STEPS AND LADDERS IN VIRTUAL REALITY

MEL SLATER, MARTIN USOH, ANTHONY STEED

Department of Computer Science and
London Parallel Applications Centre,
Queen Mary and Westfield College,
University of London,
Mile End Road,
London E1 4NS,
UK.

ABSTRACT

This paper describes a technique for walking through, and climbing or descending steps and ladders in virtual reality. The idea is that human participants in the virtual reality (VR) carry out a whole body gesture similar to walking, by walking in place. A pattern analyser distinguishes between walking in place behaviour, and any other behaviour, and moves the participant through the environment when it detects the walking in place. Such "walking" while on steps or ladders similarly causes appropriate virtual movement. We discuss this in the context of a paradigm for interaction called "body centred interaction". This attempts to maximise the match between the mental body model formed as a result of proprioceptive information generated by limb and body movements, and the sensory data displayed by the VR system, within the constraints imposed by limited tracking information. We argue that the sense of presence in the VR is enhanced by such body centred interaction techniques, and we present experimental evidence in support of this claim.

1. Introduction

This paper describes an interaction technique that allows people to walk, and to climb or descend steps and ladders in virtual reality. Instead of the traditional methods of interaction based mainly on hand gestures [Robinett & Holloway, 1992; Vaananen & Bohm, 1993], participants walk and climb or descend steps and ladders by employing whole body gestures that are similar to the corresponding actions that would be required in everyday reality. Although a VR system may be very powerful in generating a sense of presence in an environment created by computer displays in the visual, auditory and tactile/kinesthetic modalities, presence may be diminished by reliance on inappropriate interactive techniques. For example, navigating the environment through pointing, may be suitable for an application such as a simulated space walk, but is unlikely to be satisfactory for architects walking through a virtual building interior. Climbing steps or ladders by virtual flying may similarly be inappropriate in an application such as training for fire fighting. The presence induced through immersion in a wide field-of-view visual display, and motion parallax through head-tracking, may be lost through the interactive techniques employed.

In earlier work [Slater et. al., 1993] we presented a technique called the Virtual Treadmill, that allows participants to walk through a virtual environment by walking in place in the real physical environment. A pattern recogniser based on a neural network used the stream of data from the Head-Mounted Display (HMD) to distinguish head movements corresponding to "walking in place" from any other kind of behaviour. Thus a participant could, for example, really walk while staying within sensor range, and such movements would correspond to walking within the virtual environment. However, in order to move large distances outside the range of the sensors, participants walk in place to be moved through virtual space. Thus whole body movements similar to walking are employed for virtual walking, even though the person stays within a small area in physical reality.

Here we discuss the utility of this idea for climbing or descending steps and ladders. In Section 2 we discuss a general paradigm for interaction in VR that we call body centred interaction. The Virtual Treadmill (VT) is an instance of this paradigm. Section 3 discusses the VT, and presents experimental results of a case-control study on the influence of alternative navigation techniques on the subjective sense of presence. Section 4 discusses the application of the VT to steps and ladders, with conclusions in Section 5.

2. Presence and Interaction

A virtual reality system requires normal proprioceptive information (about the moveable parts of our body) that we unconsciously use to form a mental model of the body, to be overlaid with sensory data that is supplied by computer generated displays. Proprioception allows us to form a mental model that describes the dynamic spatial and relational disposition of our body and its parts. This relationship between proprioceptive information and sensory data relies on consistency, predictability and completeness in order to function properly. For example, when proprioceptive information arises because we have moved a leg in such a way that it comes into contact with another object, the sensory data must correctly inform us, in all modalities, that this has indeed occurred: we see our leg move, we hear the "woosh!" as it glides through the air, we feel it touch the object (and feel any expected level of pain), we hear the sound caused by our leg hitting the object, and we see the object itself react in accordance with our expectations. This loop is the crucial component of a convincing reality: the "reality" is virtual when the sensory data is computer generated.

The human system itself, of course, provides the proprioceptive information. This must be consistent with the dynamically changing data provided to the senses by the computer generated displays, and in such a way that the person must - eventually and quickly - be able to form a predictive model of this relationship. Through this predictive model, the person learns how to interact with objects (and other participants) in the virtual world. Loomis noted that the ability of the human to model the lawful relationship between afference and efference over time was a crucial requirement for distal attribution in real and virtual environments [Loomis, 1992a; 1992b].

A VR system requires not only displays to the senses of the human participant, but also a means for tracking the movements of the person's body, so that this information can be transmitted to the computer system to update the sensory data. Thus there is an active and enabled representation of the human body in the virtual world, controlled through the normal proprioceptive mechanisms that allow interaction in the real world. We call this representation the "virtual body" (VB).

We take subjective presence to mean the extent to which human participants come to "believe" (or suspend disbelief) that they are in the locality in which their VB is represented to be. This depends on their degree of identification with their VB. Since the VB is a representation of "self", and the VB is located in a particular environment, a high degree of identification with the VB implies a corresponding belief that self is located within that environment. Identification by the person with their VB would be a function of the extent to which the VB matches the mental model of the real physical body formed by the proprioceptive system. This match is not necessarily required for visual appearance, but with respect to body movements and dynamics. For example, a significant lag between real limb movements and displayed movements of the corresponding virtual limbs would reduce the degree of match. Here proprioception would be out of step with sensory data.

Note that in this analysis we are not employing the usual criteria for immersion and consequent (tele)presence - such as a wide field of view, binocular display, high resolution displays, high quality graphics. The central feature for us is the relationship between the person's body and proprioceptive system to the computer generated displays, as explained above. If in everyday physical reality, we shut one eye, or see the world through tunnel vision, are we any less present? Such impairments to the quality and quantity of sensory data may well affect our task performance, but do not in themselves affect the degree of presence. Further discussion of presence can be found in [Held & Durlach, 1992; Sheridan, 1992; Heeter, 1992; Steuer, 1992; Barfield & Weghorst, 1993].

The main hypothesis of this paper is that interaction methods that attempt to match proprioceptive information and sensory data are likely to result in a higher reported sense of presence than methods which ignore this. For example, an interaction technique that generates proprioceptive feedback consistent with walking, is likely to generate a higher sense of presence than a technique which does not generate such feedback, in a situation where flow in the optic array indicates that walking is occurring. In the next Section we detail results of an experiment based on this idea. We call such interaction paradigms "body centred interaction".

3. Navigation using The Virtual Treadmill

3.1 Hand Gesture Based Techniques

Here we consider navigation through an environment at ground level in a simulation of walking, as would be required in an architectural walkthrough application. VPL used the DataGlove [Fisher, 1986; Brooks et. al., 1990]: a hand gesture would initiate movement, and the direction of movement would be controlled by the pointing direction. Velocity was controlled as part of the gesture: for example the smaller the angle between thumb and first finger the greater the velocity. This was demonstrated, for example, at SIGGRAPH 90.

DIVISION's ProVision system [Grimsdale, 1991] typically employs a 3D mouse (though it supports gloves as well). Here the direction of movement is determined by gaze, and movement is caused when the user presses a button on the mouse. There are two speeds of travel controlled by a combination of button presses. In our use of DIVISION's system, we adjusted the interface so that a single (thumb) button press causes forward movement in the direction of pointing, but without control over velocity.

Song and Norman [1993] review a number of techniques, distinguishing between navigation based on eyepoint movement, as opposed to object movement. Here we are interested in "naturalistic" navigation and so do not consider the latter. Fairchild et. al. [1993] discuss a metaphor for navigation, where the participant moves in the direction of body lean. This is an example of a body centred interaction technique, since it utilises the whole body in an activity that naturally moves the head and viewpoint in the desired direction of travel. The technique involves extending the apparent movement in virtual space in comparison with the real movement. In fact this is an "ice skating" metaphor, which may not be appropriate to architects taking their clients on a virtual tour, which is our primary application focus.

In the context of architectural walkthrough we require participants to experience a sense of moving through the virtual building interior in a manner that seems natural. Brooks et. al. [1992] used a steerable treadmill for this purpose. However, the use of any such device as a treadmill, footpads, roller skates [Iwata & Matsuda, 1992] imposes constraints on the movements of participants. For example, they cannot step off the treadmill in order to move around naturally in the area permitted by the effective sensor range.

3.2 The Virtual Treadmill

In [Slater et. al., 1993] we introduced a new technique based on walking in place, as described in Section 1. The two main advantages of this method are first, that the participant generates proprioceptive feedback from body movements similar (but not identical to) those caused by naturally walking. Thus there is greater correspondence between sensory data (indicating vection) and proprioceptive data. Second, the person's hand remains free for other activities, and is not involved in navigation at all.

The two disadvantages are that first, it is based on a neural network analysis of the HMD data. Since no two people have an identical method for walking in place, ideally, a different network should be trained for each user. However, we do have a network based on one person that we have designated as "standard", and most people can use this without special training. A full description of the implementation of the neural network, and corresponding results can be found in [Slater, et. al., 1994].

In two studies with users we have found the second disadvantage: that is, from the point of view of accuracy of movement from place to place, and general ease of getting around, users tend to prefer the pointing technique rather than walking in place. This result was not unexpected, since generally, as Brooks observed with the real treadmill, more energy is required for this activity, compared to just making a hand gesture, or pressing a mouse button. This is the same in real life - compare walking to driving a car. Moreover, accuracy is clearly a problem compared to hand-gestural interfaces, since the neural network does not work with 100% accuracy, but in all our experiments, correctly identifies behaviour as either walking in place or not, between 85 and 95 per cent of the time.

3.3 Experimental Results on Presence

It is the sense of presence with which we are mainly concerned. Accuracy can always be improved with better pattern recognisers and improved pattern training techniques. Investment in this type of research, however, is only justified if there are indications that the sense of presence is enhanced with these techniques. Here we discuss the results of an experiment that compared two different techniques for navigation with respect to the effect on reported sense of presence.

There were 16 subjects, divided into two groups of eight. These were selected by asking for volunteers on the QMW campus, excluding people who had experienced our virtual reality system before, or who knew of the purposes of our research. The control groups (the "pointers") moved through the environment using the DIVISION 3D mouse, by pressing a button, with direction of movement controlled by pointing. The experimental groups (the "walkers") used the (VT) walking technique. All subjects used the same ("standard") network based on the walking in place behaviour of one individual. Both walkers and pointers used the mouse for grasping objects. Intersecting the virtual hand with an object and pulling the first finger (trigger) button, resulted in the object being attached to the hand. The object would fall when the trigger button was released.
The task in the experiment was to pick up an object located in a corridor, take it into a room and place it on a particular chair. The chair was placed in such a way that the subjects had to cross a chasm over another room about 20 feet below, in order to reach it. The subjects could get to the chair either by going out of their way to walk around a wide ledge around the edges of the room, or by directly moving across the chasm. This was a simple virtual version of the famous visual cliff experiment [Gibson & Walk, 1960].

The experiments were implemented on a DIVISION ProVision200 system. The ProVision system includes a DIVISION 3D mouse, and a Virtual Research Flight Helmet as the head mounted display (HMD). Polhemus sensors are used for position tracking of the head and the mouse. The displays are colour LCDs with a 360×240

resolution and the HMD provides a horizontal field of view of about 75 degrees. The frame update rate achieved during the experiments was about 15 frames per second.

All subjects saw a VB as self representation. They would see a representation of their right hand, and their thumb and first finger activation of the 3D pointer buttons would be reflected in movements of their corresponding virtual finger and thumb. The hand was attached to an arm, that could be bent and twisted in response to similar movements of the real arm and wrist. The arm was connected to an entire but simple block-like body representation, complete with legs and left arm. Forward movement was accompanied by walking motions of the virtual legs. If the subjects turned their real head around by more than 60 degrees, then the virtual body would be reoriented accordingly. So for example, if they turned their real body around and then looked down at their virtual feet, their orientation would line up with their real body. However, turning only the head around by more than 60 degrees and looking down (an infrequent occurrence), would result in the real body being out of alignment with the virtual body.

Subjective presence was assessed in three ways: the sense of "being there" in the VE, the extent to which there were times that the virtual world seemed more the presenting reality than the real world, and the sense of visiting somewhere rather than seeing something. Each was rated by subjects on an ordinal 7 point scale, where 7 was the highest score, using a questionnaire given immediately after the experiment. These three scores were combined into one by counting the total number of 6 or 7 responses from the three questions. Hence, the result was a value between 0 and 3.

Other questions relevant to the analysis concerned the degree of nausea experienced in the VR, and the extent of association with the VB: ("To what extent did you associate with the computer generated limbs and body as being 'your body' while in the virtual reality?"). They were also asked to rate the degree of vertigo, if any, induced by the virtual precipice, and also to compare their reaction to this in relation to how they would have reacted to a similar situation in real life. ("To what extent was your reaction when looking down over the drop in the virtual reality the same as it would have been in a similar situation in real life?").

All subjects were watched by an observer, who, in particular, recorded whether or not they moved to the chair by walking around the ledge at the side of the room, or by walking directly across the precipice. In the event, only four subjects out of the sixteen (two from each group) walked across the precipice.

The main conclusion from the statistical analysis was that for the "walkers", the greater their association with the VB the higher the presence score, whereas for the "pointers" there was no correlation between VB association and the presence score. In other words, partipants who identified strongly with the virtual body had a greater degree of reported presence if they were in the "walking" group than if they were in the "pointing" group. Association with the VB is important, for without this we would not expect the "body centred interaction" hypothesis to be relevant. There were two other statistically significant factors. First, path taken to the chair: a path directly over the precipice was associated with lower presence. This is as would be expected, and is useful in corroborating the veracity of the presence score. Second, degree of nausea: a higher level of reported nausea was associated with a higher degree of presence. This same result has been found in each of our studies. We speculate that the vection in VR is a cause of both simulator sickness and an influence on presence [McCauley & Sharkey, 1993]. Finding nausea and presence associated would therefore not be surprising. There is the further point that presence is concerned with the effect of the environment on the individual. A person who experiences nausea as a result of the VR has certainly been influenced by it!

3.4 Statistical Analysis

The dependent variable (p) was taken as the number of 6 or 7 answers to the three questions as stated above. The independent variable was the group (experimental or control). The explanatory variables were VB, degree of association with the Virtual Body; S the reported nausea, and P for path (= 1 for a path around the sides of the room, and 2 for a direct path across the precipice).

This situation may be treated by logistic regression [Cox, 1970], where the dependent variable is binomially distributed, with expected value related by the logistic function to a linear predictor.

Let the independent and explanatory variables be denoted by $x_1, x_2, \ldots, x_k$. Then the linear predictor is an expression of the form:

$$\eta_i = \beta_0 + \sum_{j=1}^{k} \beta_j x_{ij} \quad (i = 1,2,\ldots,N) \tag{1}$$

where N (=16) is the number of observations. The logistic regression model links the expected value $E(p_i)$ to the linear predictor as:

$$E(p_i) = \frac{n}{1+\exp(-\eta_i)} \tag{2}$$

where n (=3) is the number of binomial trials per observation.

Maximum likelihood estimation is used to obtain estimates of the β coefficients. The deviance (minus twice the log-likelihood ratio of two models) may be used as a goodness of fit significance test, comparing the null model ($\beta_j = 0$, j = 1,...k) with any given model. The change in deviance for adding or deleting groups of variables may also be used to test for their significance. The (change in) deviance has an approximate χ^2 distribution with degrees of freedom dependent on the number of parameters (added or deleted).

Table 1 shows the results. The overall model is significant. For a good fit, the overall deviance should be small, so that a value of less than the tabulated value is significant. No term can be deleted from the model without significantly increasing the deviance (at the 5% level).

The analysis relies on the assumption that the dependent variable is binomially distributed. This assumption is made as a heuristic, but cannot be justified in an obvious way. The presence-related questions were each separated by at least three others in the questionnaire, and for any respondent, not knowing the purposes of the study, and not aware of the concept of presence, it would be reasonable to assume that their answers did not directly influence one another, and therefore that the "trials" were independent.

Table 1

Logistic Regression Equations

$\hat{\eta}$ = fitted values for the presence scale

VB = VB association, S = Nausea, P = Path

Group	**Model**	**When P=2 (path directly over precipice)**
Walkers	$\hat{\eta}$ = -16.9 + 2.6*VB + 1.3*S	-2.7
Pointers	$\hat{\eta}$ = -3.1 + 0.1*VB + 1.3*S	-2.7

Overall Deviance =11.424, d.f. = 10

χ^2 at 5% on 10 d.f. = 18.307

Deletion of Model Term	**Change in Deviance**	**Change in d.f.**	**c^2 at 5% level**
S	6.624	1	3.841
P	3.867	1	3.841
Group.VB	10.922	2	5.991

An alternative analysis was carried out, where the three presence scores were combined into a single scale using principal components analysis [Kendall, 1975]. The first principal component is the linear combination of the original variables that maximises the total variance. The second is orthogonal to the first and maximises the total residual variance. The first two principal components accounted for 96% of the total variation in the original three variables (the first for 67% and the second for 29%). The single presence score was taken as the norm of the vector given by the first two principal components.

Table 2

Regression Equations

$\hat{y}$ = fitted values for the presence scale based on principal components

(Coefficients are given to 1 d.p.)

VB = VB association, S = Nausea, C = Vertigo comparison

Group	**Model**	**When C=2 "same as real life"**
Walkers	$\hat{y}$ = -4.5 + 1.7*VB + 1.2*S	+ 2.5
Pointers	$\hat{y}$ = 3.4 + 0.3*VB + 1.2*S	+ 2.5

A regression analysis using this new presence score resulted in a model qualitatively similar to that described above. Here though, instead of P (path) being significant, the variable representing the comparison between vertigo experienced in the virtual world with what might have been experienced in the real world, was significant instead. A higher degree of presence was associated with the comparison resulting in a "same as real life". The overall regression was significant at 5% with a multiple squared correlation coefficient of 0.81. This is summarised in Table 2.

4. Steps and Ladders

4.1 Walking on Steps and Ladders

In the previous sections we have made a case, together with supporting experimental evidence, that the walking in place technique tends to increase subjective presence, in comparison with the pointing technique based on a simple hand gesture, provided that there is an association with the VB. This is in support of the idea that techniques based on the "body centred interaction" paradigm, would tend to induce relatively high presence.

The same idea can be applied to the problem of navigating steps and ladders. When the collision detection process in the virtual reality system detects a collision with the bottom step of a staircase, continued walking will move the participant up the steps. Walking down the steps is achieved by turning around, and continuing to walk. If at any moment the participant's virtual legs move off the steps (should this be possible in the application) then they would "fall" to the ground immediately below. Since walking backwards down steps is something usually avoided, we do not provide any special means for doing this. However, it would be easy to support backwards walking and walking backwards down steps by taking into account the position of the hand in relation to body line: a hand behind the body would result in backwards walking.

Ladders are slightly different; once the person has ascended part of the ladder, they might decide to descend at any moment. In the case of steps the user would naturally turn around to descend. Obviously this does not make sense for ladders. Also, in climbing ladders it is usual for the hands to be used. Therefore, in order to indicate ascent or descent of the ladder, hand position is taken into account. While carrying out the walking in place behaviour on a ladder, if the hand is above the head, then the participant will ascend the ladder, and descend when below the head. Once again, it is a whole body gesture, rather than simply use of the hand that is required in order to achieve the required result in an intuitive manner. If at any time the virtual legs come off the rungs of the ladder, then the climber will "fall" to the ground below.

4.2 Evaluation for Usability

At the time of writing we have only carried out a simple study to test for usability. A scenario was constructed consisting of steps leading up to the second storey of a house. The steps led in through a doorway, which entered into a room consisting of a few everyday items such as a couch, tv, and so on. There was a window, and a ladder down to the ground outside propped up against the wall just below the window. There was a bucket on the ground outside, at the foot of the ladder. Examples are shown in the colour Plates.

The task was to walk up the steps, enter into the room, climb onto the ladder and down to the ground, pick up the bucket, take it back up into the room, down the stairs, and back outside. The designer of this scene was taken as the "expert" - and completed the scenario in 3 minutes, including one fall from the ladder. Five other people, all of whom had used the VR system before, were invited to try out the scenario. One person also completed the task in 3 minutes, without any falls. Another took 4 minutes, also without any falls. The third required 5 minutes with 2 falls from the ladder. The remaining two each took 8 minutes, with 1 and 2 falls from the ladder respectively.

The results of this simple experiment were encouraging enough for us to consider the possibility of devising specific pattern recognisers for these types of activities.

5. Conclusions

This paper has presented an argument for a body centred paradigm for interaction. Instead of overloading the idea of hand gestures, whether with a glove or 3D mouse, as the primary mechanism for accomplishing tasks in VR, we suggest that appropriate "whole body" gestures might provide a more intuitive interface. In particular, we argue that the sense of presence, ultimately the whole point of VR, is a function of the match between the mental body model formed from proprioceptive data, and the sensory data supplied by the VR system. A body centred interaction paradigm tries to maximise this match, within the constraints imposed by the limited body tracking information typically available. Hence, when walking through a virtual environment, the human participant should carry out an activity that is something like really walking.

We have described techniques for climbing or descending steps and ladders. The technique may be useful in circumstances where the interaction style should be relatively mundane, rather than requiring magical effects such as "flying". Training for fire fighting would fall into this category.

Acknowledgements

This work is funded by the U.K. Science and Engineering Research Council (SERC), and Department of Trade and Industry, through grant CTA/2 of the London Parallel Applications Centre. Anthony Steed is supported by a SERC research studentship.

References

Barfield, W. and S. Weghorst [1993] "The Sense of Presence Within Virtual Environments: A Conceptual Framework," in G. Salvendy and M. Smith (eds.),*Human-Computer Interaction:Software and Hardware Interfaces*, Vol B, ElsevierPublisher, 699-704.

Brooks, F.P. Jr, Ouh-Young Ming & Batter, J. [1990] "Project Grope - haptic displays for scientific visualization," *Computer Graphic*s *(SIGGRAPH)* 24(4) 177-185.

Brooks, F.P. et. al. [1992] "Final Technical Report: Walkthrough Project, Six Generations of Building Walkthroughs," Department of Computer Science, University of North Carolina, Chapel Hill, N.C. 27599-3175.

Cox, D.R. [1970] *Analysis of Binary Data*, London: Menthuen.

Fairchild, K.M., Beng Hai Lee, Loo, J., Ng, H., Serra, L. [1993] "The Heaven and Earth Virtual Reality: Designing Applications for Novice Users," *IEEE Virtual Reality Annual International Symposiun (VRAIS)*, September 18-22, Seattle, Washington, 47-53.

Fisher S. [1986] "Telepresence master glove controller for dexterous robotic end-effectors," *SPIE Intelligent Robots and Computer Vision*, 1986.

Gibson, E.J. and R.D. Walk [1960] "The visual cliff," *Scientific American*, 202, 64-71.
Grimsdale, C. [1991] "dvS-Distributed Virtual Environment System," *Proceedings of Computer Graphics 91 Online Conference*, London.

Held, R.M. & Durlach, N.I. [1992] "Telepresence," *Presence: Teleoperators and Virtual Environments*, 1(1), MIT Press, 109-112.

Heeter, C. [1992] "Being There: The Subjective Experience of Presence," *Presence: Teleoperators and Virtual Environments*, 1(2), MIT Press, 262-271.

Iwata, H. & Matsuda, K. [1992] "Haptic Walkthrough Simulator: Its Design and Application to Studies on Cognitive Map," *The Second International Conference on Artificial Reality and Tele-existence, ICAT 92*, 185-192.

Kendall, M. [1975] *Multivariate Analysis*, Charles Griffin & Co. Ltd.

Loomis, J.M. [1992a] "Distal Attribution and Presence," *Presence: Teleoperators and Virtual Environments*, 1(1), MIT Press, 113-119.

Loomis, J.M. [1992b] "Presence and Distal Attribution: Phenomenology, determinants, and assessment," *SPIE 1666 Human Vision, Visual Processing and Digital Display III*, 590-594.

McCauley, M.E., Sharkey, T.J. [1993] "Cybersickness: Perception of Self-motion in Virtual Environments," *Presence: Teleoperators and Virtual Environments*, 1(3), 311-318.

Robinett, W. & Holloway, R. [1992] "Implementation of Flying, Scaling and Grabbing in Virtual Worlds," *ACM Symposium on Interactive 3D Graphics*, Cambridge MA.

Sheridan, T.B. [1992] "Musings on Telepresence and Virtual Presence," *Presence: Teleoperators and Virtual Environments*, 1(1), MIT Press, 120-126.

Slater, M., Steed, A. & Usoh, M. [1993] "The Virtual Treadmill: A Naturalistic Metaphor for Navigation in Immersive Virtual Environments," in M. Goebel (ed.) *First Eurographics Workshop on Virtual Reality*, 71-86.

Slater, M., Steed, A. & Usoh, M. [1994] "Virtual Body Walking", submitted.

Song, D. & Norman, M. [1993] "Nonlinear Interactive Motion Control Techniques for Virtual Space Navigation," *IEEE Virtual Reality Annual International Symposium (VRAIS)*, September 18-22, Seattle, Washington, 111-117.

Steuer, J. [1992] "Defining Virtual Reality: Dimensions Determining Telepresence," *Journal of Communication* 42(4), 73-93.

Vaananen, K. & Bohm, K. [1993] "Gesture Driven Interaction as a Human Factor in Virtual Environments - an approach with Neural Networks," in R.A. Earnshaw and M.A. Gigante (eds) *Virtual Reality Systems*, Academic Press, 93-106.