Haptic Force Feedback in Mediated Interaction

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Abstract

In face-to-face communication and collaboration people are used to being able to both see and hear other persons. People also take for granted the possibility to give objects to each other, to shake hands or to get someone's attention by a pat on the shoulder. However, most systems for mediated collaboration do not take physicality into account. Now emerging media space technologies like three-dimensional haptic interfaces makes it possible to interact physically in shared haptic object spaces. Many questions then arise about the effects of these modalities on communication and collaboration.

1 The sense of touch

The perception of touch is complicated in nature. The human touch system consists of various skin receptors, receptors connected to muscles and tendons, nerve fibres that transmit the touch signals to the touch centre of the brain, as well as the control system for moving the body. Different receptors are sensitive to different types of stimuli. Tactile perception is defined as perception mediated solely by variations in cutaneous stimulation (Loomis and Lederman, 1986). There are receptors sensitive to pressure, stretch of skin, location, vibration, temperature and pain. Contrary to what one might think, there does not seem to be one receptor type for sensing pressure, another for sensing vibration and so forth. Rather, the different receptors react to more than one stimulus type (Burdea, 1996). The skin on different parts of the body is differentially sensitive to touch. The ability to localise stimulation on the skin depends on the density of the receptors, which are especially dense in the hands and face. Moreover, a great deal of information provided by the kinesthetic system is used for force and motor control. The kinesthetic system enables force control and the control of body postures and motion. The kinesthetic system is closely linked with the proprioceptic system, which gives us the ability to sense the position of our body and limbs. Kinesthetic perception is defined as perception from joints and muscles, by limb movement alone, of hardness, viscosity and shape (Loomis and Lederman, 1986). Receptors (Ruffini and Pacinian corpuscles, and free nerve endings) connected to muscles and tendons provide the positional information. Haptic sensing is defined as the use of motor behaviours in combination with touch to identify objects (Appelle, 1991). In haptic perception both the cutaneous sense and kinesthesis convey significant information about distal objects and events. The haptic system unifies input from many sources, e.g., position of fingers, pressure, into a unitary experience.

Manipulation of objects can take many forms and one taxonomy illustrates how diverse functions haptics fulfils in everyday life (Lederman, and Klatzky, 1987). People use different strategies depending on the purpose of the tactile manipulation, such as investigating the weight, form, texture or softness of an object. Joint manipulation of objects can take just as many forms. One example is jointly grasping an object and moving it through an area that might have restrictions (Ruddle et al., 2002). Another example is moving an object by pushing from both sides and lifting the object together. Yet another type of joint manipulation is grasping an object and handing it to another person. In a shared haptic object-space people can coordinate joint movement of objects by signalling direction through haptic force and they can give objects to each other almost without verbal communication. Also, the bilateral (Biggs and Srinivasan, 2002) qualities of haptic perception make it possible to both move an object and to get information from it at the same time. In a collaborative situation these aspects of haptic sensing might facilitate the joint understanding of complex information or how something is constructed

2 Psychology of touch

The use of the sense of touch for understanding information in the form of texture and shape is often neglected in computer interface design because of the traditionally perceived dominance of vision for interacting with graphical objects. Touch has by a number of philosophers been seen as dominant over other senses in terms of an existence proof for objects, that is, we test reality of a mirage or illusion by trying to touch it (Heller and Schiff, 1991). Humans tend to think of touch as the "reality sense" because we know that it is relatively easy to fool vision by distorting lenses, differences in lightning and viewing conditions. Traditionally touch has been dismissed as a lower sense whereas vision and hearing are looked upon as the higher senses. Katz (1989) however, argued that touch from a perceptual viewpoint must be given precedence over all other senses because its perceptions have the most compelling character of reality. Katz argued that:

"touch plays a far greater role than do the other senses in the development of belief in the reality of the external world. What has been touched is the true reality that leads to perception; no reality pertains to the mirrored image, the mirage that applies itself to the eye."

Other senses are more ambiguous than touch and therefore touch is often used to check on reality. It is hard to imagine that we would believe what we see rather than what we feel. Most people think that an object is rather stable over time regarding its size and shape. This is probably a consequence of the fact that, even though the retinal size and shape of an object can differ due to viewing conditions, angles and distance, the touch percept is more or less stable. We think that an object has only one true size and shape and only one true surface structure. The fact that people generally perceive touch percepts to be stable becomes a very important aspect to consider when designing haptic interfaces. Because people trust the haptic perception, and are usually not used to simulated haptics, inconsistencies in the haptic simulation can have serious consequences. One problem is that people explore what they see to a larger extent than things that are invisible but haptically perceivable. This means that, if great care is taken to design a complete haptic object, but the visual graphics for example only reveal parts of the haptic model of the object, the risk is large that only the visible parts will be explored. Some haptic illusions can also surface because perceptual events that are very infrequent in the real world can be easily simulated. One example is that if two boxes with different sizes but equal weight, that seem to be of the same material, are lifted by a person, the larger object is perceived to be lighter than the smaller one. This is because in nature a larger object should be heavier than a smaller one if they are of the same material.

Gibson (1979) argues that all aspects of the world provide affordances. Ground affords support for walking, air affords breathing, water affords drinking and solid materials afford manipulation by the human body and primarily the hands. Depending on the qualities that a solid material has it affords different kinds of manipulation and different things can be manufactured, usually fabricated by hand. Gibson (1979) argued that:

"To identify the substance in such cases is to perceive what can be done with it, what it is good for, its utility; and the hands are involved"

Gibson (1979) gives a number of examples of affordances that different objects have that depend on their properties or qualities: colour, texture, composition, size, shape and features of shape, mass, elasticity, rigidity and mobility. An elongated object of moderate size affords wielding, hitting, or raking. A graspable rigid object affords throwing and an elongated elastic object affords binding or weaving. In contrast to many other psychologists Gibson thought that phenomenal (psychologically perceived) objects are not built up of easily discriminative parts or qualities but are instead perceived as integrated unified entities that afford certain behaviours. We identify an object as one whole entity, one specific thing, not as a bunch of separate qualities. Gibson (1979) argued that:

"It is never necessary to distinguish all the features of an object and, in fact it would be impossible to do so. Perception is economical. Those features of a thing are noticed which distinguish it from other things that it is not - but not all the features that distinguish it from everything that it is not"

Among researchers that study the tactile sense, the importance of movement in relation to touch perception has been recognised (Gibson, 1979; Katz, 1989). Gibson thought that movement was essential for perception, the movement of the limbs and head relative to the body and the locomotion relative to the environment. Accordingly, Gibson makes a distinction between passive and active touch. Touch is passive when the person does not move and information is imposed on the skin (Heller and Schiff, 1991). Active touch consists of self-produced movement that allows the perceiver to obtain objective information about the world. It was shown that people rely a lot on explorative movement to recognise shapes when blindfolded. In an experiment it was found that when "cookie cutter" shapes were pressed into the palm of the hand of the subject (passive touch) the shape recognition was as low as 29% whereas recognition was 95% when subjects could explore (active touch) the shape freely (Appelle, 1991). In essence it is generally argued that haptic perception is active touch as information is obtained through both tactile perception by the nerves in the skin and kinestetic perception by nerves in the muscles and joints. In the use of haptic interfaces, touch is usually active rather than passive.

Gibson (1979) argued that humans not only perceive the affordances of objects but that also the social behaviour of other beings, including animals, have affordances. Humans are dynamic and convey complex patterns of behaviour that other humans interpret as affording certain behaviours reciprocally in a continuous fashion. Humans interact with one another and behaviour affords behaviour. Nurturing behaviour, fighting behaviour, cooperative behaviour, economic behaviour, political behaviour – all depend on the perceiving of what another person affords, or sometimes the misperceiving of it. Gibson (1979) argued that:

"The perceiving of these mutual affordances is enormously complex, but nonetheless lawful, and it is based on the pickup of the information in touch, sound, odour, taste and ambient light"

Following this line of reasoning, multimodal input of information is important for an accurate understanding of another person's social affordances. In mediated interaction only a selection of a person's affordances in the real world can be conveyed to a receiver. In for example text-only communication a person can only communicate the message in text and the receiver of the message has to imagine for example emotions through the text description. Another person's voice conveys much more detailed social affordances through pitch, loudness, tempo and melody. Video conveys even more communication behaviour that hypothetically would improve social affordances but video is sometimes more unreliable than audio as the optic system can distort many of the social signals such as eye gaze, body size and distance.

Haptic feedback is taken for granted in our non-mediated interaction with others. Tactile contact with others is managed in very subtle ways because of the fundamental importance of protecting ourselves from harm at the same time as tactile contact is probably essential for well-being and survival. Gibson (1979) includes the importance of all senses for perceiving social affordances of others as well as for perceiving affordances of objects around us. Mehrabian (1972) includes touching as the most important variable in his construct "immediacy" along with interpersonal distance, forward leaning toward the addressee, eye contact and body orientation in that order of importance. Immediacy is one of the concepts that influenced Short et al. (1976) in their work on the social presence theory. However, haptic feedback is just starting to be used in interface design for interaction with graphical objects and has been used even less for mediated human interaction and joint manipulation of objects. Tactile contact in real encounters provides the most fundamental proof of something being real and believable. This is probably also true in social interaction even when the haptic interaction is very limited, as when two divers pull at each end of a rope, a buddy-line, when diving in murky waters in order to stay in contact. The tactile contact is an important aspect of social interaction but even more so might the tactile contact be that people avoid, like hitting the other on the nose. These aspects are most probably important when for example building trust between people.

3 Haptic shared virtual environments

In the real world, haptics is frequently involved in human-human interaction, like hand shaking or tapping someone on the shoulder. Handing over objects is for example a common event in face-to-face interaction. A frequent and watchful example of this occurs when being given a cup of coffee in an airplane both the flight attendant and the customer have to pay attention to subtle haptic signals to ensure that the hand off is securely accomplished. The question is how such an event can be supported when the interaction takes place in a shared virtual environment. Although not as well studied as single user interface interaction, a few authors have investigated issues regarding joint manipulation of virtual objects in a haptic collaborative virtual environment (Ishii et al., 1994; Basdogan et al., 2000; Sallnäs et al., 2000; Oakley et al. 2001; Sallnäs 2001; Hubbold, 2002; Jordan et al., 2002; Sallnäs and Zhai, 2003).

One study showed that subjects not only performed tasks significantly faster but also more precisely when manipulating objects together in a haptic compared to a nonhaptic collaborative virtual environment (Sallnäs et al., 2000; Sallnäs 2001). In this experiment tasks required that subjects lifted cubes by pushing from each side of the object in order to build different composed objects. It was found that people took significantly longer time to perform the five tasks in the visual only condition without haptic feedback than in the condition with haptic feedback (Sallnäs et al., 2000). It was also found that subjects made significantly more mistakes in performing the two tasks that required that subjects lifted cubes in the visual only than in the visual/haptic condition (Sallnäs 2001). Results also showed that when haptic force feedback was provided subjects' perceived virtual presence was significantly improved but not their social presence (Sallnäs et al., 2000) measured by questionnaires. An explanation for this could be that haptic feedback improved the feeling of realism and control and interactivity, very much in accordance with Katz (1989) who argued that the touch is the primary sense for proof of realness, but that the audio contact over the phone channel is more important for social presence than haptic feedback is. It has been repeatedly shown that providing audio communication is the most important for increasing social behaviour but that for example adding video does not make as conclusive improvements. It was also shown that people reported that they performed the tasks and the collaboration significantly better when getting haptic feedback from the objects, the context and the other person's movements.

Intuitively haptics may play a critical role when people pass objects between each other. The giver has to sense that the recipient has firmly grasped the object before releasing it. The recipient has to feel that the giver is releasing it before taking it towards oneself. It is difficult to imagine that such a task could be accomplished without haptic feedback. A study was performed in order to investigate how haptic force feedback affects people's performance when handing over objects in a collaborative virtual environment (Sallnäs and Zhai, 2003). In an experiment, subjects passed a series of cubic objects to each other and tapped them at target areas. Their performance with and without haptic force feedback was evaluated. The subjects could not communicate verbally with each other during this experiment. Furthermore, the study was placed in the framework of Fitts' law (Fitts, 1954) and it was hypothesized that object hand off constitutes a collaboratively performed Fitts' law task, with target distance to target size ratio as a fundamental performance determinant. Results showed that task completion time indeed linearly increased with Fitts' index of difficulty, both with and without force feedback. It was a little surprising that the time required for handing over objects did not differ significantly between the haptic and nonhaptic condition even though there was a large difference in favour of the haptic condition. However, the error rate was significantly lower with haptic feedback than without. Furthermore, it was found that people perceived virtual and social presence were significantly higher when collaborating in the visual/haptic condition. It was also found that haptic feedback significantly increased perceived performance when people performed a Fitts' law tapping task collaboratively.

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