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The Impact of Haptic ‘Touching’ Technology on Cultural Applications

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Abstract

New technologies from the area of virtual reality (VR) now allow computer users to use their sense of touch to feel virtual objects. Touch is a very powerful sense but it has so far been neglected in computing. State-of-the-art haptic (or force-feedback) devices allow users to feel and touch virtual objects with a high degree of realism. An artefact’s surface properties can be modelled so that someone using a haptic device could feel it as a solid, three-dimensional object with different textures, hardness or softness. These haptic devices could have a large impact on museums. For example: making very fragile objects available to scholars, allowing visitors who live far from museums to feel objects at a distance, letting visually-impaired and blind people feel exhibits that are normally behind glass, and allowing museums to show off a range of artefacts that are currently in storage due to a lack of space. This paper describes the background to haptics, some of the possibilities of haptic technology and how they might be applied to cultural applications.

Keywords

Haptics, force-feedback, human-computer interaction, museum applications, visual impairments, blindness.

Introduction

Haptic technology provides the possibility of widening access to information and artefacts held in museums. Haptic, or force-feedback, devices allow people to use their sense of touch in computer-based applications. Until recently, most computer-based simulations of objects were visual. The user might don a headset that presents a three dimensional image or look at a computer screen to see an object. There might also be some sound to improve the display. One key element that is missing is the ability to feel the object – get a sense of how heavy it is, what it is made of, or its surface texture. Haptic technologies try to solve this problem. An artefact’s surface properties can be modelled so that someone using a haptic device could feel it as a solid, three-dimensional object with different textures, hardness or softness.

There are many applications for this new technology. In this paper potential uses in cultural applications will be discussed, along with some examples of how the technology is being used in research projects at Glasgow to give some idea of what its capabilities are. To begin, some

of the main terms used in the study of haptics and our sense of touch are described, followed by an overview of the main technologies currently available.

Haptic perception

Haptics is a general term relating to the sense of touch. This is very broad and there are many component parts to the global sense of touch [11]. Not all of these parts are well understood as there has been much less psychological research into touch than into the senses of hearing or vision [8]. This section outlines some of the key aspects of touch.

The word ‘haptic’ has grown in popularity with the advent of touch in computing. The human haptic system consists of the entire sensory, motor and cognitive components of the body-brain system. It is therefore closest to the understood meaning of proprioceptive (see Table 1) [17]. Under this umbrella term, however, fall several significant distinctions. Most important of these is the division between cutaneous and kinesthetic information [15] (see Table 1). There is some overlap between these two categories; critically both can convey the sensation of contact with an object. The distinction becomes important however when we attempt to describe the technology. In brief, a haptic device provides position input like a mouse but also stimulates the sense of touch by applying output to the user in the form of forces. Tactile devices affect the skin surface by stretching it or pulling it, for example. Force feedback devices affect the finger, hand, or body position and movement. Using these definitions (summarised in Table 1), devices can be categorised and understood by the sensory system that they primarily affect.

Term	Definition
Haptic	Relating to the sense of touch.
Proprioceptive	Relating to sensory information about the state of the body (including cutaneous, kinesthetic, and vestibular sensations).
Vestibular	Pertaining to the perception of head position, acceleration, and deceleration.
Kinesthetic	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 the sensation of pressure rather than temperature or pain.
Force Feedback	Relating to the mechanical production of information sensed by the human kinesthetic system.

Table 1: Definitions of main terms used when describing haptics and the sense of touch [15].

Haptic technology

Haptic devices allow users to feel virtual objects [12]. Minsky *et al.* (in [1]) describe the technology thus: “Force display technology works by using mechanical actuators to apply forces to the user. By simulating the physics of the user’s virtual world, we can compute these forces in real-time, and then send them to the actuators so that the user feels them”. What this really means is a person using a haptic device can feel a simulation of a solid object as if it was really in front of them [16, 20].

Basic haptic devices have been used in research laboratories for some time (going back to the 1960’s for some robotic teleoperator systems [19]). However, as Stone suggests [19] “... it is only quite recently that haptic technologies have appeared that are capable of delivering

believable sensory stimuli at a reasonable cost, using human interface devices of a practical size”. It is more recently still that these devices have become commercially available and robust enough to be used by the general public. Burdea [3] provides a good review of haptic technology with details of the mechanics of most of the major devices.

The main haptic device used in research is the PHANToM from SensAble Technologies [12] (see Figure 1). This is a very high resolution, six degrees-of-freedom (DOF) device in which the user holds the end of a motor-controlled, jointed arm (with respect to haptic devices, degrees-of-freedom refers to the number of dimensions of movement. For the PHANToM this is x,y,z dimensions plus pitch, roll and yaw). It provides a programmable sense of touch that allows users to feel textures and shapes of virtual objects, modulate and deform objects with a very high degree of realism. One of the key (and most compelling) features of the PHANToM is that it can model free-floating three-dimensional objects – for example, a user of the PHANToM could feel an object such as a Roman helmet from all sides – front, back, top, bottom – just as if holding it in his/her own hand. In our classification from Table 1 it (and the Wingman device below) is a force-feedback device as it applies forces to the user and can resist his/her movements or even move the user around.

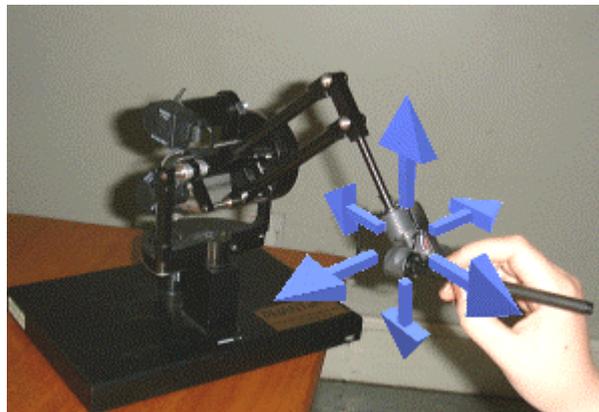


Figure 1: A PHANToM 1.0 haptic device (from SensAble Technologies, www.sensable.com) with overlaid arrows showing possible movements. The device is shown here with the user holding a stylus; a thimble attachment is also available that the user puts a finger into.

There are several alternative devices available. For example, the Wingman force-feedback mouse from Logitech is a simpler alternative to the PHANToM. It only provides 2 DOF (x and y dimensions, like a normal desktop mouse) but is much smaller and can be used as a replacement to a standard PC mouse (see Figure 2). This does not allow the exploration of free-floating objects in 3D but can allow the representation of flat surfaces and edges (as might be found on a coin, for example).

Cost haptic of devices

The most sophisticated devices can cost a large amount of money. The PHANToM in Figure 1 is generally considered one of the highest fidelity and most flexible devices on the market but costs over £20,000. This is clearly impractical for many individuals and museums to buy. On the other hand the Logitech Wingman force-feedback mouse costs only £60 and will run on a standard PC, making it a much more practical solution. There are some devices that are cheaper still: for example, the ‘rumble packs’ that can be added to computer games consoles provide only limited (1 DOF) feedback but can cost as little as £15.



Figure 2: The Logitech Wingman force-feedback mouse (www.logitech.com). It is attached to a base that replaces the mouse mat and contains the motors used to provide forces back to the user.

The prices of devices will fall in the future. There is a large demand for force-feedback controllers for games (a range of joysticks and steering wheels are currently available that allow users to feel when a gun is fired or when a car crashes). This is increasing demand and thus lowering cost. This also means that many devices are built to be robust to withstand harsh treatment in games, making them good for public displays of the type that might be found in a museum.

Some limitations of current haptic technology

Even the best haptic devices are limited in some respects. One of the main limitations is that all contact is through a single point (like a single finger or a probe). There are no whole hand devices that yet provide high fidelity force-feedback. This limits the range of applications that haptic devices are currently good for.

A further problem is that cutaneous feedback (see Table 1) is very limited in most haptic devices as they stimulate the sense of touch by applying output to the user in the form of forces and movement. Subtle surface textures are normally perceived cutaneously as tiny deformations in the surface of the skin. This is very difficult to do mechanically and most haptic devices do not do it at all. This limits the range of surface textures that can be displayed. However, it is still possible to model some surprisingly subtle things. For example, Dillon *et al.* [5] are modelling textiles using the Wingman mouse and Crossan *et al.* [4] are using the PHANToM to train students in medical examinations (see below). McGee *et al.* are trying to solve the problem by using other senses – they are investigating the use of sound to add in some of the cutaneous feedback missing from the PHANToM with another sense [13].

The use of haptic technology for cultural applications

Haptic technology is already being used in museums, but on a small scale in very specialised situations. One such is the University of Southern California's Interactive Art Museum (digimuse.usc.edu). This museum has begun to look at the use of the PHANToM device within the museum to allow visitors to feel artefacts. As McLaughlin *et al.* [14] say: "Our team believes that the 'hands-off' policies that museums must impose limit appreciation of three-dimensional objects, where full comprehension and understanding rely on the sense of

touch as well as vision. Haptic interfaces will allow fuller appreciation of three-dimensional objects without jeopardizing conservation standards”. This is one of the key reasons for using haptic technology – to improve the experience of objects and artefacts that visitors have. Just looking at exhibits, even as 3D graphical models, is limiting. If allowed, most visitors would immediately pick up an object, feel it, trace its shape and surface texture, feel its weight [11]. Just having a visual presentation misses out on much important information that can be gained by touch. Haptics allows the visual displays to be extended to make them more realistic, useful and engaging for visitors.

Four main benefits might come from the use of haptics. A number of these extend the use of graphics and 3D graphical models already used in some museums; others provide new experiences that are currently not available.

Allow rare, fragile or dangerous objects to be handled

Objects which are very fragile, rare or dangerous may not be handled by museum visitors or scholars. Visual models can be created but there are many aspects of the object that this does not capture – for example, how heavy does it feel? How rough is its surface? To solve this problem objects could be haptically modelled and then visitors or researchers could feel them using a haptic device. This means that these objects can be made available to large numbers of people.

Allow long distance visitors

There are many potential visitors to a museum who cannot get to visit. They might live far away or be immobile, for example. If objects are haptically modelled and then made available on a museum’s Website then other access methods become possible. A school could buy a haptic device so that children can continue to feel and manipulate objects after they have been for a visit. A scholar could examine the haptic aspects of an object from a university across the world. With a haptic device at home a visitor could feel and manipulate the object via the Internet.

Improve access for visually disabled people

Visually impaired and blind people often lose-out when going to museums because objects are behind glass. There are over 1 million people in the UK who are blind or partially-sighted [18]. The UK’s Disability Discrimination Act legally requires museums to provide access for people with visual disabilities [9] but this can be very difficult to do. Some museums provide special exhibits that blind people can feel. However, these exhibits are usually small and may not contain the objects that the blind visitor is interested in (there is also the problem of fragility from the point above). With haptic technologies such visitors could feel and interact with a much wider range of objects, enriching their experiences in a museum. Many normally sighted users would also enjoy the opportunity to touch museum exhibits.

Increase the number of artefacts on display

With limited amounts of space museums can only show a limited range of artefacts from their collections. If other objects that are not on show are modelled graphically and haptically then visitors could experience these on computer, without taking up museum space. With several haptic devices a museum could allow many people to feel objects at the same time, sharing the experience.

Potential problems with haptic devices in museums

One of the main problems with devices such as the PHANToM is cost. As they are so expensive it is impractical to use them on a large scale. As discussed above, prices are falling so this may not be a problem in the future. It is therefore important to investigate the use of such devices now.

Another problem is reliability and robustness. Most of the devices are fairly reliable and robust because they have been built for games or other demanding environments. We have used our PHANToM devices at University open days and careers fairs many times with lots of people using them over long periods of time and have had few problems. However, they are always supervised by an attendant. This will be costly to do in a museum for a long period of time.

Projects at Glasgow

To give an indication of some of the possibilities of haptics for cultural applications some of the research being undertaken at Glasgow will be outlined. Not all of these applications are cultural ones but they do show the capabilities of haptic devices and some of the different types of things for which they can be used.

Senses in Touch II

The Computing Science Department and Hunterian Museum at Glasgow University recently completed a haptic museum exhibit. This built on a previous exhibition held in the museum in 1998, called Senses in Touch, which allowed blind people to feel real objects from the museum. The Senses in Touch II exhibit [7] was designed to allow blind and partially-sighted museum visitors to feel virtual objects in the collection via a PC and Wingman haptic mouse (see Figure 2). It was particularly aimed at blind and partially sighted school children visiting the museum. Figure 3 shows some screen shots from the exhibit (it also contained synthesised speech to give information to blind users).

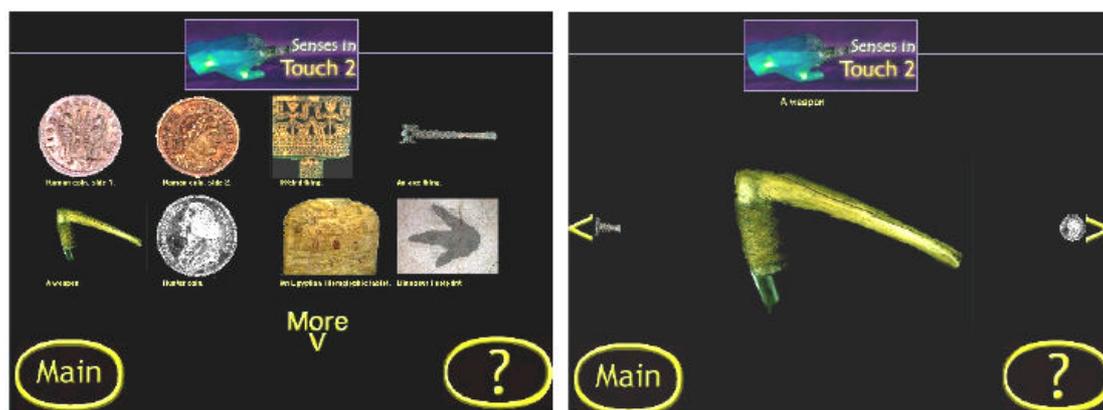


Figure 3: Screenshots from the Senses in Touch II museum exhibit. In the left image shows the menu of objects that are available to feel. The right image shows the detail of one particular object (an Adze).

Objects were chosen for the exhibit based on the nature of the Wingman mouse – it can only present objects in two dimensions. Objects such as coins, engraved Egyptian hieroglyphics and the cast of a dinosaur footprint were used as they had strong edges that could be felt, but were two-dimensional. Each object was modelled by using a greyscale image, with the

different levels of grey in the image representing areas of different heights (white = high, black = low). Crossing an edge in which the gray level increased corresponded to moving over a raised edge, and an oppositional force was applied (to the user this felt like moving over an edge). Conversely, moving between two areas in which the gray level decreased caused a force to be applied towards the lower area. This gave a good sense of a range of different heights with the mouse. This method was simplistic but worked well for certain types of objects:

- *Objects with many varied textures:* e.g. the rope work in the adze provided an interesting contrast in texture compared to the wooden handle. Likewise, a William Hunter coin provided a smooth coin background in contrast to ridged hair.
- *Objects with strong, simple edges:* e.g. the outside of the coins or the edges of an individual hieroglyphic symbol.

The exhibit was designed iteratively with input from experts and users at each stage to make sure that it was effective and usable by our target user group. In particular, there was detailed input from the Glasgow and West of Scotland Society for the Blind (GWSSB). The exhibit was put into the museum for testing for a period of several weeks and the designers conducted walkthroughs and questionnaires with visitors to assess its effectiveness. Fifty people evaluated the system and 26 questionnaires were returned. Unfortunately, over the time the evaluations took place no blind school children came to the museum, so the evaluations were conducted on sighted people (although evaluations were done with blind people at the GWSSB). The results from the evaluations showed that people in general liked the exhibit and could use it easily [7]. Children in particular found it very engaging. An interesting observation from the museum was the use of the virtual exhibits in conjunction with the real ones. The computer running the exhibit was located near a tablet of Egyptian hieroglyphics, which visitors were not allowed to touch. However, the hieroglyphics were modelled in the Senses in Touch II exhibit. The result of this was that children would look at the real hieroglyphics, go to the computer to feel the virtual version, go back to the hieroglyphics to have another look, and so on. In that situation the proximity meant that the real and virtual exhibits worked very well together. The children really wanted to know what the hieroglyphics felt like and the virtual exhibit allowed them to find out.

MultiVis – presenting graphical information in haptics

An area of research interest at Glasgow is making information accessible to blind and partially sighted people. Senses in Touch II was part of this, as is the MultiVis project. Here the aim is to provide access to visualisation techniques (such as graphs, tables and 3D plots) that are currently very hard for blind people to use. These occur in many areas of everyday life, for example from a graph showing the value of the Pound against the Dollar, to technical information used in the fields of mathematics, science and engineering. There are currently only limited methods for presenting information non-visually to blind people (mainly Braille and synthetic speech) and these do not provide an equivalent speed and ease of use to their graphical counterparts [6].

As part of the MultiVis project we have developed a system to allow line graphs and bar charts to be presented via a haptic device (in this case both the PHANTOM and Wingman mouse are being used). The lines are grooves cut into a virtual haptic surface and users can run their fingers along these to feel the shape of the line (see Figure 4). Subjects in experimental evaluations of the graphs have used them very successfully. They were easily

able to find maximum, minimum and intersection points. For tables the value in each cell is mapped to height so that a surface is created. Users can then move over the surface, easily finding high and low points.

Haptic devices used in this way allow users to interact directly with their data – to get an overview of a graph users could just run their fingers along it. This has many advantages over raised paper graphs that are used by blind people [10]. For example, our system is dynamic so that we can render a haptic scene in real-time, rather than having to wait for a raised paper graph to be printed. Our scenes can be fully three-dimensional rather than just raised lines. Users can also change the graphs themselves, e.g. by changing the value of X in the graph and seeing what effect it has, just as a sighted person might do with pen and paper. For a museum these techniques would allow information about exhibits to be presented to blind visitors more effectively. For example, a graph of geological era, showing how landscapes change over time is easily understood by a sighted person but presenting this graphical information to a blind person is very difficult. The techniques developed for MultiVis would allow it to be presented to a blind person in an effective way.

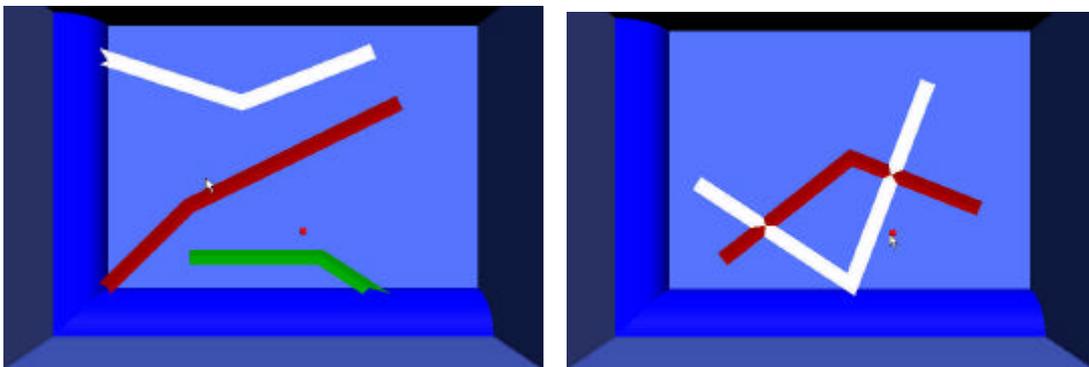


Figure 4: Screenshots from the MultiVis system showing two line graphs with multiple lines on each.

Veterinary training applications

The Department of Computing Science is working in collaboration with the School of Veterinary Medicine at Glasgow to provide a training system for vet students using haptics [4]. Medicine (in particular surgical training) was one of the first areas to adopt haptic technology [2], especially in the area of minimally-invasive surgery training. Learning how to examine and operate on humans and animals is difficult and potentially dangerous for the patients. For the Vet School using a simulator:

- Improves safety for the animals;
- Reduces cost as fewer animals need to be kept at the School;
- Allows the students more time to practice examinations;
- Provides access to rare or unusual cases that the student might not encounter during normal study.

The Horse Ovary Palpation Simulator (HOPS, see Figure 5) allows Vet students to learn how to perform ovarian palpation to assess the stage of ovulation. This is an important but difficult technique to learn. The student must learn to discriminate the different surface features on an ovary, to size them and how hard to press. With a simulator all of this can be done without danger to an animal. The system uses the PHANToM (Figure 1) and the ovaries are modelled as free-floating objects.

The HOPS system shows the subtlety that is available via haptic devices. The ovaries are soft, the surface features small and they move whilst being examined, but they can be modelled effectively so that students can learn how to perform examinations. For a museum a haptic simulator (along with a visual display) might allow visitors to try out activities that would normally be too dangerous or difficult to do, expanding the range of experiences offered.

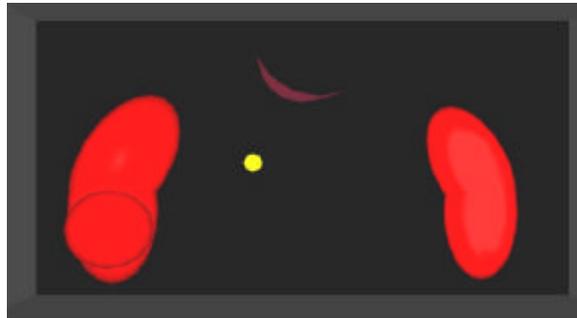


Figure 5: A screenshot from the HOPS system showing two ovaries being examined. The yellow dot in the centre is the cursor.

Conclusions

Touch plays a key role when examining objects in the real world but until recently it was not possible to use this realistically in virtual environments and computer-based displays. This has meant that some of these displays lacked realism and usefulness. Now haptic technologies are available that let museums add this missing aspect back into their computer-based exhibits. They allow the visual displays to be extended to make them more realistic, useful and engaging for visitors and scholars. This has many potential benefits for museums, for example in allowing greater access to rare and fragile objects, allowing access for people who live far away and cannot easily get the museum, improving the opportunities for blind and visually-impaired people, and increasing the number of artefacts on display. Haptic devices have a lot to offer museums and are likely to have a big impact on the quality and usefulness of computer-based exhibits.

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Author Profile

Dr Stephen Brewster is a Reader in human-computer interaction and has been in the Department of Computing Science at the University of Glasgow since October 1995. Previously, he was a Research Fellow working for the European Union. He has been working in the area of computer accessibility by blind and visually-impaired people since 1990. He received his PhD from the University of York and has over 60 publications in scientific conferences and journals.

The main theme of Brewster's research is multimodality - investigating the use of multiple senses to communicate information, and especially the use of sound and touch. One of his main research areas is the use of three dimensional sound and force-feedback to provide access to highly graphical information such as graphs, tables and 3D plots to blind and partially sighted people.

Dr Brewster leads the Multimodal Interaction Group at Glasgow. The Group focuses primarily on the use of non-speech sounds (like music and sound etc.) and haptic (or force-feedback) interaction to improve human-computer interfaces for physically disabled people and sighted, partially-sighted and blind people.

For details of our work see <http://www.dcs.gla.ac.uk/~stephen>