was conducted using a Silicon Graphics Indigo2 Maximum Impact workstation, a Virtual Research VR4 HMD, Polhemus Fastrack magnetic tracking system and a Division '3D' mouse.

Results

The total time to solve the Tower of Hanoi problem, for the different devices using seven steps are shown in Figure 2.

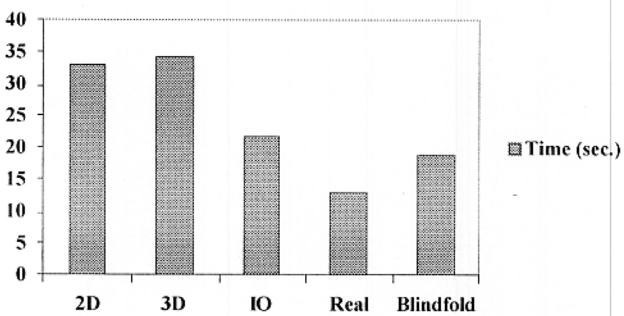


Figure 2. Performance times for the three conditions

A one-way Analysis of Variance, with five levels (2D mouse, 3D mouse, IO, real and blindfold interaction), was calculated. The results show a significant main effect across levels [$F(4,12) = 35.6$, $p<0.0001$]. Post-hoc Tukey tests (at $p<0.05$) indicate significant differences between the real x 2D, 3D and IO conditions; between blindfold x 2D and 3D conditions; and, more importantly between IO x 2D and 3D conditions. It is interesting to note that no difference existed between 2D and 3D, between real and blindfold, nor difference between IO and blindfold conditions.

Figure 3 shows the movement path for one participant moving the smallest IO. The frame rate of normal video is used, i.e. a mark represents 1/24th sec. Notice that the 'real' condition has a far smoother progression of movement, and that the 'IO' condition has lengthy delays on and off the pole (See Table 2).

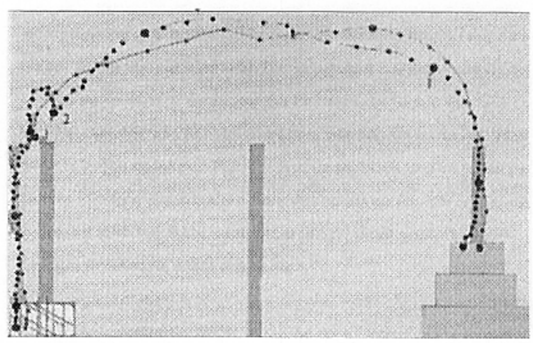


Figure 3. Movement path for the Tower of Hanoi problem

Table 2. Movement analysis of the small ring in a real and VE with an IO

	Move From Left Peg	Inter-Peg Movement	Place Onto Peg
Real Environment	56 mm/Sec	73 mm/Sec	30 mm/Sec
VR With IO	16 mm/Sec	40 mm/Sec	16 mm/Sec

During the design of this experiment, update rates of the system were maintained at a high enough level to attain a high degree of presence (i.e. >25fps) (Richard, et al, 1993). Although this reduces some of the limitations of VR systems, there was no measurement of system lag. The immersive VR experiment was set up so that the participant was orientated towards the Tower of Hanoi problem, enabling all movements to be within the operating range of magnetic sensors, and achieving the highest level of accuracy (Polhemus, 1993). However, the experiment did not seek to investigate the effects of system lag on movement tasks, which may account for the slower movement with the IOs, and also the differences in locating the ring onto the pole. However, this is not sufficient to explain IO x 3D results.

4. Discussion

The study investigated whether, with the introduction of IOs for object manipulation tasks, times could be improved with the provision of tactile, force and kinaesthetic feedback, over (i) 2D and (ii) 3D immersive with a 3D mouse interaction techniques. The study demonstrated superior performance when using IOs. Reports from participants suggest a possible explanation of this benefit, that: when using the 3D mouse, performance is visually guided, i.e., the objects are being 'driven' across the screen. With the IO, visual feedback plays less of a role, (with tactile feedback being provided by the object) allowing movement to be aimed at the target. The lack of any difference between blindfold and IO conditions suggests that users of IO might trade tactile feedback against visual feedback.

5. Conclusion

The use of IOs for object manipulation tasks offers a simple alternative to complex haptic devices currently available. A user can simply reach out in the VE and grasp a 'real' object, providing all the relevant sensations obtained in the real world. The use of IOs seems to offer a good alternative for object manipulation tasks in immersive VR systems, where an encompassing sense of haptic feedback is required.

References

Burdea, G.C., "Force and Touch Feedback for Virtual Reality", Wiley-Interscience Publication, ISBN 0-471-02141-5, 1996.

Ellis, R.E., Ismaeil, O.M., Lipsett, M.G., "Design and evaluation of a high-performance haptic interface", Robotica, Vol. 14, pp. 321-327, 1996.

Fitts, P.M., "The information capacity of the human motor system in controlling the amplitude of movement", Journal of Experimental Psychology, 47, pp. 381-391, 1954.

Gupta, R., Sheridan, T., Whitney, D., "Experiments Using Multimodal Virtual Environments in Design for Assembly Analysis", Presence, Vol. 6., No.3., pp. 318-338, 1997.

Hand, C., "A survey of 3D interaction techniques", Computer Graphics Forum, 5, pp. 269-281, 1997.

Hinckley, K., Pausch, R., Goble, J.C., Kessell, N.F., "Passive real-world interface props for neurosurgical visualisation", CHI '94, pp. 452-458, NY:ACM, 1994.

Matlin, M.W., "Sensation and Perception", Allyn and Bacon, Inc., pp. 337, 1988.

Murakami, T., Nakakima, N., "Direct and intuitive input devices for 3D shape deformation", CHI '94, pp. 465-470, NY:ACM, 1994

Polhemus, "3SPACE User's Manual", Polhemus, P.O. Box 560, Colchester, Vermont, 05446, US, 1993.

Richard, P., Burdea, G., Coiffet, P., "Human performance in tasks involving virtual objects with force feedback", Proceedings of Interface to Real and Virtual Worlds Conference, Montpellier, France, pp. 229-238, 1993.

Shimoga, K.B., "A Survey of Perceptual Feedback Issues in Dexterous Telemanipulation: Part I. Finger Force Feedback, Part II. Finger Touch Feedback". IEEE pp. 263-279, 1993.

Taylor, P., "Tactile and kinaesthetic feedback in virtual environments", Transactions of the Institute of Measurement and Control, Vol. 17, No. 5, pp. 225-233, 1995.