Body Centred Interaction in Immersive Virtual Environments

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> "Well then, what about the actual getting of wisdom? Is the body in the way or not...? I mean, for example, is there any truth for men in their sight and hearing? Or as poets are forever dinning into our ears, do we hear nothing and see nothing exactly?" (Socrates, Phaedo, 65A).[1]

1. Introduction

The technology to immerse people in computer generated worlds was proposed by Sutherland in 1965, and realised in 1968 with a head-mounted display that could present a user with a stereoscopic 3-dimensional view slaved to a sensing device tracking the user's head movements (Sutherland 1965; 1968). The views presented at that time were simple wire frame models. The advance of computer graphics knowledge and technology, itself tied to the enormous increase in processing power and decrease in cost, together with the development of relatively efficient and unobtrusive sensing devices, has led to the emergence of participatory immersive virtual environments, commonly referred to as "virtual reality" (VR) (Fisher 1982; Fisher et. al. 1986; Teitel 1990; see also SIGGRAPH Panel Proceedings 1989,1990).

Ellis defines virtualisation as "the process by which a human viewer interprets a patterned sensory impression to be an extended object in an environment other than that in which it physically exists" (Ellis, 1991). In this definition the idea is taken from geometric optics, where the concept of a "virtual image" is precisely defined, and is well understood. In the context of virtual reality the "patterned sensory impressions" are generated to the human senses through visual, auditory, tactile and kinesthetic displays, though systems that effectively present information in all such sensory modalities do not exist at present. Ellis further distinguishes between a virtual space, image and environment. An example of the first is a flat surface on which an image is rendered. Perspective depth cues, texture gradients, occlusion, and other similar aspects of the image lead to an observer perceiving

[1]Socrates: Great Dialogues of Plato, translated by W.H.D Rouse, A Mentor Classic, 1956,

three dimensional objects. The second, a virtual image, is the perception of an object in depth, leading to accommodation, convergence, and possibly stereopsis - for example, as might be generated by a pair of binocularly separated pictures fused to provide a stereoscopic image. The third, a virtual environment, incorporates the observer as part of the environment, so that head motions result in motion parallax from the observer's viewpoint, and a number of physiological and vestibular responses associated with focusing and object tracking are stimulated.

The human participant is "immersed" in the virtual environment (VE) in two ways. First, through the VE system displaying the sensory data depicting his or her surroundings. Part of the immediate surroundings consist of a representation of the participant's body and the environment is displayed from the unique position and orientation defined by the place of the participant's viewpoint within the environment. (We mean "display" and "viewpoint" with respect to all sensory modalities). Body tracking devices, such as electromagnetic sensors enable movements of the person's whole body and limbs to become part of the dynamic changes to objects in the VE under his or her immediate control (see Kalawsky, 1993). This is the second aspect of immersion: that proprioceptive signals about the disposition and dynamic behaviour of the human body and its parts become overlaid with consistent sensory data about the representation of the human body, the "Virtual Body" (VB). Putting this another way: proprioception results in the formation of an unconscious mental model of the person's body and its dynamics. This mental model must match the displayed sensory information concerning the VB. The VB is then under immediate control of the person's motor actions, and since the VB is itself part of the displayed VE, the person is immersed in the VE. We call such environments "Immersive Virtual Environments" (IVEs).

The term "immersion" is a description of a technology, which can be achieved to varying degrees. A necessary condition is Ellis' notion of a VE, maintained in at least one sensory modality (typically the visual). For example, a head-mounted display with wide field of view, and at least head tracking would be essential. The degree of immersion is increased by adding additional, and consistent modalities, greater degree of body tracking, richer body representations, decreased lag between body movements and resulting changes in sensory data, and so on.

Immersion may lead to a sense of presence. This is a psychological emergent property of an immersive system, and refers to the participant's sense of "being there" in the world created by the VE system. Note that immersion is a necessary rather than a sufficient condition for presence - immersion describes a kind of technology, and presence describes an associated state of consciousness.

In addition to the necessity of an immersive technology, the interaction techniques in a virtual reality may also play a crucial role in the determination of presence. For example, if through the limitations of body tracking, people must carry out everyday activities in an unnatural or artificial way, for example, moving through the world by pointing, this may lever them out of the illusion provided by the VE, thus reducing the sense of presence. In this Chapter we introduce a paradigm for interaction in IVEs called "Body Centred Interaction" (BCI). The fundamental idea is that interaction techniques that maximise the match between proprioceptive and sensory data will maximise presence, within the constraints imposed by the display and tracking systems.

In the next section we examine the role of the body in everyday reality, and the VB in virtual reality. We consider presence more closely in Section 3. The BCI paradigm is examined in detail in Section 4, together with a number of examples, including walking, scaling and communication. In Section 5 we discuss the use of the VB in communication between human participants. Conclusions are presented in Section 6.

2. The Body

2.1 The Physical Body in Everyday Reality

Possession of a body is so obvious that its major functions can be overlooked (Synnott, 1993). It fulfils several crucial functions. It is:

- The physical embodiment of self;

- The medium of interaction, through the use of our bodies we interact with and are able to change the world;

- The anchor of the self in the sensory world: our sensory organs receive data about external reality which our mind/brain system interprets as perceptions of the world;

- A medium of communication: it allows us to communicate with other humans through the use of sound and gestures. By changing the world we construct powerful media of communications.

- It is the social representation of self in several respects: we recognise the existence of others through their bodies, we decorate our bodies in various ways to indicate aspects of our social status, and so on.

The body is our connection with reality, it is the means through which we participate in everyday reality. Our sensory organs take in data about external reality which leads to perception, cognition and eventually to behaviour which converts this information into meaningful action through which we change external reality.

It is a relatively recent view that it is through the body and sensory perception that we come to understand reality. For example the ancients held the belief that the body is what prevents us from knowing reality:

Socrates:

> "And I suppose it [the soul] reasons best when none of these senses disturbs it, hearing or sight, or pain, or pleasure indeed, but when it is completely by itself and says good-bye to the body, and so far as possible has no dealings with it, when it reaches out and grasps that which really is." [2]

It is a fundamental part of modern scientific, and perhaps common sense thought, that sense perceptions are the ultimate foundation of our knowledge about ourselves and the world.

[2] Plato,The Phaedo, op. cit.

2.2 Proprioception

Proprioception is defined by Oliver Sacks as "... that continuous but unconscious sensory flow from the movable parts of our body (muscles, tendons, joints), by which their position and tone and motion is continually monitored and adjusted, but in a way which is hidden from us because it is automatic and unconscious" (Sacks, 1985). Proprioception allows us to form a mental model that describes the dynamic spatial and relational disposition of our body and its parts. We know where our big left toe is, without looking, by relying on this body model. We can touch our nose with our right forefinger, with closed eyes, similarly by relying on this unconscious mental model formed from the proprioceptive data flow.

Sacks quoted the philosopher Wittgenstein in pointing out the fundamental nature of the proprioceptive sense, considered by many as a kind of hidden "sixth sense":

Wittgenstein:

> "The aspect of things that are most important for us are hidden because of their simplicity and familiarity. (One is unable to notice something because it is always before one's eyes). The real foundations of his enquiry do not strike a man at all".

Proprioception is best appreciated when lost: Sacks describes the case of a woman who lost this sense, and was unable to move her body under conscious control. It was only through visual feedback, by looking in a mirror, that she was eventually able to move with conscious volition.

2.3 Virtual Bodies

Virtual reality offers a challenge to the everyday relationship between mind and body. This relationship is so fundamental that we normally do not think about it. Only in times of injury and crisis does the relationship come to the fore. However, entering into a virtual reality can be a shock: based on sensory data the mind may be fooled into the illusion of being in an alternative world - the results of head tracking strongly confirm this, since a turn of the head to the right swings the world to the left as in everyday reality. Motion parallax and stereopsis provide further evidence. And yet --- look for what you would expect to see - your own body, and it may be missing, perhaps replaced by a disembodied polygonized "hand".

The proprioceptive stream is informing us, as always during the conscious state, that the body is still there as usual. The sensory data contradicts this, there is no body. The virtual body concept is an attempt to reduce the contradiction between sensory data and proprioception by constructing a body representation slaved to the available tracking devices.

Our programs and experiments outlined in this Chapter 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. Polhemus sensors are used for position tracking of the head and the mouse. Scene rendering is performed using an Intel i860 microprocessor (one per eye) to create an RGB RS-170 video signal which is fed to an internal NTSC video encoder and then to the displays of the Flight Helmet. These displays (for the left and right eye) 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 10-15 frames per second.

With the VB we have used throughout participants see a representation of their right hand, and their thumb and first finger activation of the 3D buttons on the DIVISION 3D mouse, are reflected in movements of their corresponding virtual finger and thumb. The hand is attached to an arm, that can be bent and twisted in response to similar movements of the real arm and wrist. The arm is connected to an entire but simple body representation, complete with legs and left arm. Forward movement is accompanied by walking motions of the virtual legs. When participants turn their real head around by more than 60 degrees, then the virtual body is reoriented accordingly. So for example, if they turn their real body around and then looked down at their virtual feet, their orientation lines up with their real body. However, turning only the head around by more than 60 degrees and looking down (an infrequent occurrence), results in the real body being out of alignment with the virtual body.

3. Presence

3.1 The Absence of Presence

An IVE may lead to a sense of presence for a participant taking part in such an experience. Presence is the psychological sense of "being there" in the environment based on the technologically founded immersive base. However, any given immersive system does not necessarily always lead presence for all people: the factors that determine presence, given immersion, is an important area of study (Barfield, 1993; Held and Durlach, 1992; Heeter, 1992; Loomis 1992a; Sheridan, 1992; Slater and Usoh, 1994a,c; Zeltzer, 1992).

Like proprioception, presence is so fundamental to our everyday existence that it is difficult to define. Imagining the loss of presence is more difficult than imagining the loss of proprioception. The concept of presence "no where" is logically unsound, since presence implies a "somewhere". Equating loss of presence with loss of consciousness does not lead to any further understanding. However, it does make sense to consider the negation of a sense of presence as the loss of locality, such that "no presence" is equated with no locality, the sense of where self is as being always in flux. Interestingly, Sacks describes the case of a man without the capability for present day memory. It was essentially impossible to have a conversation with him, since the context would be lost after a few moments, when he forgot who he was talking to, and what the conversation was about. This is a kind of neurological loss of presence. Imagine a VR system that continuously and randomly changed the environment, so that the human participant could form no stable sense of locality, and no relationship with any object: everything being continually in flux. Such an environment would not be presence inducing.

3.2 Presence and the Body

It can be argued that there is an inherent logical connection between the degree of presence and the VB. If the match between proprioception and sensory data about the corresponding dynamics of the body is high, then the person immersed in the VE is likely to identify with their VB. If sensory data confirms that this VB functions effectively within the larger (computer generated) environment, then there must be presence within that environment.

The VB has become identified with "self", the VB is immersed within a particular environment, therefore self must be in that environment.

There is empirical evidence from a number of case-control studies providing evidence for this idea. The first pilot study divided 17 subjects into two groups, experimental and control. The experimental group had a VB as described in Section 2, and the control group had a very impoverished VB consisting only of a 3D arrow pointer that responded correctly to (right) had movements and orientations. All subjects carried out the same tasks, which involved moving from a corridor into a number of rooms, and each room exercised a different aspect of the experiment. For example, in one room objects spontaneously flew towards the face of the subjects, and in another, they were perched on a plank over the edge of a precipice.

In this experiment presence was measured in two ways. The first was by a particular question in a questionnaire administered after the experience (To what extent did you experience a sense of being "really there" inside the virtual environment?). This was measured on a 6 point scale, from 1 = "Not at all really there" to 6 = "totally there".

The second method was to observe the reactions of the subjects to "danger" - in particular did they exhibit the looming effect when objects flew towards their faces (ie, did they "duck"), and second, did they react in an observable manner, including verbal exclamations, when over the virtual precipice. The results suggested a positive association between the VB and the observed reaction to "danger". If a reaction to danger indicates presence, then possession of a VB did positively influence presence. These results are extensively reported in (Slater and Usoh, 1992; 1993a). A first analysis did not find a positive relationship between VB and reported sense of presence as indicated by the responses to the questionnaire.

The situation was more complex than this, however. We were puzzled by the fact that these 17 people had all had very similar experiences, and yet their reactions were so different to one another, including their responses to the presence question. The human participant in a VE does not simply absorb the VE generated sensory data, but processes this through the mental models and representation systems typically employed by the person in everyday reality. Since people have different models of the world and corresponding preferences in (unconsciously) processing sensory data, and since the VE typically offers very biased sensory data (ie, very much biased towards the visual), this might explain the variation in people's responses.

We carried out a post-hoc analysis of the questionnaire data, including an analysis of essays written by the subjects twenty four hours after the end of the experiment. This was based on a neuro-linguistic programming (NLP) model of subjective experience, which states that all such experience is encoded in terms of three main representation systems, Visual, Auditory and Kinesthetic (VAK) (Dilts et. al., 1979). The Visual system includes external images and remembered and constructed internal images. The Auditory system includes external sounds, and internal remembered and constructed sounds. It also includes internal dialogue, that is the person talking to him- or her-self on the inside. The Kinesthetic system includes kinesthetic and tactile sensations and also emotional responses (which are decomposed into specific patterns of internal tactile and kinesthetic sensations). The model claims that people have a tendency to be dominant in one or other of these systems, and that such dominance may be reflected in language patterns: specifically, in the (visual, auditory, kinesthetic) predicates and references they tend to use. For example, when a person says "I see what you mean", this is taken not just as an arbitrary and accidental choice of expression, but as an indication of their internal processing - they may be literally making an internal picture of the situation under discussion. They could equally well have said "I hear what you're saying" or "I have a feeling for what you say", but instead chose the visual predicate.

NLP also distinguishes between egocentric and exocentric perceptual positions. The perceptual position is the standpoint from which the person experiences and remembers events. A person might remember an event from an associated (egocentric) standpoint, and see the event unfolding in his mind's eye from the viewpoint in which it was originally experienced. This is called the first perceptual position. Alternatively a person might remember the event from a dissociated (exocentric) perspective - either from the point of view of another actor in the scene (second position), or from an abstract, disembodied point of view (third position). For example, a person trying to convince someone in an argument might say: "I can feel that it is right" (first position, K) or "You can tell that it is right" (second position, A) or "It can be seen that it is right" (third position, V). The representation systems and perceptual position are logically orthogonal - there being nine possible combinations in this example.

Using the essays written by the subjects as part of the post-experiment information that we collected, we counted the number of V, A, K predicates and references used as a proportion of the total number of sentences written by each subject. Similarly, we classified each sentence as belonging to either the first, second or third perceptual position. Hence variables were constructed that attempted to measure the extent of dominance with respect to representation system and perceptual position for each subject in the experiment, and these were included as explanatory variables in a statistical (regression) analysis of the data with the reported degree of presence taken as the dependent variable.

Since the VR system we were using presented the participant mainly with visual information, we expected - if the NLP hypothesis were useful - that visual dominance would be positively correlated with reported presence, and auditory dominance negatively correlated. The results were rather startling - even though the regression analysis was not statistically secure (the dependent variable being a measurement on an ordinal scale) the explanatory power of the model was very high indeed, with a multiple squared correlation coefficient of 0.99, and with a very high level of fit (better than 1% significance). The regression model resulted in the following conclusions:

(a) That independently of whether or not the subject has a virtual body, the higher the proportion of visual predicates and references used, the greater the sense of presence, and the higher the proportion of auditory predicates and references the lower the sense of presence.

(b) For those with a virtual body, the higher the proportion of kinesthetic references and predicates the higher the sense of presence. For those without a virtual body, the higher the sense of kinesthetic terms the lower the sense of presence.

(c) The level of presence increases with first perceptual position (P1) up to the mean level of P1, and then decreases. (The model was quadratic in P1). This is the same for each group, except that the rate of change is steeper for those in the control group.

The analysis and results are reported in (Slater and Usoh, 1993a; 1994a,c).

It is result (b) that is most interesting in the present discussion. It indicates a relationship between kinesthetic dominance, the VB and reported degree of presence. The K system is the system of the body - it is very strongly related with proprioception as discussed in Section 1. This result gave us a clue that there is a relationship between the VB, proprioception and presence.

The experiment described here was only a pilot, and it was unsatisfactory from the point of view of direction of causality. We could not say that representation systems were a causal factor in presence, since the data used for measuring these was obtained after the VR experience. It could have been said that that experience itself was a causal factor determining the representation systems used when writing about it. Therefore, we carried out a further major study, with 24 subjects, where we used a questionnaire to assess dominant representation systems and perceptual position well before the VR experience. This study, where each participant did have a VB, resulted again in a model with very strong explanatory power for the representation systems, but no significant effect was found for perceptual position. Again, the higher the visual dominance the greater the degree of presence, the higher the auditory dominance, the lower the degree of presence, and also (this time since all had the same VB) the higher the kinesthetic dominance, the higher the degree of presence. The experiment and results are discussed fully in (Slater, Usoh and Steed, 1994c).

This experiment used a more comprehensive measurement of presence based on:

(a) The subject's sense of "being there" - a direct attempt to record the overall psychological state with respect to an environment;

(b) The extent to which, while immersed in the VE, it becomes more "real or present" than everyday reality;

(c) The "locality", that is the extent to which the VE is thought of as a "place" that was visited rather than just as a set of images.

This last is similar to the idea of Barfield and Weghorst who write that "... presence in a virtual environment necessitates a belief that the participant no longer inhabits the physical space but now occupies the computer generated virtual environment as a 'place'" (op. cit., p702). Each of these was measured on a 7 point scale, and the overall score for an individual was the number of highest scores (6 or 7) out of three.

Especially interesting in this experiment is that we programmed the virtual left arm and hand to mirror the movements of the corresponding right hand limbs. The idea was to see the extent to which subjects would match their real left hand with the virtual one. Four out of the 24 subjects exhibited this matching behaviour. These four subjects had a significantly higher score on the K representation system than the other subjects (in fact by more than double). We speculate that these subjects had a requirement to match the proprioceptive with the sensory data. They saw their virtual left hand move, and the only way that the matching was possible was to move their real left hand in conjunction.

These four subjects must have had a very high degree of identification with their virtual bodies. In our first pilot experiment, where the virtual left arm was in a fixed position, some of the subjects wrote about their confusion or perhaps lack of identification with the VB. Strange effects were observed, and recorded:

• One subject on noticing the fixed virtual left arm began to move her real left arm very rapidly, in a manner indicating panic.

• Another wrote "I thought there was really something wrong with my [left] arm";

• Others talked of their virtual bodies being - "a dead weight", a useless thing", "nothing to do with me".

Such remarks were reminiscent of Sack's patients who lost the proprioceptive sense in some of their limbs. This suggests that the lack of a normal relationship between the proprioceptive system and the behaviour of the VB could be very important factor in people's acceptance of and responses to immersive virtual environments.

3.3 Presence Summary

In this Section we have examined the concept of presence in a VE, and in particular the relationship between the physical body, virtual body and presence. There are three aspects to the relationship that we have discussed so far. The first is that proprioception provides a sense of the physical body and its activities, leading to a mental body model. Presence is likely to be enhanced the more that this mental body model behaviourally matches the virtual body representation in the VE. Since the participant is only aware of this VB through the sensory (mainly visual) data supplied by the immersive system, presence requires that proprioceptive data be continually overlaid with consistent virtual sensory data. The second, is that evidence suggests that, other things being equal, a virtual body will, in any case, enhance the sense of presence. Third, the body is the repository of the sensory apparatus, which in turn leads to the fundamental representation systems based on the senses (visual, auditory and kinesthetic). The representation systems are a powerful factor in explaining people's reported sense of presence. In particular, this is true for people who are dominant on the kinesthetic representation system - that is, those for whom proprioceptive data (how they "feel") is an important explicit and verbalised component of their mental processing.

The unique feature of modern virtual reality systems is that they are general purpose presence transforming machines. Systems and applications have existed for many years that provide a high degree of presence: flight simulators are an obvious example. However, such systems always provide a very high sense of presence within a particular and fixed environment. A flight simulator can, for example, never be used to provide a sense of presence within a supermarket. An IVE system, can, however, be used to provide a sense of presence in an airplane cockpit, and also in a supermarket: it is only a question of the database and interaction model used. Obviously, since a flight simulator is specialised to airplanes it is typically much more successful than a virtual reality system for its particular application domain: but at the great cost always associated with very special purpose systems. The choice between an IVE and a traditional simulator then becomes a question of economics.

Steuer has gone as far as taking presence as the defining feature of VR: "A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" (Steuer, 1992). We are tempted to extend this definition to include the importance of the VB:

> A virtual reality is a real or simulated reality in which the self has a (suspension of dis-) belief that he or she is in an environment other than that which his/her real body is located. Self perceives sensory information

correlated with proprioceptively valid feedback about the behaviour and state of his/her body in that environment.

We have concentrated here on presence as the central phenomenon of virtual reality, and have examined its relationship to the body and VB. In the next Section we show how we have exploited these relationships in the construction of interactive techniques.

4. Body Centred Interaction

4.1 Motivation and Concepts

In the first pilot experiment on presence discussed in Section 3, we observed that some subjects found it exceedingly difficult to move around the VE using a navigation metaphor based on hand gesture pointing. For example, the following are reports from their essays written after the experience:

> "Sometimes [I had] a desperate need to actually walk when virtually walking, there does seem to be a conflict between what the eyes see and the body feels - eg, my feet appear to be floating but I can feel my feet on the ground."
>
> "Trying to separate virtual and physical movement: constantly being aware - my initial response was to make the physical move then forcing myself to use the mouse instead... The amount of concentration I had to use was something I remember particularly. Moving around with the mouse, forwards and backwards - and with the helmet turning around - it was difficult to reconcile the two ways of moving."

This illustrates in the negative the central idea of the BCI paradigm: interaction techniques should be constructed so that there is a match between sensory data ("what the eyes see") and proprioceptive feedback ("what the body feels"). The typical approach is to either overload almost all forms of interaction onto a set of hand gestures or manipulations (Vaananen and Bohm, 1993; Brooks et. al., 1990) or to use inappropriate methodology taken from screen based interfaces, such as menus and icons. We are reminded of a famous passage written by Marx:

> K. Marx:
> "Men make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under circumstances directly encountered, given and transmitted from the past. The tradition of all the dead generations weighs like a nightmare on the brain of the living. And just when they seem engaged in revolutionising themselves and things, in creating something that has never yet existed ... they anxiously conjure up the spirits of the past to their service and borrow from them names, battle cries and costumes ..."[3]

[3]K. Marx, The Eighteenth Brumaire of Louis Napoleon, in Marx and Engels, Selected Works in One Volume, Lawrence and Wishart Ltd, 1968.

Virtual reality must, on the contrary, invent its own new ways of thinking, appropriate and native to the new technology.

Body Centred Interaction involves a number of components:

(a) Inference about the state of the body from limited information

One of the concepts of the BCI approach is the construction of an abstract (device independent) control model that defines the mapping between physical tracking capabilities and the associations with virtual body dynamics. For example, consider two extremes - a full body suit that tracks the position of all the major limbs of the body, compared to a six degrees of freedom 3D mouse held in one hand. It is assumed in both cases that there is a HMD that tracks the position and orientation of the head. Now in the former case, there is a relatively straightforward mapping between the tracking information and the position and orientation of the virtual body and its limbs. In the latter case, only the head position and orientation and the position and orientation of one hand is known. Hence in this case, the position and orientation of the VB as a whole is a matter for inference. The objective is to construct a consistent inferential model for this mapping. The discussion in Section 2.3 illustrates a primitive example of this.

(b) Body centred feedback

Interaction requires feedback about the state of the VB, and its relationship to the environment. This involves the generation of real-time shadows and reflections, that include the VB (as well as shadows of objects generally). It also involves the use of a graphics viewing model that simulates and stimulates peripheral vision, in spite of the relatively small field of view actually provided by the visual display devices.

In previous work (Chrysanthou and Slater, 1992) we have constructed an algorithm for dynamic shadows in the context of polygonal scenes illuminated with local lighting. Shadows are well-known to be important in understanding spatial relationships (Puerta, 1989). The shadow of the person's own VB would be an exciting method for feedback in this context. Mirrors and reflections are an obvious extension of this work.

Today's HMDs typically provide a reduced field of view compared to the average human FOV. Hence, unlike the situation in everyday reality, the participant is typically not always aware of the state of his virtual body, or of events that would normally be signalled by peripheral vision. We have developed a graphics viewing pipeline that does simulate peripheral vision, and have shown experimentally that it is possible to stimulate the behaviour associated with peripheral vision in spite of the relatively small FOV of HMDs (Slater and Usoh, 1993b).

We are currently developing implementations of both the rapid shadow and peripheral vision models on the VR system.

(c) Magical and Mundane Interaction

Interaction is the ability of the participant to move through and change the world, that is, navigation and manipulation. This falls into two further categories, which we call *mundane* and *magical*. Mundane interaction is that which attempts to faithfully reproduce a corresponding interaction in everyday reality. For example, the process of picking up an object, or driving an automobile. Magical interaction involves actions that are not possible in everyday reality - such as a person flying by his or her own volition, walking through walls, tele-portation - that is moving instantaneously from place to place, psycho-kinesis - that is, action on an object at a distance, and other similar examples. Table 1 classifies these types of interaction.

Table 1
Magical and Mundane Interactions

Interaction	**Examples**	**Manipulation Examples**	**Navigation Examples**
Mundane Reproduction of interactions from the world of everyday reality.	picking something up; walking; driving an automobile.	object selection and placement; transformations, deformations.	walking; driving or flying a vehicle; space walks.
Magical Production of interactions that are only imaginable in everyday reality.	flying by own volition; tele-portation; psycho-kinesis.	scaling the environment; psycho-kinesis	flying under own volition; teleportation

To the extent that a VR system is to be used as a simulation of everyday reality, for example, for the purposes of training, it is necessary for the actions that a person makes in the VE to be intuitively associated with the corresponding actions that they would need to take in everyday reality. It is also possible for magical interaction to be accomplished in an intuitive way, involving the marshalling of mental models for activities on the part of the participant that even though achieving magical effects, can seem to be accomplished naturally. We have found that interactions based directly on the use of the person's VB seem to satisfy this criterion. The following sections consider examples from both categories: mundane - walking, climbing and descending steps and ladders; magical - scaling the environment and remote object selection.

4.2 Walking: The Virtual Treadmill

A standard solution for navigation in IVEs is to make use of the hand-held pointing device. VPL used the DataGlove (Fisher 1986; Foley, 1987) with which 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.

DIVISION's ProVision system 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. Other methods of navigation are discussed in (Brooks, 1992; Fairchild, 1993; Iwata and Matsuda, 1992; Mackinlay et. al., 1990; Robinett and Holloway, 1992; Song and Norman, 1993).

In the experiments mentioned above we adjusted the ProVision's standard interface, and based direction of movement on the pointing direction of the 3D Mouse. This disassociation of gaze and direction of movement gives the participant an extra degree of freedom in exploring the VE.

We mentioned above the difficulty that some subjects have using a pointing device for navigation. In some contexts such an approach might be natural, for example in a simulated space walk - but then the normal methods of moving around, such as taking one or two small steps would need to be disabled with perhaps the participant seated in a chair. The pointing method would be the only method for movement over large or small distances, so that the conflict mentioned by the subjects could not occur.

Brooks noted that "Physical motion powerfully aids the illusion of presence, and actual walking enables one to feel kinesthetically how large spaces are..." (Brooks, 1992). As part of the Building Walkthrough project at the University of North Carolina, a steerable treadmill was constructed, that allowed users to actually experience walking through virtual buildings and building sites. The Virtual Treadmill is a similar idea, but implemented only in software, and without the restrictions necessitated by a real treadmill where the user cannot step off from it in order to really walk a few steps.

The idea of the Virtual Treadmill is straightforward - whenever participants carry out the activity of walking on the spot, that is standing in one place but with leg motions similar to walking, the system moves them forward in the virtual space, with direction of movement governed by gaze. This is achieved by passing all HMD data through a pattern recogniser filter which is able to distinguish head movements characteristic of such "walking on the spot" behaviour from any other behaviour at all. Therefore, virtual ground is covered in this technique by almost really walking, or by taking one or two actual physical steps: each case involving whole body movements similar to those of walking in everyday reality. Contrast this with the usual method used in VR, which is sometimes moving by actually walking, and other times using a pointing hand gesture. In the new method there is no use made at all of the hand-held pointing device. This can be reserved solely for other forms of interaction such as object manipulation.

Two studies with users were carried out regarding the influence of the Virtual Treadmill on navigation and presence. In each study there were 16 subjects divided into experimental and control groups - the experimental group were "walkers" - they used the Virtual Treadmill idea, and the controls were "pointers" - they used the hand gesture with the 3D mouse as usual. A full report of the first study is given in (Slater, Steed and Usoh, 1993c). We concentrate here only on the results relating to presence. The task of both groups was to navigate through a room containing many obstacles, pick up an object, take it out into a corridor, and then locate and enter another room at the far side of the corridor. The objective was to place the object on a chair in that room. This chair was reachable only by crossing a chasm over a precipice. The control group first carried out this task as "pointers", answered a questionnaire, and then repeated the experiment as "walkers", and completed a second questionnaire. The experimental group did this in the opposite order. At the end of the first part of the experiment, each group had experienced only one type of navigation technique, only "walking" or "pointing". After the second part of the experiment, each person had experienced both types. Three control group subjects were not included in the comparative part of the study because the walking technique did not work for them at all. Overall though, the pattern recogniser correctly predicted behaviour, that is it distinguished between walking on the spot and other activities with a success rate of between 85% and 95%.

Table 2 shows the results of this experiment in regard to subjective reporting on presence. There is no difference in presence between the two groups immediately after the end of Part I of the experiment, that is after each subject had experienced one method of walking. However, in the comparison after Part II, amongst those who had a preference, the walking method led to a higher subjective sense of presence. However, comparisons such as these are suspect, since it cannot be known whether the experience of the first session influenced the results of the second session.

Table 2

Subjective Reporting on Presence

<table>
<tr><th colspan="3">Being there</th><th colspan="3">Real or present</th><th colspan="3">Seeing/visiting</th></tr>
<tr><td colspan="3">Please rate your sense of being there in the computer generated world...</td><td colspan="3">To what extent were there times during the experience when the computer generated world became the "reality" for you, and you almost forgot about the "real world" outside?</td><td colspan="3">When you think back about your experience, do you think of the computer generated world more as something that you saw, or more as somewhere that you visited?</td></tr>
<tr><td colspan="3">In the computer generated world I had a sense of "being there"...</td><td colspan="3">There were times during the experience when the computer generated world became more real or present for me compared to the "real world"...</td><td colspan="3">The computer generated world seems to me to be more like...</td></tr>
<tr><td colspan="3">1. not at all</td><td colspan="3">1. at no time</td><td colspan="3">1. something that I saw</td></tr>
<tr><td colspan="3">...</td><td colspan="3">...</td><td colspan="3">...</td></tr>
<tr><td colspan="3">7. very much</td><td colspan="3">7. almost all of the time</td><td colspan="3">7. somewhere that I visited</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Group</td><td>Mean</td><td>Median</td><td></td><td>Mean</td><td>Median</td><td></td><td>Mean</td><td>Median</td></tr>
<tr><td>Exp.</td><td>6</td><td>6</td><td></td><td>5</td><td>5</td><td></td><td>5</td><td>5</td></tr>
<tr><td>Control</td><td>5</td><td>5</td><td></td><td>4</td><td>3</td><td></td><td>5</td><td>4</td></tr>
<tr><td colspan="3">Part II comparison:

prefer:
walking: 6
same: 5
mouse: 2
TOTAL:13</td><td colspan="3">Part II comparison:

prefer:
walking: 7
same: 5
mouse: 1
TOTAL:13</td><td colspan="3">Part II comparison:

prefer:
walking: 7
same: 6
mouse: 0
TOTAL:13</td></tr>
</table>

In the second study the scenario was slightly different. The task 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 the shorter distance across the chasm. This was a simple virtual version of the famous visual cliff experiment by E.J. Gibson (Gibson and Walk, 1960). 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. Other statistically significant factors were:

(i) 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.

(ii) 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 sense of motion in VR is a cause of both simulator sickness and an influence on presence (McCauley and Sharkey, 1993). Finding nausea and presence associated would therefore be expected, even though there may not be a direct causal link between them. 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!

These results were obtained from a logistic regression analysis, that is, counting the number of 6 or 7 scores across the three presence questions and using this count out of three as the dependant variable. Here the dependent variable is binomially distributed, with expected value related by the logistic function to a linear combination of independent and explanatory variables (Cox, 1970).

An alternative analysis of the same data was carried out, where the three presence scores were combined into one overall score using a principal components analysis. A statistically significant normal regression model was obtained, with qualitatively similar results to the first analysis. The overall regression was significant at 5% with a multiple squared correlation coefficient of 0.81. Here though, instead of path to the chair being significant, a variable representing the comparison between vertigo experienced in the virtual world with what might have been experienced in the real world in a similar situation, was significant instead. Subjects were asked to rate their reaction to the visual cliff regarding the extent to which it was the same or different to what they would have expected it to be in real life. In the analysis a higher degree of presence was associated with the comparison resulting in a "same as real life". Loomis suggests that one objective way of assessing presence is the degree to which reactions are the same in virtual as in real environments (Loomis, 1992b). Again this lends support to the measure of presence used actually bearing a strong relationship to the phenomenon of presence.

This experiment, in including the degree of subjective association with the virtual body, allowed for a more sophisticated analysis. The central thesis of the BCI paradigm, that presence is likely to be enhanced with interaction techniques that attempt to match proprioception and sensory data, especially that regarding the VB, seems to be supported - since only for the "walkers" was there a positive correlation between VB association and presence. This experiment is reported in (Slater, Steed and Usoh, 1994b).

4.3 Steps and Ladders

The Virtual Treadmill has easy adaptation to other forms of navigation beside walking at ground level. Applications such as architectural walkthrough, or training for fire fighting, require participants to walk up steps or climb and descend ladders. Again, it is certainly possible to use a hand gesture, or allow participants to fly, and in some applications this would be acceptable if a degree of realism in these activities were not required. In the fire fighting example though, trainees would typically be required to carry objects (buckets, hoses, etc) while climbing steps or ladders, so that the use of hand based gestures for navigation would not be suitable. Also, in a real fire fighting situation, the fire fighters do expend energy in moving through the scenario, and here what may be thought of as a disadvantage of the Virtual Treadmill - it certainly requires more energy to perform than pressing a button or making a hand gesture - becomes an advantage in terms of realism.

At the time of writing we have adapted the Virtual Treadmill to steps and ladders in a straightforward manner. When the process monitoring collision detection notifies the system of a collision between the VB and the bottom or top rung of a staircase or ladder, subsequent walking on the spot motions will move the participant up or down as appropriate. For steps, we do not currently support walking backwards down steps (this is never a good idea in reality). For ladders, we extend the whole body gesture so that while the hand is above the head and the person is moving on a ladder, they will climb up the ladder, and while the person's hand is below their head, they will move down the ladder.

Plates 1, 2 and 3 show exterior views of a VB as it is climbing or descending steps and ladders, in one case holding a bucket.

4.4 Scaling the Environment

Scaling the environment as a whole is useful in applications where an overview of the entire scene is required, or alternatively when details need to be enlarged. This could be accomplished by defined hand gestures, or by menus and sliders. The BCI approach, however, requires the participant to carry out a whole body gesture which is semantically appropriate for the activity. Scaling the environment up is equivalent to shrinking the participant's VB. This can be accomplished by the person pushing down on his or her head with his hand and flexing the knees to lower the head, in an attempt to become smaller. Corresponding with this activity, the VB will become smaller, and the world will appear to grow larger, while the hand remains on top of the head. Shrinking the world is equivalent to growing the body. This can be accomplished with a placement of the hand under the chin, in a gesture of pushing upwards which grows the VB, and correspondingly the world appears to shrink.

This technique also supports magical navigation. Isaac Asimov's *Fantastic Voyage* can be accomplished in VR by shrinking the body to a tiny size in relation to the environment, so that the participant can move through what would in reality be microscopic spaces. (In the famous book, a doctor entered into the blood stream of a patient). Another application, would be to grow the body to a very large size, so that one small step would take the participant across to the other side of the environment. VR allows us to become microscopic creatures, or giants. The BCI paradigm tries to accomplish these magical techniques in an intuitive manner.

4.5 Body Centred Interaction Summary

The BCI paradigm therefore attempts to match sensory and proprioceptive data. An aspect of this is that it uses whole body gestures rather than limited hand based gestures or screen based interfaces in order to accomplish interactions. The goal is always to provide a gesture which corresponds in a semantic sense to the type of interaction. Hence walking is carried out by "almost walking", shrinking the body is accomplished by pushing down on the head. Other examples are easy to construct - for example selection of a distant object might be carried out by stretching the hand as far as possible away from the body. When the VR system detects such an event, it will grow the arm in the direction of pointing. Obviously, the kind of gestures possible are limited by the body tracking data available: the more of the body that is tracked, the more sophisticated can the gestures be. However, even with just the HMD tracker and glove or hand-held 3D mouse, quite a large number of different, intuitively appealing whole body gestures can be defined.

5. Communications

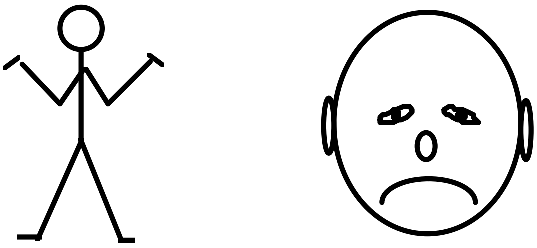
So far we have concentrated on a single isolated self and body within the VE. In this Section we briefly consider the implications of the BCI paradigm for people communicating in a shared VE. In this context the body becomes a social as well as a personal object. The body is not only a private representation of self, and a means for interaction, but also a medium of communication with others. Others are represented to self through their bodies and the relationship of the body of others to that of self is extremely significant personally, socially, and culturally. In a recent book on the sociology of the body, Anthony Synnot discusses this aspect of the physical body:

> Anthony Synnot (Synnot, 1993):
>
> "The body social is many things: the prime symbol of self, but also of the society; it is something we have, yet also what we are; it is both subject and object at the same time; it is individual and personal, as unique as a fingerprint or odour-plume, yet it is also common to all humanity ... The body is both an individual creation, physically and phenomenologically, and a cultural product; it is personal, and also state property."

Virtual bodies play a vital role in shared environments. The MultiG project at the Swedish Institute of Computer Science (Fahlen, 1992; 1993) has constructed a distributed VE where participants at physically different locations take part in, for example, joint virtual meetings. People become aware of each other in the VE through a complex function of their aura ("a space that can be seen as the enabler of interactions with other objects"), focus (a "space within which the object directs its attention") and nimbus (a space "where the object projects some aspect of its presence to be perceived by other objects"). Participants are represented by a simple VB model (a block with eyes) which is nevertheless quite powerful in representing the presence of another being.

The body in MultiG is a static entity, with no limbs. However, in meetings body posture by itself can indicate the real events which are taking place, as opposed to the superficial events at the level of verbal discussion. Body posture can be conveyed with very little information - for example, in Figure 1(a), the person depicted does not have to say anything for the observer to know what is being expressed.

Synnot shows that the face is the most powerful social symbol of self. Again, in meetings, where facial expression contradicts verbal agreement - which is likely to be more important? In Figure 1(b) we know that something is profoundly wrong in spite of the overt verbal agreement.



(a) How should I know? (b) "I'm happy with the agreement"

Figure 1: Body Posture and Facial Expression

Support for this kind of "body centred interaction" requires a different form of tracking technology. Rather than monitoring the body from the outside, using electromagnetic sensors such as the Polhemus, the body can be monitored from the "inside", using electrical recordings of the activity of the individual muscles or nerves, and electroencephalographic (EEG) recordings of potentials from the surface of the skull overlaying the motor cortex. There have been some applications of such biofeedback technology in VR (Lusted, Knapp and Lloyd, 1992; 1993). Such work offers great promise for a different kind of sensor and tracking technology, more in tune with the requirements of BCI.

6. Conclusions

In this Chapter we have concentrated on the role of the physical and virtual body in VR. The virtual body plays a primary role in immersive virtual environments:-

- it is the representation of self;
- it is likely to be a factor in increasing presence;
- it is the foundation of a model for interaction, body centred interaction;
- it is a medium of communication with others in shared environments;
- it may lead to a theory of virtual reality, through understanding of the relationship between the physical body, the virtual body, proprioception and presence.

The essence of Virtual Reality is that we (individual, group, simultaneously, asychronously) are transported bodily to a computer generated environment. We recognise our own habitation there, through our body becoming an object in that environment. We recognise the habitation of others through the representation of their own bodies. This way of thinking can result in quite revolutionary forms of virtual communication. For example in asynchronous communication, suppose a person (X) wishes to leave a message for someone else (Y) who will enter the environment at some time after X has left. A traditional way of thinking would be to leave a written or perhaps auditory message. The VB, however, allows X to leave a copy of his or her VB there in the environment to interact with Y, to perhaps act out a scenario depicting the required information (for example, in a training application). It is these new ways of thinking that must be adopted if VR is to fulfil its potential.

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