Environment and Planning D: Society and Space 2006, volume 24, pages 691 – 708

DOI:10.1068/d394t

Feel the presence: technologies of touch and distance

Mark Paterson
School of Cultural Studies, University of the West of England, St Matthias Campus, Oldbury Court Road, Bristol BS16 2JP, England; e-mail: Mark.Paterson@uwe.ac.uk
Received 16 October 2004; in revised form 12 January 2005

Abstract. Haptic devices for computers and video-game consoles aim to reproduce touch and to engage the user with 'force feedback'. Although physical touch is often associated with proximity and intimacy, technologies of touch can reproduce such sensations over a distance, allowing intricate and detailed operations to be conducted through a network such as the Internet. The 'virtual handshake' between Boston and London in 2002 is given as an example. This paper is therefore a critical investigation into some technologies of touch, leading to observations about the sociospatial framework in which this technological touching takes place. Haptic devices have now become routinely included with video-game consoles, and have started to be used in computer-aided design and manufacture, medical simulation, and even the cybersex industry. The implications of these new technologies are enormous, as they remould the human – computer interface from being primarily audiovisual to being more truly multisensory, and thereby enhance the sense of 'presence' or immersion. But the main thrust of this paper is the development of ideas of presence over a large distance, and how this is enhanced by the sense of touch. By using the results of empirical research, including interviews with key figures in haptics research and engineering and personal experience of some of the haptic technologies available, I build up a picture of how 'presence', 'copresence', and 'immersion', themselves paradoxically intangible properties, are guiding the design, marketing, and application of haptic devices, and the engendering and engineering of a set of feelings of interacting with virtual objects, across a range of distances.

> "'Going to the Feelies this evening, Henry?' enquired the Assistant Predestinator. 'I hear the new one at the Alhambra is first-rate. There's a love scene on a bearskin rug; they say it's marvellous. Every hair of the bear reproduced. The most amazing tactual effects'."
>
> Aldous Huxley (1984)

Introduction: intimate distances

Huxley's fanciful vision of a sensory cinema known as the 'Feelies', as opposed to the 'movies', would make an object not just look real, but feel real. It would have presence. The Feelies are unlikely to occur in that particular form, but elsewhere the technologies of touch, or what is known in engineering terminology simply as 'haptics', are moving into the mainstream. The emergence of touch within the human – computer interface is interesting enough, but in October 2002 newspapers reported the first 'virtual handshake', when researchers at Boston's Massachusetts Institute of Technology (MIT) TouchLabs and London's University College London held virtual hands and manipulated objects together over the Internet using haptic interfaces (Arthur, 2002, page 7; BBC News, 2002; Kim et al, 2004). These interfaces provide the sensation of touch by exerting accurately controlled forces on the fingers. By this means it is possible to simulate not only the feel of a virtual object, but also its texture and elasticity. Sharing these objects and properties over large distances, and being able to manipulate them virtually, encourages talk of 'presence'. The term 'telepresence', coined in the history of robotics to mean the sense of presence at a distance (Sheridan, 1989), is exactly what the virtual handshake achieved, and Kim et al (2004) extend this to speak of 'copresence'—to be able to interact with and feel the presence of another. But what is this sense of presence and copresence, and how is it enabled by touch? Can the spatially proximate sense of touch be communicated and experienced over a distance, and what are the effects of this? The question will be answered using a mixture of theoretical work concerning space, distance, and presence, along with empirical work based on participant observation and interviews in research labs and technology demonstration.

Although the rhetoric of virtual reality has diminished, technologies of touch have been quietly proliferating, finding uses in such diverse areas as military training, long-distance keyhole surgery, mine clearance, Internet sex, undersea and interplanetary exploration, and, most commonly, video games (for example, Amato, 2001a; Arthur, 2002; Hannaford, 2000; Stone, 2000). It is here that the engendering and engineering of a sense of presence are effected, through the hitherto missing aspect of the sensation of touch. A current MIT telerobotics journal is entitled *Presence*, and the notion of presence has pervaded engineering and telerobotics since their earliest days. The Links Corporation's first flight simulators, in the 1930s, were little more than wooden crates on mechanical stilts (Hillis, 1999). The need to recreate the haptic components of flight such as vibration, pitch, and roll, which played with the balance senses of the body, occurred through mechanical reproduction. Even now, haptic technology remains largely mechanical, but the sense of presence is increasingly aided by electronics, engaging directly with the somatic senses of kinaesthesia, proprioception, and the vestibular sense, greatly enhancing the simulation of being there. Speaking of the virtual handshake experiment, Slater noted that touch is the most difficult aspect of virtual environments to simulate, but that it "enhances the sense of being together even though the physical distances involved are vast" (quoted in BBC News, 2002). In this paper I will investigate ideas of presence and copresence through haptic technologies, the effects of feeling proximity at a distance, from high-end computation in medical simulation and virtual environments through to low-end haptics in video-game consoles and computer mice. The significance of haptics therefore lies in its increasing popularity and ubiquity, both in home entertainment and in commercial product design; in its ability to enhance the sense of presence of an object in a game world or on the desktop; and, more importantly for this paper, in the ability for this sense of presence to be communicated by touch over a distance—to literally feel the presence of another.

Although the concept of multimedia has been trumpeted for years, usually this has been equated with vision and sound only. Touch often ranks third in the hierarchy of the senses (for example, Downton and Leedham, 1991, page 19). With smell devices currently in prototype at MIT and elsewhere (see Paterson, 2006), haptics is a fast-growing aspect of multimedia (Kramer quoted in Hodges, 1998; Stephen Furner, BT Research Laboratories, Martlesham Heath, Suffolk, interview, 8 September 2000), evidenced by the vast engineering, human–computer interface, and medical simulation literature. After many years of overemphasis on the visual elements of computing in personal computers and video-game consoles, then, the other senses are being reasserted. Haptic technologies have made an appearance in high-end workstations for computer-aided design and manufacture, as well as in lower end home computers, and are standard in controllers for video-game consoles such as Sony's PlayStation 2, Microsoft's Xbox, and Nintendo's GameCube. Effectively this means adding what Hayward (quoted in Hodges, 1998) calls a "new mechanical channel", or a further strand, to human–computer interaction. Whereas the keyboard is a passive mechanical channel between the computer and the user, haptics enables a more active exploration and allows the user not just to *see* three-dimensional shapes represented on the screen, but also to *feel* them and interact with them. The implications for enriched sensory experience, as we shall see, are not limited to playthings. Haptic devices are becoming cheap and ubiquitous, and are increasingly accessible via everyday technologies such as mobile phones. These unfolding technologies are a set of augmentations that begin to play with an emerging multisensory realm, one that talks of the engendering and engineering of 'immersion', of 'presence', and of 'aura' through the addition of touch. Although the phenomenon of haptic interaction with computing devices and of the literal manipulation of information is interesting in itself, the main focus of this paper is the effects of haptics enhancing this sense of presence at a distance. In this paper I will therefore roughly trace the arc between haptics as proximal tactile interaction and the feeling at a distance that haptic simulations allow, between the sense of presence that comes from distance and the sense of copresence that fosters feelings of nearness and intimacy.

In the first section, 'Proximal touch', I look at the multisensory nature of the human–computer interface, our way of interacting with and accessing information through the computer. The addition of touch to the computer interface originally emerged to facilitate access to those with visual impairments. In this respect, haptics is one of a number of what Laurel calls "enabling technologies" (quoted in Rheingold, 2000, page 340), which ease human–computer interaction. This theme of the proximity of interaction is examined further in the section "Taking hold of an object close at hand", in which I look at the simulation of touch as a form of mimesis, and echo comments by Benjamin (1999) on auratic properties of objects as a prelude to thinking what happens to aura over distance. The present immediacy of our interactions with virtual objects is enhanced by the collocation of vision and touch, and this is the subject of the next section, "The senses of presence". Subsequently, in "Bringing distance to life" there is a more protracted discussion concerning the sense of immediacy and presence of an object over long distances, this 'telepresence' being aided by haptic technologies. Here, I enter into geographical debates concerning technologies and distance, reworking some recent sociospatial contributions concerning the senses, the body, and technologies (for example, Latham, 1999; Laurier, 2001; Laurier and Philo, 2003; Thrift, 2000) to articulate better the sense of presence at a distance, and this will connect into Dreyfus's articulation of 'skilful coping'. Afterwards, some conclusions will be drawn concerning the increasing ability to touch and be touched at a distance, and how haptic technologies are influencing our notions of touching, presence, communication and distance.

Proximal touch: the human – computer interface

> "The screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, and *feel real*."
>
> Sutherland (1965, page 507, emphasis mine)

With the reproduction of sound at a relatively advanced level, and the creation of artificial scents at the very beginning of its digital life (Mullins, 1998; Paterson, 2006), the role of touch in computing is becoming established, and the technologies in some shape or form are becoming increasingly prevalent. Whether for research or for entertainment, these devices augment interaction with virtual objects. The user's 'sense of presence' (Yelistratov et al, 1999) in a virtual space is reciprocally constituted by the sense of the virtual presence of an object. The goal, then, is to create the illusion of tangibility through mimetic machines, and the greater the fidelity of haptic sensation the greater the user's sense of presence in a virtual space. But mimesis is not representation, as Murphie notes: "It is always first and foremost a form of production"

(2002, page 193). This distinction will become important as we move away from realistic representations of touch, towards complex, creative operations that involve the tactile, both near and afar.

If our everyday interactions with proximal objects in the physical world are taken for granted, most haptic technologies attempt to replicate such interaction in a virtual world. These are some of the problems that mimetic machines of touch must face, to give the sense of interacting with objects by supplying composite sensations that include the cutaneous, the vestibular, the proprioceptive, and so on (see table 1) to engender the right 'feel'. In both physical, real-world interaction and interaction with digital sensation, then,

> "A significant component of our ability to 'visualize', remember and establish cognitive models of the physical structure of our environment stems from haptic interactions with objects in the environment. Kinesthetic, force and cutaneous senses combined with motor capabilities permit us to probe, perceive and rearrange objects in the physical world" (Massie and Salisbury, 1994, page 295).

This visualisation of cognitive models is the case even without the microdetailed touch stimulation of the fingertips and other sensitive areas. The forces and motions that are reported back to us from our fingers and limbs through the tactile–muscular system, Massie and Salisbury argue, generate "significant information about the spatial map of our environment" (1994, page 295). The haptic system as these engineers understand it does not consist solely in the cutaneous sense of the skin surface. What is significant here is the user-oriented intention, trying to engender the right 'feel' to an object, whether it be a model of a gearshift mechanism, a virtual prototype of a car door, the feeling of weighted switches when turning on and off in the virtual world, and the ability "for users to distinguish between massive and low-mass objects by feel alone" (1994, page 298). This discovery, from a user-centred perspective in this case, is one of ponderability—that is, reproducing or mimicking the sensation of weight and mass.

Table 1. Terminology of haptics (after Oakley et al, 2000, page 416).

Haptic	Relating to the sense of touch in all of its forms, including those below
Proprioceptive	Relating to sensory information about the state of the body (including cutaneous, kinaesthetic, and vestibular sensations)
Vestibular	Pertaining to the perception of head position, acceleration, and deceleration
Kinaesthetic	Meaning the feeling of motion. Relating to sensations originating in muscles, tendons, and joints
Cutaneous	Pertaining to the skin itself or the skin as a sense organ. Includes sensation of pressure, temperature, and pain
Tactile	Pertaining to the cutaneous sense but more specifically to the sensation of pressure rather than temperature or pain
Force feedback	Relating to the mechanical production of information sensed by the human kinaesthetic system.

Haptics is always that larger human system of perception that deals with touch, and so the human haptic system consists of "the entire sensory, motor and cognitive components of the body–brain system" (Oakley et al, 2000, page 416). Thus table 1 employs a rigorous use of haptics and associated terminology that I will use throughout this paper, but the key concept in haptic technology is 'force feedback'. At one end of the spectrum, low-fidelity force feedback in video-game controllers produces vibrations and rumble through the use of electric motors. Further up the spectrum, higher fidelity force feedback devices such as SensAble Corporation's PHANToM (Personal Haptic Interface Mechanism) (http://www.sensable.com) can produce a credible illusion of a tangible object in virtual space, through a combination of resistances and free play produced by electric motors in a workspace. While the skin detects temperature through thermoreceptors, and extreme pressure, heat, and pain through nociceptors, it is through mechanoreceptors that normal pressure is sensed (Dix et al, 1998, page 23). Force feedback occurs through a combination of cutaneous mechanoreceptor sensation and kinaesthesia: in other words, pressure and movement in space over a certain duration. In space and duration its presentment to us is a feeling of solidity, which haptic devices emulate through the use of force feedback. In fact, the inherently spatial and temporal characteristics of touch are described by the English empiricist philosopher John Locke: "The idea of *solidity* we receive by our touch; and it arises from the resistance which we find in body to the entrance of any other body into the place it possesses, till it has left it" (quoted in Appelbaum, 1988, page 20, original emphasis). As a set of artificial or illusory resistances in haptic devices, the tactile illusion of solidity is produced through electric motors in the device that work to selectively counter the movement of the user. With the variability of the electromotor force opposing that of the user, varying levels of hardness, softness, or elasticity can be modeled. Haptic devices that use force feedback appear to attach physical sensations to virtual objects, and, in the words of Mahoney (1997, page 42), the user's "force is input and reflected via a physical interface device, which can be anything from a joystick or steering wheel to a thimble or an exoskeletal structure."

This explains the technology, but the significance of haptics lies in the user's experience of a simulated object or environment. Like the Feelies in Huxley's *Brave New World*, the use of touch for interface and entertainment purposes is premised on the idea that the sense of immersion in an artificial environment is augmented by touch in addition to vision and sound. Whether in virtual reality, virtual environments, or the burgeoning market of video-game controllers, haptics is going 'mainstream' (Rosenburg quoted in Hogan, 1998). The addition of the haptic to the visual and aural enhances the experience of the user, and is commonly expressed in terms of immersion or presence. For example,

> "Being able to touch, feel and manipulate objects in an environment, in addition to seeing (and hearing) them, provides *a sense of immersion* in the environment that is otherwise not possible. It is quite likely that much greater immersion in a VE [virtual environment] can be achieved by the synchronous operation of even a simple haptic interface with a visual and auditory display, than by large improvements in, say, the fidelity of the visual display alone" (Srinivasan and Basdogan, 1997, page 393, emphasis mine).

The addition of the sense of touch allows, in Johnson's words, a sense of the "direct manipulation" of objects, in which "the user makes things happen in an immediate ... way" (1997, page 179), and therefore allows a sense of being immersed, being engaged in the task at hand. If the various technologies involved in the provision of this sense of touch differ in terms of sophistication then we can say, as do Macpherson and Keppell (1997), that there is a 'degree of immersion'. From inexpensive video-game haptics to 'fully immersive' virtual reality, the perceived degree of immersion differs according to the fidelity of the technologies being deployed, and this itself affects the perceived separation between the tools of the human–computer interface and the actual task at hand. We will explore this further in terms of Merleau-Ponty's 'sharpness of perception', in this case haptic acuity or 'grip'.

Historically, work on haptics at University of North Carolina at Chapel Hill used the Argonne Remote Manipulator, a large mechanical arm that augmented a three-dimensional visual display. This was used for nanolevel molecular modeling and manipulation (Stone, 2000, page 2). Haptic devices were later developed to work at the finger, hand, arm, and whole-body levels. Both Immersion Corporation's Impulse Engine 2000 (1995) and the PHANToM work at fingertip level. The TeleTact pneumatic glove, which later appeared in W Industries' *Virtuality* recreational virtual-reality devices in video-game arcades, was prototyped in 1989 and went through several generations until it became a handheld device as opposed to a wearable glove. This development of haptics continues through to complete tactile bodysuits. While Stone recognises the military origins of the majority of these devices, he also details current use of haptic technology in an industrial setting, such as training in surgery (also discussed by Amato, 2001a), remote surgical operations, and in training in land-mine clearance. The literature on haptics for surgical simulation and laparoscopic and keyhole surgery training has proliferated in the last few years.

Taking hold of an object close at hand

Following Benjamin's notion of aura and its loss in reproducible images of photographs and cinema, Gržinić suggests that the new technologies of telerobotics represent "a way to restore the aura, to restore the sense of *time* and *place* that the image conveys" (2000, page 220, emphasis mine). I want to pursue this theme and others in the exploration of haptic technologies, which are genealogically related to telerobotics (devices to aid the manipulation of objects at a distance) and telepresence (the evocation of a sense of presence of objects at a distance). Indeed, the virtual handshake experiment is an example of telepresence as Manovich defines it, being "representational technologies used to enable action, that is, allow the viewer to manipulate reality through representations" (2001, page 165). If we disregard his use of the term 'viewer', arguably the participant uses representations of an object, which are not only visual but also haptic, through the use of force feedback.

Benjamin's discussion of the mimetic faculty, and Taussig's subsequent discussion of "mimetic machines" that provide a "new sensorium" (1993, page 24), thereby affecting the nature of experience, are potentially useful starting points from which to commence discussions of technologies of touch. However, this is not simply an expansion of the sensorium in the way that technologies are supposed to do—the machinic extensions of the senses of the human. Writing about the transformation of the sensorium in modernism, for example, Danius describes the way that sensory technologies have gone from *prosthesis*, the "essentially external relationship between the senses and their technological supplements", to *aisthesis*, the "interiorization of technological modes of perceiving" (2002, page 194). Her argument is certainly applicable to those immediate haptic sensations such as video-game controllers or tactile mice, in which repeated operations start to bind actions (shooting an alien, driving a car) with force feedback sensations (weapon recoil, the rumble when departing the road surface). However, the notions of presence and copresence at a distance complicate this, and I will argue that there is more to attend to than interiorisations of perception.

Writing of the transformations of experience that new technologies were capable of effecting, Benjamin famously discussed the desire to take something close at hand, "to get hold of an object at very close range by ways of its likeness, its reproduction" (quoted in Taussig, 1993, page 32). Here, the importance of this idea lies in the nature of the haptic experience, recreated through digital means, being unambiguously illusory: a phantom-like presence. With teleoperation and telemanipulation (the ability to conduct operations with objects through mechanical means) able to be conducted over large distances, the need for something close at hand, and the production of these tangible presences through artificial means, collapses the distance and makes an extremely distant, or even nonexistent, object immediately present, actually manipulable, or graspable. The ghostly, those virtual possibilities that become locally actualised, Valéry calls "the active presence of absent things" (quoted in Denning, 1996, page 116, quoted in Thrift, 2000, page 222) and this is particularly apt in considering the naming of one of the most important haptic devices, the PHANToM. Given a high resolution of sensors and actuators in such a device, Hannaford explains:

> "we create 'knots' or 'ports' in space through which we can see, hear, touch and manipulate distant objects or people as though they were present. Multiple locations can be brought together at such a port and effectively superimposed in space and time" (2000, page 274).

Hannaford goes on to ask, as we shall do, what this means in terms of a sense of presence. Thinking of this presence at a distance can be conjoined, however, with another definition of aura, that of Josipovici: "Aura does not abolish distance, to adapt a wonderful phrase Benjamin once used ... , *it brings distance to life*" (1996, page 10, emphasis mine). Before there is more detailed discussion of this in relation to the case study of the virtual handshake, I wish to remain within the near-space of the computer desktop. If the origin of force feedback was to bring those distances of telemanipulation to life then the user's experience of haptics is the intimacy of touch, the prehensile and exploratory space of touch within reach. Haptic interfaces open up a tactile space on our desktop, too.

Appropriately enough, the majority of my analysis will concentrate on Massie and Salisbury's device, the PHANToM desktop haptic interface, invented in 1993 (figure 1). There are reasons for this. First, it is currently the most advanced haptic device, with far higher tactual resolution than any other. Second, it is versatile, being employed in a variety of nonmilitary applications, such as design, medical simulation, and rehabilitation. Third, I personally experienced using the device, as various models were employed by academic institutions and corporations within the course of empirical research.

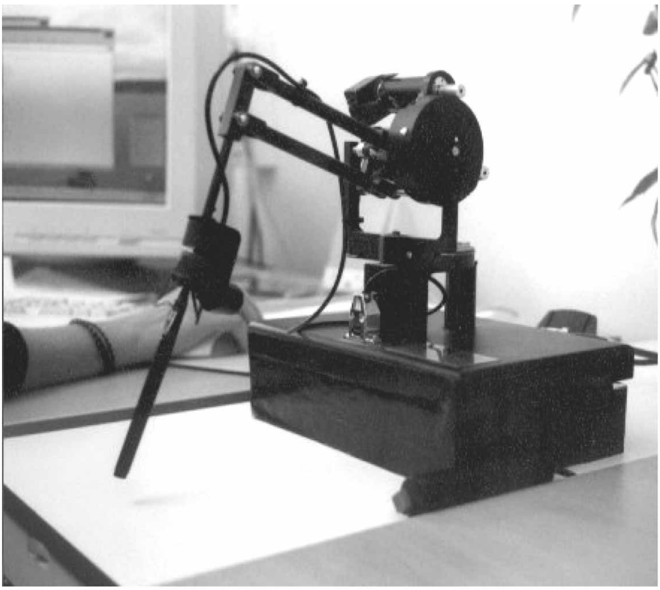

Figure 1. The PHANToM interface at CERTEC, University of Lund, Sweden (© 2000, author's photograph).

In addition, it forms the basis of other devices such as the ReachIn Desktop, used for design work and medical simulation, which I also experienced first-hand. Fourth, its name is suggestive of a theme that recurs in haptic marketing literature: a phantasm being illusory, both absence and presence.[(1)] Fifth, it was the device involved in the 'virtual handshake' cited at the beginning of this paper. The PHANToM is a machinic example of the intangible (digital data, the virtual) becoming tangible. It produces sensations, and creates tactile effects. More than a set of tactile–muscular interactions, and especially in conjunction with a visual display, it provides a sense of presence of a virtual object. Like mimesis, haptics becomes a form of production, to enhance operations, to provide richer user experience, even to promote experimentation through free-flowing play and creativity. But, primarily, haptics creates a whole set of forces and corresponding sensations, a fusion of feelings that are generated and retro-engineered from the perspective of the user, not imposed by programmers or coders themselves, in order to recreate the right 'feeling'. For example,

> " Users of the PHANToM provide evidence that our visual, haptic and auditory senses are closely linked and that all three sensory modes are required for navigation within virtual environments.... Many users claim that they can 'see a sphere' after touching a virtual sphere with the PHANToM" (Massie and Salisbury, 1994, page 299).

This is confirmed with my own experience of the interface, at MIT TouchLabs in Boston, British Telecom Labs at Martlesham Heath, CERTEC (the Division of Rehabilitation Engineering Research) in Lund, Sweden, and ReachIn Technologies AB of Stockholm. The feeling elicited through force feedback in this 'thimble-gimbal' (Salisbury, 1995) interface of virtual objects is one of solidity, of texture, sometimes of elasticity of a surface. All these sensations are reproduced through software algorithms in the applications program interface, appropriately enough called 'Ghost'. Mostly, the haptic models of virtual objects accompany visual representations on a screen, so that one can see and feel an object simultaneously, the haptic sensation confirming the visual impression or vice versa. But the decoupling of the haptic from the visual may also take place. For example, with no visual representation on screen the feeling of a switch that can remain on or off is still somehow 'visualised' as a haptic model. These sensations will be examined further below.

The senses of presence: visual and haptic collocation

The hand-based manipulation of virtual objects can occur with or without a visual component to aid the recognition of the object. Visuo–haptic collocation, the correspondence between visual and haptic stimuli, is essential to have a believable sense of interaction with a virtual object (Dionisio et al, 1997, page 465), and therefore enables more sophisticated training and medical simulation to take place. Haptics alone without visual rendering produces an unusual feeling, and the visual alone, despite being the primary method of three-dimensional modeling and rendering, leads to ambiguities and is an unwieldy method of object manipulation. Haptics therefore offers the verification of an object in space, to get a real sense of the presence of that object, in a way that vision alone cannot do. As Massie shows:

> "Touching something with the Phantom resolves all of the ambiguities on the screen. For example, if you see a shaded, rendered sphere on screen, your brain is trying to interpret this 2-D projection and reconstruct a 3-D image from that without the

[(1)] 'Phantom' and 'phantasm' mean "Something that appears to the sight or other sense, but has no material substance; an apparition, a spectre; a spirit, a ghost", or "Something having the form or appearance, but not the substance, of some other thing; a (material or optical) image *of* something" (*Oxford English Dictionary* 2nd edition, 1989).

advantage of binocular vision. So you're subconsciously making decisions like whether the sphere is concave or convex. As soon as you touch it, you know immediately what it is" (quoted in in Mahoney, 2000, page 41).

Visuo–haptic collocation therefore reduces visuospatial ambiguities, as well as augmenting the purely invisible haptic set of forces as experienced through the interface. Noyes and Mills, in distinguishing between 'immersive' and 'nonimmersive' virtual reality, claim that for virtual reality to be truly immersive there needs to be "some form of haptic input[,] so the user wears gloves or uses some other specially designed three-dimensional interactive device which is usually hand-held" (1999, page 124), and certainly we can class the PHANToM as such a device. The process of pointing and manipulating in a three-dimensional space involves a complex set of coordinated perceptions and responses, and haptics helps to resolve these ambiguities, making a strictly 'nonimmersive' work space more 'immersive' as a result, they argue (page 129). Within the desktop-based work space of the PHANToM there is certainly a sense of presence of the object for the user.

ReachIn Technologies AB of Stockholm exemplify this visual–haptic collocation. Specialising in medical simulation, their ReachIn Desktop is a graphic display that overlooks and obscures a small PHANToM, thereby producing a very 'real' sense of manipulating an object. As the computer display is reflected onto a screen, the visual element is superimposed directly onto the haptic, so that manipulation of the virtual object occurs in what appears, from above, to be a 'shared' space of vision and touch. By collocating representations of the haptic with the visual more effectively, this device allows a more realistic feeling of manipulating a virtual object, one that can better evoke the feelings of weight, mass, ponderability, and other real-world behaviours: "When the stylus [of the PHANToM] hits something displayed in the mirror, you find that the objects there have surfaces, weight, viscosity and all the other properties of real world objects that you can feel through a tool", they boast (ReachIn.se, 2001). To manipulate a virtual object with the hand, and to have the image change accordingly on the screen over the haptic device, produces a credible sensation of a tangible virtual object. The superimposition of a visual display over a haptic set of forces is a more sophisticated form of visuo–haptic collocation, although ReachIn themselves more awkwardly call it 'visu-haptic' (Thurfjell, interview, 13 September 2000). A technology demonstration that I tried, the medical simulation of the injection of a hand with a hypodermic syringe, revealed the startling but subjective sense of realism this device could attain. In this demonstration, the ReachIn Desktop provided the haptic sensation with enough visual detail to see veins on the hand, along with the springiness of the skin as felt through the PHANToM underneath, in conjunction producing an uncannily realistic sensation. When the needle was manipulated into the skin, the skin-puncturing moment was reproduced through the force feedback in the PHANToM below. These sensations were not just felt as localised kinaesthetic forces by the fingertips, but engendered a visceral feeling, the synthesis of the visual and the haptic mimicking the sensation of injecting into the springiness and resistances of flesh:

> "But when it comes to the visuo-haptic what makes a big difference is the collocation, which is both ... but somehow this collocation thing of ReachIn makes a big impact on the gut feeling. And we don't know why, but that's empirical!" (Tomer, interview, 13 September 2000).

As well as this visual–haptic collocation being the basis for surgical simulations of complex procedures in medical training, for example, it is possible to conduct surgical operations across large distances through a network: the sensations being associated with proximal interactions, yet allowing the performance of operations in remote regions or even behind enemy lines (for example, Amato, 2001a).

The visceral component, something that emerges from the visuo–haptic collocation, finds an application not only in the field of medical simulation but also in creating 'digital mock-ups' or virtual prototypes. ReachIn have done work for automotive manufacturers such as Saab-Scania and Volvo.(2) In interview, Hofsten explained the way that the design of a purely hypothetical piece of engineering, in her example a gearbox, could be imbued with different sensory properties, and how these sensations could be altered and experimented upon using the ReachIn Desktop. This is a user-centred approach to design, which uses the haptic interface to produce something as unquantifiable and indefinable as the right 'feel' for a piece of new technology: the satisfying 'thunk' of a gearshift, or a car door closing, arising simultaneously from auditory, visual, and kinaesthetic stimuli, somehow visceral in nature. These visual–haptic sensations are imprecise, arising from repetitive experimentation with the conjunction of different forces and sensory stimuli, by "playing with different feelings" as Hofsten herself explains:

> "So just imagine you want to look, you want to find out what the feeling is when touching the instruments, or the gear shift for example. What do you want the feeling to be like when changing gears in the car? Do you want it to be the Scania feeling, you know, a lot of power ... you could do it just by pressing button, 1,2,3,4,5 [or] how many gears you have, but this is not the right feeling. And the old Scania drivers, they don't like it, they prefer to have the old feeling of changing gear, you know, and *this is a kind of playing with different feelings*, and they can still implement the new technology but keep the old feeling ..." (Hofsten, interview 13 September 2000, emphasis mine).

Similarly, with paper cartons, another piece of collaborative research has enabled ReachIn to try out the 'feel' of different paper types using the ReachIn Desktop, thereby reducing the number of actual prototypes that must be produced (Hofsten, interview 13 September 2000), shortening the development cycle. What is significant is the way a new language of haptic sensations is being articulated within a marketing and engineering context, so that these forces and sensory properties are mimicked, modeled, experimented with, and reproduced through the interaction between hardware and software, and the collocation of the different forces and sensations is altered and combined in new ways. It is this attempt to reproduce and articulate new sensations, by a form of retro-engineering from the experience of the user, that shares concerns with nonrepresentational 'theory', particularly the "new means of expression" that emerge from "the expanding space of virtuality of the body and technology" (Thrift, 2004, page 93). Although space does not allow further consideration of this area, we can note that the admixture of sensory properties by haptic hardware and software opens up a discussion of the right 'feel' of a virtual object, and has genuine impact on future design and the crafting of actual objects (for example, Amato, 2001b; Paterson, 2005; 2006b). The engendering of the 'feel' of a virtual object is impacting digital creativity and craft, where manual contact with the material can now be mediated by a haptic interface: for example, actually manipulating 'virtual clay' (for more extensive discussion of these aspects see Paterson, 2005; 2007; also see McCullough, 1998). Whether the virtual is a set of somatic, kinaesthetic possibilities in dance, or virtual clay to be moulded on the desktop, it is a 'performative experiment' of play that "encourages the discovery of new configurations and twists of ideas and experience" (Schechner, 1993, page 42, quoted in Thrift, 2000, page 221). Mimesis, it was remarked earlier, is about production rather than representation; this play of haptics produces sensation but also variation.

(2) For another discussion about the engineering of sensations see, for example, Latham and McCormack's discussion of 'automobility' (2004).

What is in effect a form of virtual prototyping affects the computer-aided design and manufacture in the development process, adding the simulation of material properties of an object through haptic interactions. Although the present technology allows only an imprecise mimicking of the touch sensation, the combination of haptic sensations and visual representation—that is, visuo–haptic collocation—can, as we have seen, produce startlingly visceral effects.

Bringing distance to life: presence and copresence

> "For there to be a sense of presence in telepresence one would have to be involved in getting a grip on something at a distance."
>
> Dreyfus (2000, page 58)

Let us now bring distance into the discussion. As Burdea (1996) and Srinivasan and Basdogan (1997) have shown, there is a history of force feedback devices as augmentations to the human–computer interface. Hannaford (2000), Salisbury (1995), and Stone (2000) also write about the history of force feedback devices that originated from long-distance robot manipulation, or telemanipulation: for instance, in the handling of nuclear material, submarine, military, and space operations. "Teleoperation and telerobotics are technologies that support physical action at a distance", is how Hannaford (2000, page 247) neutrally defines these. They were at first purely mechanical, and later a combination of motors and sensors were combined so that a remote user would be able to manipulate an object literally. A vital way to get a sense of interacting with the object was through the recreation of forces and resistances of the object, however geographically distant. The goal of 'telemanipulation' or 'teleoperation', the remote operation of a device, was therefore achieved through force feedback, so the earliest haptic devices were force-feedback devices. The feeling engendered through this long-distance operation has been called 'telepresence': that is, "the experience of presence in an environment by means of a communication medium" (Steuer, quoted in Hillis, 1999, page 182).

Transatlantic touching: the virtual handshake experiment

Rather than attempting a survey of various haptic technologies, one way to discuss some spatial effects of haptics devices is to concentrate on the example of the virtual handshake. This has the advantage of distilling some spatial themes that are relevant to readers of this journal, while bypassing the always incomplete cataloguing of various technological developments. Let us therefore return to that first virtual handshake mentioned in the introduction, the transatlantic touching between PHANToM haptic interfaces at MIT in Boston and University College London in 2002. Discussed in newspapers and in the popular press (for example, Arthur, 2002; BBC News, 2002), the experiment was written up by researchers at both institutions in the telerobotics journal *Presence* (Kim et al, 2004). Along with a summary of the experiment, the paper used questionnaires to elicit responses from the participants concerning "the subjective levels of presence and copresence experienced" during performance of the task (page 328). Having discussed the notions of presence in the near space of the human–computer interface, I wish to address copresence and the effects of space in particular in this section.

We have discussed the sense of presence in terms of the manipulation of virtual objects on the computer desktop being enhanced by force feedback, and telepresence as the use of force feedback in the interaction with objects and virtual objects at a distance. The virtual handshake experiment utilised two sets of haptic devices, each with a human user manipulating a virtual object. The aim was the collaboration between users on each side of the Atlantic to manipulate an object on the screen through a haptic interface. This involved feelings of copresence. In their words, the "fundamental aspect of shared experience is the sensory communication between geographically separated users that enables them to display their actions to each other through a connected network" (Kim et al, 2004, page 328). The network in this case was WWW2, a fast Internet backbone, created in order to minimise system delay in the conveyance of tactile information to the user. For, as Noyes and Mills explain, "the delay between a hand movement and a corresponding change on the display" (1999, page 132) would not only shatter the sense of real-time engagement with an object, but also seriously challenge the ability to carry out useful tasks.

There are various ways of thinking these distributed tactile and spatial relations, one being so-called 'actor-network' theory, and there are advantages in variations of this approach. Bingham, for example, defines 'remote control' as the ability to "act at a remove", to exert "force at a distance with predictable and repeatable consequences" (1996, page 650). Thus we could talk of the virtual handshake experiment alongside such familiar examples as Portuguese shipping networks and the immutable mobiles of laboratory life, and something about the laboratory-based arrangements over networks lends itself to this. Indeed, one of Law's (1986) observations of shipping networks is the amount of work necessary to maintain the network, and to minimise the degeneration in communications between components within it. This is to reduce the 'noise' between the centre and the periphery, pertinent to the noise that Noyes (Noyes and Mills, 1999) described above concerning network delays in real-time haptic engagement. We could also follow Law and Mol (2001) in rethinking these networks along metaphors of fluidity or, more aptly concerning the flickering of presence and absence, of fire. Or we could combine approaches, to correlate a materialist semiotics with the media theory of Friedrich Kittler (1999), for example, where the establishment of order and the building of ergonomic pathways could be analysed in computer inputs and outputs, a way to think about the historical – material shaping of the mouse, the keyboard, the game pad. Yet there is something more immediate and sensorily engaging occurring, as discussed in the section on visual – haptic collocation, and the notion of the feeling of the presence of an object and of the copresence of another operator at a distance is experienced otherwise than as a stable maintenance of topologies. And here we start to ask about the role of a mediated telepresence as compared with direct perception, if the task requires the manipulation of a virtual object. As Dreyfus argues, "what gives our sense of being in direct touch with reality is that we bring about changes in the world and get perceptual feedback concerning what we have done" (2000, page 57). Deceptively straightforward as this seems, some unforeseen implications emerge when we consider this occurring over a distance. If we assume that network latency is kept to a manageable level, there is no perceived difference between being in direct touch with an object across the Atlantic and being in touch with a virtual model on a computer desktop. Benjamin's notion of aura collapses if the distances involved do not qualitatively affect the feeling of the manipulation process, the sense of presence of an object or copresence of another person.

The notion of copresence in the virtual handshake experiment is defined by Kim et al in terms of "human – human interaction" (2004, page 329) as opposed to human – computer interaction, aided by haptic devices at either end. The task involved lifting a virtual cube represented on the screen, which required cooperation between the users by manipulating PHANToM devices, each respondent exerting pressure on the cube as a collaborative exercise in order to lift it off the ground for as long as possible. The task itself being straightforward, the real purpose of the experiment was to gauge the role of haptics in the sense of presence and copresence. Methodologically, this was measured statistically by Kim et al through questionnaires for each respondent conducted after the experiment, asking basic questions to elicit responses on a score range of 1 to 7, such as:

> "(1) To what extent, if at all, did you have a sense of being with another person?
> (2) To what extent were there times, if at all, during which the computer interface seemed to vanish, and you were directly working with the other person? ...
> (6) During the time of the experience, did you often think to yourself that you were just manipulating some screen images with a pen-type device, or did you have a sense of being with another person?" (Kim et al, 2004, page 335).(3)

The results, unsurprisingly, showed a statistical correlation between haptics and the sense of copresence. Obviously, to gauge subjective experiences of copresence required a more qualitative approach, and, although discussion of my haptic interactions is centred on the computer desktop, we could extrapolate from feelings of presence in the near-space of the desktop to feelings of copresence over the network space of the Internet. Tying in with my earlier observations on visuo–haptic collocation above, they conclude that: "Visual immersion along with haptic immersion would greatly increase the collaboration over a vast physical distance" (2004, page 336).

In contrast to the statistical survey Kim et al conducted, having experienced using the PHANToM device to accomplish various tasks (playing with a ball, injecting a hand) we can speak almost phenomenologically of bringing the remote into nearness, into the near-space of proximal touch. Hence long-distance control, the exertion of force at a distance, simultaneously brings the distant into an almost phenomenologically felt near-space of proximity, while also maintaining that distance. In the words of Cooper, long-distance control is possible:

> "Through a sequence of short-distance achievements of remote control, all of which embodied the following steps: (1) the substitution of a symbol or technical device for direct human involvement; which led to (2) the curious effect of bringing the remote—that which is cut off by a limit or boundary—near, while at the same time keeping it at a remove" (1992, page 259, in Bingham, 1996, page 650).

These sensations of bringing the remote into nearness are more akin to Laurier's example of reaching for a mobile phone, of being "digitally accomplished in that place" (2001, page 493), itself an adaptation of Sudnow's (1993) famous example of observing a jazz pianist from the outside: a skilled absorption that does not require the separation of representation from the task at hand. As Dreyfus describes this, our active and involved body puts us directly in touch with perceived reality, and can be described as "everyday coping", "absorbed activity", or simply as "going with the flow" (2000, page 57). No inner mental representation is required to perform these activities, to become digitally accomplished in that place, whether it is the locale of the computer desktop or over a network.

Dreyfus's phenomenological approach to technology is helpful, and especially so in the case of haptic manipulation, where we may invoke Merleau-Ponty's concept of 'maximum grip', the notion that in grasping something we do so in order to obtain the most satisfactory purchase on it, either on the parts or on the whole. This is a perceptual attitude that translates from immediate practical contexts in virtual and actual worlds alike, and therefore does so both in the immediate space of the desktop and at a distance. The minimisation of network latency, the delay between performing an action and obtaining feedback through an interface and on the screen, increases the

(3) Obviously, such questions are undoubtedly methodologically naïve, and the statistical analysis of what Kim et al describe themselves as the "subjective sense of presence and copresence" (2004, page 328) is better served by other methods; nevertheless, the interest in this paper lies in it not only being a technology demonstration, but also attempting to define and evaluate novel feelings and sensations.

grip on the task at hand; in Merleau-Ponty's words, this increases the "sharpness of perception":

> "This maximum sharpness of perception and action points clearly to a perceptual ground, a basis of my life, a general setting in which my body can co-exist with the world" (1992, page 250).

It is with this nonrepresentational notion of getting a grip that Dreyfus can then argue, as at the beginning of this section: "for there to be a sense of presence in telepresence one would have to be involved in getting a grip on something at a distance" (2000, page 58). This is skilful coping with things and people, using several sensory dimensions in real time, an illusion that breaks as soon as network latency appears. But skilful coping with things is what invokes a sense of presence, and skilful coping with people is what invokes the sense of copresence, where the sharpness of perception involves high-fidelity force feedback over a network without latency. With this haptic acuity over a distance, we can become digitally accomplished in a variety of places.

Conclusion: haptics and information-space

> "The computer molds the human even as the human builds the computer."
>
> Hayles (1993, page 90)

Although Huxley's Feelies are unlikely to occur the way he envisaged, haptic technologies are adding further sensory content to mediated communication, bringing what was distant into present proximity. For the sake of focus, in this paper I have mostly concentrated on desktop haptics, even if the two desktops are geographically separated. Before making conclusions about touching at a distance, however, I wish to consider very briefly a more distributed sense of haptics, moving away from the computer desktop or joystick. Alternative ways that haptics are being employed include digital arts installations, especially the multiple and distributed tangible 'widgets' used in Edinburgh's *Tacitus* project (for example, Shillito et al, 2001) which have been displayed in publicly accessible spaces, and include haptic components.(4) Kangas (2002) has observed the uptake of haptics in games and the advent of wearable computing, and notes how these have affected the human–computer interface. From this she sees haptic devices becoming embedded in everyday objects such as tables and couches, using tactile stimuli as a communicative tool.(5) And, from a more utilitarian perspective, the use of haptic information to provide spatial information for the blind and visually impaired is an important consideration (see, for example, Jacobson et al, 2002; Paterson, 2002).(6)

Through discussion of a variety of haptic technologies, although primarily the example of the virtual handshake conducted in 2002 between London and Boston, there are a number of observations concerning experiences of touch and space that I

(4) Multimedia installations that use presence and movement in innovative ways away from the computer desktop include David Rokeby's *Very Nervous System* (1991), Marcus Novak's *transArchitecture: Transmitting the Spaces of Consciousness* (1995), and *Sensor Space* (1997–98), and the IO-Dencies series (1997–99). Also of note is Väätänen et al's (2001) project which deals with social gaming and the detection of movement as a collective in order to navigate space. These works and others show that presence and copresence have been investigated in informational space for some time.

(5) MacLean and Roderick (1999) also depart from the desktop in their haptic doorknob project, using the doorknob as a communication device to provide instantaneous temperature feedback, based on certain prescribed ambient conditions—for example, if an important meeting is happening.

(6) Dan Jacobson (University of Calgary) and Reg Golledge (University of California, Santa Barbara) have been collaborating for years on spatial information and mapping systems for the visually impaired, and their virtual collaborations are available at http://www.hapticsoundscapes.org.

wish to make. First, although touch is often associated with near-space or even with intimacy, it is obviously of concern in the human – computer interface because it effects, in Johnson's phrase, "direct manipulation" (1997, page 179). Second, if haptic technologies can provide sensations of direct manipulation with a virtual object on the computer desktop, then, in Benjamin's words, "taking hold of an object close at hand" produces a sense of presence of the object through force-feedback sensations, the mimicking of sensations of solidity, and spatial extension of an object. Especially through the collocation of the visual with the haptic, these produce a sense of presence whether the virtual object is produced on a local machine, or whether the data are relayed across the Internet from another continent. The implication is that, given the absence of a noticeable network latency, the effects of distance are collapsed, and tasks or operations that are being conducted at great distance can theoretically be introduced into the proximate space of a local computer desktop. Haptics therefore reach out way beyond the human – computer interface itself. Third, we have discussed copresence, the haptic manipulation not only of objects, but with other users. This is notable for the accomplishment of collaborative tasks, but will become increasingly significant for other human – human interactions, as suggested by MIT's ComTouch project (http://tangible.media.mit.edu/projects/comtouch). So, fourth, the expensive and specialised haptic devices utilised in the virtual handshake experiment should not blind us to the near ubiquity that inexpensive force-feedback devices already enjoy through video-game console controllers, and will continue to do so in future communications devices.

My last points are interconnected, and concern some of the underlying spatial assumptions behind much of this paper and the literature on haptics. When in 1936 Benjamin wrote about the hunger for the aura or presence of an original artwork increasing as a result of the proliferation of mechanical copies, the categories of 'original' and 'copy' were distinct (see Benjamin, 1999). For Benjamin, only the original work had aura, and never its reproductions. Without even using the language of simulation and simulacra, we have noticed that the distinction is elided, as objects can be virtual and still have a presence. This point is strengthened when we consider these objects can be located at a distance but felt locally and that this also applies to copresence, the presence of another. Like the telephone, perhaps, only with the haptic modality, we proceed as if the person is actually 'there'—a convincing enough sense of copresence. In collaborative tasks such as the virtual handshake, then, this is the phenomenological extension of the task at hand over a network: being digitally accomplished here and elsewhere. As Johnson prophesies, "We can be sure that the exploratory, spatial quality of the medium—the haptics of information-space—will be of enormous importance" (1997, page 221). Indeed.

Acknowledgements. First, I must acknowledge my great debt to researchers and engineers Calle Sjöstrom and Kirsten Rassmus-Gröhn at CERTEC in Lund, Sweden; Stephen Furner at BT Research Labs, Martlesham Heath; the ReachIn team in Stockholm; and Dr Mandayam Srinivasan at MIT TouchLabs. Without exception they were welcoming and generous, both with time and ideas. In addition, I would like to thank the three anonymous reviewers who helped to refine and shape the paper, and who were also generous with their help and comments. Last, I would like to thank Emma Roe for her readings of various drafts, and Nigel Thrift for his encouragement throughout.

References

Amato I, 2001a, "Helping doctors feel better" *Technology Review* April, 64 – 71

Amato I, 2001b, "Touchy subjects: from digital clay to the 'nanoManipulator' " *Technology Review* April, 70 – 71

Appelbaum D, 1988 *The Interpenetrating Reality: Bringing the Body to Touch* (Peter Lang, New York)

Arthur C, 2002, "Touching moment 3,000 miles apart becomes a virtual reality" *The Independent* Home News, 30 October, page 7

BBC News, 2002, "Virtual hands reach across the ocean", 30 October, http://news.bbc.co.uk/2/hi/technology/2371103.stm
Benjamin W, 1999 *Illuminations* translated by H Zorn, Ed. H Arendt (Pimlico, London)
Bingham N, 1996, "Object-ions: from technological determinism towards geographies of relations *Environment and Planning D: Society and Space* **14** 635 – 657
Burdea G C, 1996 *Force and Touch Feedback for Virtual Reality* (John Wiley, Chichester, Sussex)
Cooper R, 1992, "Formal organisation as representation: remote control, displacement and abbreviation", in *Rethinking Organisation: New Directions in Organisational Theory and Analysis* Eds M Reed, M Hughes (Sage, London) pp 254 – 272
Danius S, 2002 *The Senses of Modernism: Technology, Perception and Aesthetics* (Cornell University Press, Ithaca, NY)
Denning G, 1996 *Performances* (University of Chicago Press, Chicago, IL)
Dionisio J, Henrich V, Jakob U, Rettig A, Ziegler R, 1997, "The virtual touch: haptic interfaces in virtual environments" *Computers and Graphics* **21** 459 – 468
Dix A, Finlay J, Abowd G, Beale R, 1998 *Human – Computer Interaction* 2nd edition (Prentice-Hall, Englewood Cliffs, NJ)
Downton A, Leedham G, 1991, "Human aspects of human – computer interaction", in *Engineering the Human – Computer Interface* (McGraw-Hill, London) pp 13 – 26
Dreyfus H, 2000, "Telepistemology: Descartes' last stand", in *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet* (MIT Press, Cambridge, MA) pp 48 – 63
Gržinić M, 2000, "Exposure time, the aura, and telerobotics", in *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet* Ed. K Goldberg (MIT Press, Cambridge, MA) pp 215 – 224
Hannaford B, 2000, "Feeling is believing: a history of telerobotics", in *The Robot in the Garden: Telerobotics and Telepistemology in the Age of the Internet* Ed. K Goldberg (MIT Press, Cambridge, MA) pp 246 – 275
Hayles N K, 1993, "Virtual bodies and flickering signifiers" *October* **66** 69 – 91
Hillis K, 1999 *Digital Sensations: Space, Identity and Embodiment in Virtual Reality* (University of Minnesota Press, Minneapolis, MA)
Hodges M, 1998, "It just feels right" *Computer Graphics World* **21** 48 – 56
Hogan H, 1998, "Virtual touch", http://www.hightechcareers.com/doc697/virtualtouch697.html
Huxley A, 1984 *Brave New World* and *Brave New World Revisited* (Chatto and Windus, London)
Jacobson R D, Kitchin R M, Golledge R G, 2002, "Multimodal virtual reality for presenting geographic information", in *Virtual Reality in Geography* Eds P Fisher, D Unwin (Taylor and Francis, London) pp 382 – 400
Johnson S, 1997 *Interface Culture: How New Technology Transforms the Way We Create and Communicate* (Basic Books, New York)
Josipovici G, 1996 *Touch: An Essay* (Yale University Press, New Haven, CT)
Kangas S, 2002, "From haptic interfaces to man – machine symbiosis" *M/C: A Journal of Media and Culture* **2**(6) 1999, http://journal.media-culture.org.au/9909/haptic.php
Kim J, Kim H, Tay B K, Muniyandi M, Srinivasan M A, Jordan J, Mortensen J, Oliveira M, Slater M, 2004, "Transatlantic touch: a study of haptic collaboration over long distance" *Presence: Teleoperators and Virtual Environments* **13** 328 – 337
Kittler F A, 1999 *Gramophone, Film, Typewriter* translated by G W Young (Standford University Press, Stanford, CA)
Latham A, 1999, "The power of distraction: distraction, tactility, and habit in the work of Walter Benjamin" *Environment and Planning D: Society and Space* **17** 451 – 473
Latham A, McCormack D M, 2004, "Moving cities: rethinking the materialities of urban geography" *Progress in Human Geography* **28** 701 – 724
Laurier E, 2001, "Why people say where they are during mobile phone calls" *Environment and Planning D: Society and Space* **19** 485 – 504
Laurier E, Philo C, 2003, "The region in the boot: mobilising lone subjects and multiple objects" *Environment and Planning D: Society and Space* **21** 85 – 106
Law J, 1986, "On the methods of long distance control: vessels, navigation and the Portuguese route to India", in *Power, Action and Belief: A New Sociology of Knowledge?* Ed. J Law (Routledge and Kegan Paul, London) pp 234 – 263
Law J, Mol A, 2001, "Situating technoscience: an inquiry into spatialities" *Environment and Planning D: Society and Space* **19** 609 – 621
McCullough M, 1998 *Abstracting Craft : The Practiced Digital Hand* (MIT Press, Cambridge, MA)

MacLean K E, Roderick J B, 1999, "Smart tangible displays in the everyday world: a haptic door knob" *Proceedings of the IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM '99), September 1999, Atlanta GA*, http://www.cs.ubc/ca/~maclean/publics/aim99-HapticDoorknob.PDF
Macpherson C, Keppell M, 1997, "Is the elephant really there? Virtual reality in education", conference presentation document online at http://www.infocom.cqu.edu.au/Units/aut99/00101/00101/RESOURCE/TUTORIAL/VR-PRES.PDF
Mahoney D P, 1997, "The power of touch" *Computer Graphics World* **20**(8) 41 – 48
Mahoney D P, 2000, "Innovative interfaces" *Computer Graphics World* **23**(2) 39 – 44
Manovich L, 2001 *The Language of New Media* (MIT Press, Cambridge, MA)
Massie T, Salisbury K, 1994, "The PHANToM haptic interface: a device for probing virtual objects" *Proceedings of the ASME Winter Annual Meeting, Dynamic Systems and Control, Chicago* volume 55, DSC, pp 295 – 301, http://www.sensable.com/products/datafiles/phantom_ghost/ASME94.pdf
Merleau-Ponty M, 1992 *The Phenomenology of Perception* translated by C Smith (Routledge, London)
Mullins J, 1998, "Hear me, see me, touch me" *New Scientist* 7 November, 36 – 38
Murphie A, 2002, "Putting the virtual back into VR", in *A Shock to Thought: Expression After Deleuze and Guattari* Ed. B Massumi (Routledge, London) pp 188 – 214
Noyes J, Mills S, 1999, "Virtual reality", in *Interface Technology: The Leading Edge* Eds J M Noyes, M Cook (Research Studies Press, Baldock, Herts) pp 123 – 133
Oakley I, McGee M R, Brewster S, Gray P, 2000, "Putting the feel in 'look and feel' ", in *Transactions of ACM Computer – Human Interaction 2000* (ACM Press, The Hague) pp 415 – 422
Paterson M W D, 2002 *Haptic Spaces* doctoral thesis, School of Geographical Sciences, University of Bristol, Bristol
Paterson M W D, 2005, "Digital touch", in *The Book of Touch (Sensory Formations)* Ed. C Classen (Berg, Oxford) pp 431 – 437
Paterson M W D, 2006, "Digital scratch and virtual sniff: articulating a language of smell through iSmell", in *The Smell Culture (Reader)* Ed. J Drobnick (Berg, Oxford) in press
Paterson M W D, 2007, "Digital craft, digital touch: haptics and design", in *Emerging Small Tech: Technologies at the Intersection of Cyberculture and New Media* Eds B Hawk, D Rieder, O Oviedo (University of Minnesota Press, Minneapolis, MN) forthcoming
ReachIn.se, 2001,"The feeling of the Reach In Interface", archived as http://www.led.br/~tissiani/arquivos/ePapers/papers_VRUI/chalmersMedialLab/haptic_interfaces/Chalmers%20Medialab%20-%20The%20Reach-In%20concept.htm
Rheingold H, 2000 *Tools for Thought: The History and Future of Mind-expanding Technology* 2nd edition (MIT Press, Cambridge, MA)
Salisbury K, 1995, "Haptics: the technology of touch", http://www.sensable.com/products/datafiles/phantom_ghost/Salisbury_Haptics95.pdf
Schechner R, 1993 *The Future of Ritual: Writings on Culture and Performance* (Routledge, London)
Sheridan T B, 1989, "Telerobotics" *Automatica* **25** 487 – 507
Shillito A M, Paynter K, Wall S, Wright M, 2001, " 'Tacitus' project: identifying multi-sensory perceptions in creative 3D practice for development of a haptic computing system for applied artists" *Digital Creativity* **12**(1) 195 – 204
Srinivasan M A, Basdogan C, 1997, "Haptics in virtual environments: taxonomy, research status, and challenges" *Computers and Graphics* **21** 393 – 404
Stone R, 2000, "Haptic feedback: a potted history from telepresence to virtual reality", in *Proceedings of First International Workshop on Haptic Human – Computer Interaction, Glasgow* Eds S Brewster, R Murray-Smith (Springer, Berlin) pp 1 – 7, http://www.dcs.gla.ac.uk/~stephen/workshops/haptic/papers/stone.pdf
Sudnow D, 1993 *The Ways of the Hand: The Organisation of Improvised Conduct* (MIT Press, Cambridge, MA)
Sutherland I E, 1965, "The ultimate display" *Proceedings of the International Federation of Information Processing Congress* number 2, 506 – 508
Taussig M, 1993 *Mimesis and Alterity: A Particular History of the Senses* (Routledge, London)
Thrift N, 2000, "Afterwords" *Environment and Planning D: Society and Space* **18** 213 – 255
Thrift N J, 2004, "Summoning life", in *Envisioning Human Geographies* Eds P Cloke, P Crang, M Godwin (Arnold, London) pp 81 – 103

Väätänen A, Strömberg H, Räty V-P, 2001, "Nautilus: a game played in interactive virtual space", working paper, VTT Information Technology, Tampere, http://www.vtt.fi/tte/projects/lumetila/Nautilus_GraphicsInterface2001.pdf

Yelistratov V, Strauss W, Fleischmann M, 1999, "Two approaches for intuitive navigation in virtual environments", in *Proceedings of Graphicon 99, 9th International Conference on Computer Graphics and Vision, Moscow*, http://www.bi.fraunhofer.de/publications/report/0080/Text.pdf