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Ergonomics of human-system interaction

Part 910: Framework for tactile and haptic interaction (ISO 9241-910:2011)

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Foreword

This document (EN ISO 9241-910:2011) has been prepared by Technical Committee ISO/TC 159 “Ergonomics” in collaboration with Technical Committee CEN/TC 122 “Ergonomics” the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2012, and conflicting national standards shall be withdrawn at the latest by January 2012.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 9241 consists of the following parts, under the general title *Ergonomic requirements for office work with visual display terminals (VDTs)*:

- *Part 1: General introduction*
- *Part 2: Guidance on task requirements*
- *Part 4: Keyboard requirements*
- *Part 5: Workstation layout and postural requirements*
- *Part 6: Guidance on the work environment*
- *Part 9: Requirements for non-keyboard input devices*
- *Part 11: Guidance on usability*
- *Part 12: Presentation of information*
- *Part 13: User guidance*
- *Part 14: Menu dialogues*
- *Part 15: Command dialogues*
- *Part 16: Direct manipulation dialogues*
- *Part 17: Form filling dialogues*

ISO 9241 also consists of the following parts, under the general title *Ergonomics of human-system interaction*:

- *Part 20: Accessibility guidelines for information/communication technology (ICT) equipment and services*
- *Part 100: Introduction to standards related to software ergonomics [Technical Report]*
- *Part 110: Dialogue principles*

- *Part 129: Guidance on software individualization*
- *Part 143: Forms*
- *Part 151: Guidance on World Wide Web user interfaces*
- *Part 171: Guidance on software accessibility*
- *Part 210: Human-centred design for interactive systems*
- *Part 300: Introduction to electronic visual display requirements*
- *Part 302: Terminology for electronic visual displays*
- *Part 303: Requirements for electronic visual displays*
- *Part 304: User performance test methods for electronic visual displays*
- *Part 305: Optical laboratory test methods for electronic visual displays*
- *Part 306: Field assessment methods for electronic visual displays*
- *Part 307: Analysis and compliance test methods for electronic visual displays*
- *Part 308: Surface-conduction electron-emitter displays (SED) [Technical Report]*
- *Part 309: Organic light-emitting diode (OLED) displays [Technical Report]*
- *Part 310: Visibility, aesthetics and ergonomics of pixel defects [Technical Report]*
- *Part 400: Principles and requirements for physical input devices*
- *Part 410: Design criteria for physical input devices*
- *Part 411: Evaluation methods for the design of physical input devices [Technical Specification]*
- *Part 420: Selection of physical input devices*
- *Part 910: Framework for tactile and haptic interaction*
- *Part 920: Guidance on tactile and haptic interactions*

The following parts are under preparation:

- *Part 154: Interactive voice response (IVR) applications*

Human-centred design and evaluation methods, optical characteristics of autostereoscopic displays, and requirements, analysis and compliance test methods for the reduction of photosensitive seizures are to form the subjects of future parts 230, 331 and 391.

Introduction

Tactile and haptic interactions are becoming increasingly important as candidate interaction modalities in computer systems such as special-purpose computing environments (e.g. simulation) and assistive technologies.

While considerable research exists, it involves a wide diversity of terms, meanings of terms, viewpoints, software and hardware objects, attributes and interactions. This diversity can lead to serious ergonomic difficulties for both developers and users of tactile/haptic interactions.

This part of ISO 9241 provides a common set of terms, definitions and descriptions for the various concepts central to the design and use of tactile/haptic interactions. It includes basic guidance (including references to related standards) in the design of tactile/haptic interactions. It also provides an overview of the range of tactile/haptic applications, objects, attributes and interactions.

Ergonomics of human-system interaction —

Part 910:

Framework for tactile and haptic interaction

1 Scope

This part of ISO 9241 provides a framework for understanding and communicating various aspects of tactile/haptic interaction. It defines terms, describes structures and models, and gives explanations related to the other parts of the ISO 9241 “900” subseries. It also provides guidance on how various forms of interaction can be applied to a variety of user tasks.

It is applicable to all types of interactive systems making use of tactile/haptic devices and interactions.

It does not address purely kinaesthetic interactions, such as gestures, although it might be useful for understanding such interactions.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1

haptics, noun

sensory and/or motor activity based in the skin, muscles, joints and tendons

NOTE Haptics consists of two parts: touch and kinaesthesia.

2.2

haptic, adj

appertaining to haptics

NOTE While there is no difference between *haptic* and *tactile* in most dictionary definitions, in the area of haptics, researchers and developers use *haptic* to include all haptic sensations, while *tactile* is limited to mechanical stimulation of the skin. In ISO 9241, the word *haptic* covers all touch sensations and *tactile* is used in a more specific manner. Also, both terms can be used together to assist in searches.

2.3

touch

sense based on receptors in the skin

NOTE Cutaneous receptors are used for the perception of touch.

2.4

cutaneous

belonging to the skin

NOTE Cutaneous receptors respond to mechanical stimulation and temperature changes.

2.5

tactile

appertaining to touch

2.6

vibrotactile

vibration-based stimulation of the skin

EXAMPLE A cellular phone uses vibrotactile stimulation to alert the user.

2.7

kinaesthesia, noun

sense and motor activity based in the muscles, joints and tendons

NOTE 1 Kinaesthesia includes both input and output.

NOTE 2 Receptors in the muscles, joints and tendons are used for the perception of kinaesthesia.

NOTE 3 Muscles, tendons and joints are used for motor activity.

2.8

kinaesthetic, adj

appertaining to kinaesthesia

NOTE 1 Types of kinaesthetic sensation arise from force, movement, position, displacement and joint angle.

NOTE 2 Types of kinaesthetic actions include movement, exertion of force and torque, and achievement of position, displacement and joint angle.

NOTE 3 *Proprioception* refers to the sense of one's own body position and movement. This term is often used interchangeably with kinaesthesia, although the latter is concerned more with motion. The sense of balance, for example, might fall more under proprioception than kinaesthesia.

2.9

force feedback

force presented to and detected by a user

NOTE Although this does not necessarily involve *feedback*, the term "force feedback" is commonly used in this context.

2.10

perceptual illusion

perception that does not correspond to a physical measurement of the stimulus source

2.11

sensory adaptation

change over time in the responsiveness of the sensory system to a constant stimulus

2.12

(tactile/haptic) spatial masking

effect that occurs when a distracter stimulus, which is close to the target stimulus, degrades the perception of the target

2.13

(tactile/haptic) temporal masking

effect that occurs when a distracter stimulus, which is presented immediately preceding or following a target stimulus, degrades the perception of the target

2.14

tactile/haptic object

component of an interactive system that a user can interact with haptically

2.15

(tactile/haptic) user interface element

entity of a user interface that is presented in a tactile/haptic form

2.16

(tactile/haptic) task primitive

fundamental action of a user for carrying out the tasks for which the device is designed

2.17

tactile label

label of a user interface element that is presented in the tactile/haptic modality

2.18

tactile map

map that is presented in the tactile/haptic modality with input functions

NOTE 1 The input functions include finger touching, lifting off, or moving across the map for producing position and selection.

NOTE 2 Tactile maps are often used to help blind people navigate.

2.19

stiffness

hardness

elasticity

haptic response to interactions involving force normal to a virtual object's surface

NOTE 1 "Stiffness" is often known as "hardness" when applied to rigid material.

NOTE 2 "Stiffness" is often known as "elasticity" when applied to soft material.

NOTE 3 *Maximum stiffness* is the highest equivalent spring constant of a virtual surface that can be provided by the device without instability.

2.20

burst

intentionally short tactile/haptic stimulation

NOTE A burst typically lasts between 10 ms and 1 s.

2.21

probe

object in a virtual space that is under the control of a tactile/haptic device

2.22

spatial resolution

degree to which the physical output from a user can be utilized by the device

2.23

addressability

ability to address a specific point or set of points in a workspace

3 Introduction to haptics

The science of haptics and the creation of tactile/haptic devices depend on knowledge of the human body, especially on its capability to sense both touch to the skin and kinaesthetic activity in the limbs and body joints.

Figure 1 shows the relationship between the components that make up the field of haptics. The field is divided between the study of touch and the study of kinaesthesia.

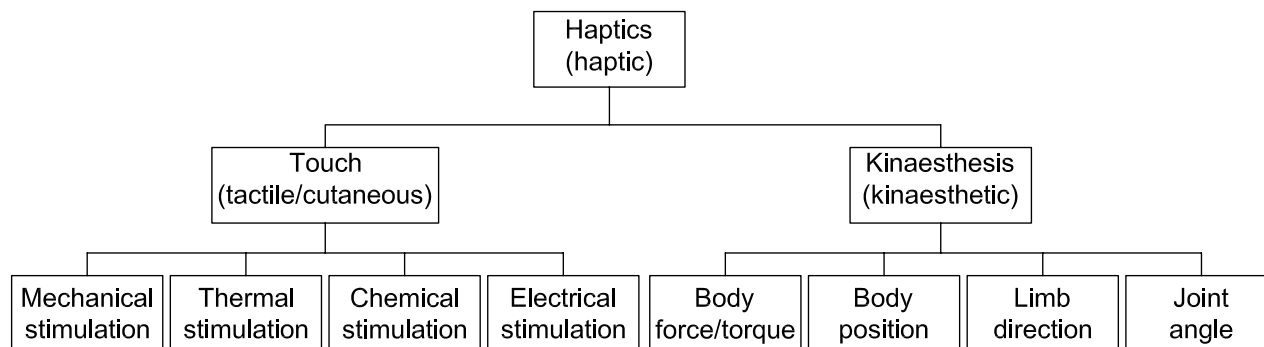


Figure 1 — The components of haptics

“Touch” includes such diverse stimuli as mechanical, thermal, chemical and electrical stimulation to the skin. Specific nerves and sensing organs in the skin respond to these stimuli with different spatial and temporal resolutions.

The *kinaesthetic* sense can be matched by kinaesthetic activity by which a user exerts force or torque on an object external to the active body part. With the combination of kinaesthetic sensing and kinaesthetic activity, the user can detect the force and torque with which the body resists the force and torque of a tactile/haptic device. Likewise, by imposing a measured force and torque on an object, the user can determine macro properties such as its inertia.

Kinaesthesia is thereby bi-directional, both sensing the environment and actively manipulating it in a two-way exchange of information and action.

NOTE 1 Active touch involves kinaesthesia, passive touch does not. Active and passive touch are often very useful concepts by which to distinguish interactions. In interactions, it is not always possible to identify the two concepts with particular devices. Depending on the task, one form of touch might be superior to another.

NOTE 2 Interaction with tactile/haptic devices might use different combinations of these haptic components at multiple points of contact.

NOTE 3 See Annex C for the details of the physiology of human haptics.

4 Human haptic exploration

4.1 Importance of the haptic sense

Haptics is of great importance for human life, much more so than is generally recognized. For instance, when you are searching for an object in your pocket or bag without the help of vision, haptics is engaged. When you identify the object you wanted, grasp it with suitable force and take it out, your actions are based on haptics. This sense can identify common objects quite efficiently, with near perfect discrimination within a few seconds, especially when the observer has some expectation about the options.

By palpating the surface of a body, a physician can obtain information about the conditions of organs under the skin and fat layers, conditions that cannot be perceived visually.

The haptic sense can also allow remote touching, as when a distant object is probed with a tool. For example, a visually impaired person may use a cane to perceive the properties of the ground at the tip of the cane.

The hands, in particular, have had an enormous importance in the biological and cultural development of human beings in their contact with the environment. They are at the same time useful for both perception and action in a continuous interaction with the environment. A hand has an impressive ability to adapt to many different kinds of manipulation tasks, from very small ones requiring high precision to large ones where large forces are needed. The actions are at all times guided by haptic feedback.

However, haptics within computer applications is new compared to visual and auditory interactions and is still relatively limited. Present-day tactile/haptic devices still need much development before they can fully utilize the capacity of the haptic sense.

Touch is also often used to confirm information we gain about the reality of the world.

4.2 Haptics and vision

4.2.1 Similarities and differences between haptics and vision

Haptics has many properties in common with vision. It can be used to locate objects in relation to the observer in near space (but only within arm's reach unless a tool is used), to find edges separating surfaces and to perceive the size and form of objects (that are not too large to be explored by a person). In perceiving texture, haptics not only matches vision but is, in many conditions, superior to it.

In some tasks, haptics lags considerably behind vision or cannot perform the task at all. For example, it is unable to be used to get an overview of a scene, perceive 3D space beyond arm's reach, perceive colours, or perceive edges in a 2D picture without embossment.

In other tasks, haptics is superior to vision. With haptics, we can directly judge the weight of objects, as well as their hardness and temperature. Vision can to some extent perceive such object properties, but only by observing another person's actions.

4.2.2 Co-location of visual and haptic space

In the real world, objects are usually perceived to occupy the same location visually and tactually but, in virtual worlds, this is not necessarily the case. The visual object can be located on a screen, while the haptic object has another location — presented on a tactile/haptic device by the side of the keyboard, for example. Advantages of co-location have been shown for object targeting and for perception of form. Informally, it has also been found that performing tasks such as finding knobs and regaining contact with lost virtual objects was facilitated under co-location conditions.

Combining the visual and haptic modalities can enrich a user's perception of a scene. The visual sense might dominate at first, allowing a quick overview of a scene and identification of objects in the scene. But a tactile display can allow a more rapid judgment of the texture of an object. The relative distances of objects can be

perceived haptically within personal space, reinforcing visual judgment of the distances. Then object properties such as mass and deformability can be confirmed only through the haptic sense.

EXAMPLE A pianist, when sight-reading music, relies on haptics to locate the position of the notes on the keyboard, but, while playing from memory, utilizes visual and haptic modalities together, making the performance more relaxed and thus enriching it.

4.2.3 Implications for haptic displays

The differences between vision and haptics make it hazardous to simply render copies of visual objects in order to present them haptically. Such copying might succeed in simple cases, but problems will often occur in more complex ones. It is important that the creation of effective haptic scenes involves the haptic consideration of their properties. An effective visual rendering of a scene is no guarantee that the same scene can be successfully rendered in a haptic sense.

Advantage can be taken of the ability of the body to quickly coordinate cross-modal maps of its environment. Both visual and tactile senses can work together to allow a more rapid location of a stimulus than is possible with either modality alone.

Other prediction experiments have shown that dynamic tactile information can be used to reorient visual attention, and that dynamic visual information can be used to accurately reorient tactile information.

4.3 Manual exploration of objects

The movements of an observer during haptic exploration of the environment are typically not random, but are specifically directed to acquire desired information. These movement patterns, called exploratory procedures, consist of a number of basic procedures such as

- a) lateral motion for perceiving texture,
- b) pressure for perceiving hardness,
- c) unsupported holding for perceiving weight,
- d) enclosure (enclosing an object in a hand or both hands) for perceiving global shape and volume, and
- e) contour-following for perceiving global shape and exact shape.

Tactile/haptic devices might limit the exploratory procedures that are available to a user, significantly decreasing exploratory performance. Special training in the movements useful for specific displays can partially compensate for this lack.

4.4 Training in exploratory procedures

Texture is less of a problem for the perception of objects than is shape. This might be because the exploratory procedure for texture is much simpler than that for shape. When exploring for texture, the user might make arbitrary movements over the object's surface, while exploring for shape requires quite specific movements. However, training in appropriate exploratory procedures for a given shape can result in much better performance. This is important to consider when evaluating haptic displays, as there is a risk of under-estimating the usefulness of a device if the users have insufficient experience with the device.

4.5 The problem of getting an overview of a scene with haptics

One of the most difficult problems with haptics in many practical contexts is gaining an overview of a scene. In vision, this overview is carried out almost instantaneously. There are situations where a “haptic glance” (short contact with the object) can provide something of the same quality as vision, especially when the observer has hypotheses about the object in question. However, it is usually a laborious and time-consuming task to identify objects in more complex conditions using haptics alone. It is often useful to enhance haptics with auditory or visual information. For instance, there could be verbal or textual information about the object, or instructions about how to explore the scene.

4.6 Minimum physical stimulation: absolute thresholds

Haptic perception is based on many kinds of sensors in the skin, as well as in the muscles, tendons and joints. A minimum of physical stimulation, called *absolute threshold*, is needed to get the sensors to react and send messages providing experience for the observer. Many physical events can stimulate the skin, from a light brush stroke to pressure from points, edges, corners and curvature. They might cause skin motion, skin stretch or vibration, and require different amounts of energy to be perceived. The spatial acuity of the skin has been found to be around 1 mm. In general, the hand is not as good in spatial discrimination as the eye but is better than the ear. With regards to temporal discrimination, the hand is better than the eye, but poorer at it than the ear.

The skin is a large sense organ and its different parts vary in sensitivity. The fingertips are among the most sensitive parts and best suited to exploring the environment. The lips and the mouth are also very sensitive. This particular sensitivity has recently been utilized by the development of a tactile/haptic device that is to be placed in the mouth. Less sensitive parts of the body, such as the stomach and back, have also been used as locations for tactile/haptic devices, but spatial resolution in these locations is much lower than in the hands and mouth.

It is important to consider the age of potential users of tactile/haptic devices, since there is a considerable decline in haptic sensitivity with age.

4.7 Minimum differences needed for perception

A minimum of physical difference between two stimulations is necessary for an observer to experience the difference. This is called the difference threshold or “just noticeable difference” (JND).

EXAMPLE 1 In discerning the difference in the direction of two forces, the difference is at least 33° in order for the difference to be detected.

EXAMPLE 2 In comparing objects by squeezing them, the resistance force in one is about 7 % larger than in the other in order for the difference to be detected.

4.8 Perception of geometric properties of objects

Object properties can be divided into geometric and material properties. Size and shape are geometric properties commonly used for the identification of objects. In the real world, the exploratory procedures of enclosure and contour-following are used to gain this information. These procedures are not always possible with current haptic displays. Perception of shape is possible with such displays but is less efficient and more time-consuming than in the real world. One key reason for this is that most tactile/haptic devices offer a single point of contact.

4.9 Perception of weight

Haptic perception of weight has been studied since the nineteenth century. Such studies recently took a new direction in considering how people judge weight on the basis of wielding the object to be judged. The stimulation in this case is the resistance to the rotational torque picked up by the haptic system. Properties such as the length of a rod or the form of an object can be judged by wielding the rod or object. The amount of liquid in an opaque container can be judged by haptics alone when the container is shaken.

4.10 Perception of material properties

An object's surface can have many material properties. It can vary from hard to soft, as well as from smooth to rough. The latter property is called *texture*, and depends on the microstructure of the surface — regular or irregular deviations from complete evenness. Microstructure can be contrasted with macrostructure that gives shape. Soft/hard and smooth/rough are the two main perceptual dimensions of haptically perceived objects. Another is sticky/slippery, based on the degree of resistance a surface makes to movements along it. There have been efforts to render thermal properties, but they have so far not been very successful.

In the real world there are complex interactions between the haptic, visual and auditory senses when texture is perceived. Sometimes they complement each other, sometimes they are in conflict, and one can dominate the others. The combined effects of all three aspects have to be taken into account when multisensory rendering is being considered.

Texture is typically perceived when a textured surface is in direct contact with a rubbing finger. But texture can also be perceived in other ways, such as by means of a hand tool — a rigid link between skin and surface. This method can be useful in virtual environments for rendering texture.

In contrast to shape, virtual surface properties are relatively easy to judge by haptics in both real and virtual worlds. In an experiment where the roughness of both real and virtual sandpaper was explored with a stylus, the judgements were very similar. However, there are sometimes problems with rendering complex, realistic haptic textures.

4.11 Number and size of contact surfaces in tactile/haptic devices

When a hand is functioning naturally, there are several contact surfaces, with the tips of several fingers typically on a surface at one time. In many present-day haptic displays, the number of contacts is low and, in most cases, it is just one. The virtual contact surface itself is also, except in a few devices, represented by only a single point. This gives a contact analogue, but not a realistic simulation.

When only one contact area is used, it is not possible to get simultaneous information from several contact areas; only successive information is available.

The use of only one finger means that enclosure cannot be used.

NOTE Enclosure is an important exploratory procedure for perceiving global shape in which several fingers grasp an object.

Results from perceptual studies have shown that the lack of spatially-distributed information across the contact points is more important than the actual number of contact points.

4.12 Summary

Even if the haptic sense cannot provide an immediate overview of a space and cannot cover distances out of arm's reach, it has great efficiency in providing information about objects and events in near space. The hands can very competently perform many tasks in real environments. They can judge geometric and material surface properties by specific exploratory procedures. They can determine weight and form by wielding the object and feeling its translational and rotational inertia (as in ascertaining the amount of fluid in a shaken container).

When rendering objects and events for haptic perception, it is important to consider the special properties of the haptic senses. Devices and software currently available provide good analogue clues that allow the partial rendering of haptic scenes. On the other hand, they limit the ways in which the user can perceive a scene by haptic means. Future devices might well make use of more of the haptic sensing modalities available to the human operator.

5 When to use tactile/haptic interactions

5.1 General

Tactile and haptic devices can be used in many different situations and for many different tasks. For some tasks they are interchangeable, for some they can be used together and for others the nature of the particular type of feedback means that one type is most effective.

Due to their compact size and power requirements, tactile displays offer a discrete, affordable means of providing access to data via the sense of touch. Tactile displays are often small enough to be mounted on other interaction devices such as a mouse, keyboard or games controller, or portable devices such as mobile telephones and personal digital assistants (or even on tactile/haptic devices providing force feedback). Tactile information is widely used within the video gaming community as an inexpensive means of providing touch feedback in handheld games controllers. Tactile sensations are crucial to success in object manipulation, edge detection and texture perception. They are also implicated in more expressive and qualitative contexts such as non-visual communication (e.g. a tap on the shoulder or a caress on the hand), and perceptions of product quality.

Tactile/haptic devices providing force feedback are typically much larger than purely tactile ones and require more power to exert stronger forces. Therefore, they are not usually mobile. They are more commonly focused on simulating real world tasks, e.g. work on surgery simulation and training. Their high fidelity and accuracy means that they can be used to teach subtle touch-based skills, even when these require the simulation of very heavy or dynamic objects.

In some respects it is easier to simulate the larger forces required to interact with objects kinaesthetically rather than the smaller cutaneous ones for tactile feedback, so devices that provide force feedback can often make more-realistic-feeling objects than tactile ones can. The following sections outline some of the major areas of use of tactile and force feedback displays.

5.2 Accessibility

Haptic displays can offer an alternative channel through which to present information if other senses are impaired. The traditional use of encodings such as Braille is effective at presenting textual information non-visually, but touch can also be used to present, or enhance, iconic and pictorial data for those whose sight is limited. Alternatively, for someone with hearing problems, touch can be used to present alarms or other messages that might otherwise be given in sound. The process of sensory substitution involves the sensing of stimuli by electronic means, transformation of the stimulus via signal processing and presentation of the transformed stimulus in another sensory modality.

Dynamic, refreshable Braille displays offer flexibility and independence. These can be applied to mobile tactile/haptic devices such as tactile/haptic feedback keypads/keyboards and information display devices for the blind. The most commonly used tactile displays evoke sensations using mechanical perturbations of the skin. This is commonly done by vibrating a small plate pressed against the skin, or via a pin or an array of pins on the fingertip. There are systems which give visually impaired people access to virtual maps via the Web that are based on the printing of maps on a Braille printer and placement on a touch tablet for input.

Tactile/haptic devices can be used to present information to people with visual impairments that make access to material such as graphs, charts or tables difficult. Braille is good for presenting textual information but not good for complex images. Visualization systems, such as line graphs or bar-charts, can be presented as grooves that allow users to explore them to feel the shape of their data. These are very successful and they can present information more effectively than raised paper alternatives, can be dynamic where paper cannot be changed, and can allow users to manipulate and change data themselves, without the need for a sighted helper.

5.3 Desktop interactions

Haptic feedback can be used in graphical user interfaces for desktop computers, e.g. using a vibrating mouse. While the effect of vibration on the acquisition of single targets might not significantly reduce targeting time, it can reduce the time the user spends over the target. The addition of tactile feedback (e.g. in the form of a constant 200 Hz vibration when the mouse is over a target) can improve targeting speed for small, discretely located targets. However, when multiple targets are present, tactile feedback can cause confusion and reduce performance as the feedback from different targets interferes with one another.

Force feedback can be used to aid in the targeting of objects on the desktop graphical user interface for those with and without sight. Different parts of the standard interface can be given haptic effects, e.g. window borders can be given ridges to make them easier to drag, or windows can be dragged by pressing down hard on them, as if sliding paper across a desk.

5.4 Mobile interactions

Tactile feedback is very effectively used by mobile telephones and pagers. Vibration motors provide notification for incoming calls and messages. The fact that the device can be in a pocket means that visual displays need not be seen. The wide range of auditory environments that the phone can be in means that sometimes sound feedback is inappropriate (e.g. in a library, the ringing sound would be disturbing; in a noisy crowd, it might not be heard at all). Tactile feedback solves many of these problems and is very popular with users.

The use of vibrations can be extended beyond simple alerts and alarms on a phone. Touchscreen phones are now common and have no physical keyboard. Although the keyboards used on touchscreen devices are based on the original physical mobile keyboards, one important feature is lost: the buttons cannot provide the tactile response that physical buttons can when touched or clicked. This results in much poorer typing performance. With the addition of extra tactile feedback, delivered by the internal vibration motor in the phone, performance in pressing the touchscreen buttons can be returned to the level of a real, physical keyboard.

Tactile progress indicators can use tactile pulses to indicate the amount of a task (such as the loading of a web page or the downloading of photos) that is remaining so that the user can look at something else whilst waiting. “Haptic emoticons” can be used to express emotions instead of graphical emoticons such as “☺”. These haptic icons can be designed to be triggered by typing the textual equivalent and can then be sent to the vibration motor on the phone.

Tactile feedback can be used to give direction information. A wearable tactile vest can display navigation information, including information on direction, rotation, speed and acceleration. The stimulation of a single actuator at the appropriate location can indicate direction, while a movement across several actuators can signal rotation. Changing the frequency, intensity or duration of the vibrations can indicate an increase/decrease in speed or acceleration. The accuracy of such a display is in the order of 10° — more than sufficient to navigate a helicopter or boat along a predefined route. Tactile feedback can be used in cars for lane departure warnings and other potentially dangerous events. Drivers often respond more rapidly to tactile alerts than to audio or visual ones.

5.5 Robotics

Telerobotics, or human-directed robotics, is an established application area for tactile/haptic devices. Systems can allow an operator to handle radioactive material in a nuclear “hot box”. The operator can look through protective glass while handling liquids in vials and using forceps, all the while manipulating handle grips on arms slung from the ceiling.

Electromechanical tactile/haptic devices can be used as part of control stations to drive robots. Adaptation of full tactile/haptic device feedback in this field is limited by the possibility of instability. Such instability can cause the robot to vibrate, damaging items in its workspace. Precautions are taken to ensure the safety of any robot system driven by a device that provides force feedback. These can include a contact sensor that detects an operator's grip on the handle of the tactile/haptic device: if the operator lets go of the handle, the robot will stop its activity and go into a safe mode.

Robot-like manipulators are under the control of operators in different fields. A crane in a construction site can be driven by an operator manoeuvring a joystick on a tool worn about the waist. Bomb disposal robots, robotic arms in space and undersea manipulators allow action at a distance in dangerous or hostile environments. In each of these examples, the control tends to be a set of wheels or levers matched to Cartesian coordinates, or even joint coordinates.

Active tactile/haptic devices can be used in conjunction with minimally invasive surgery. Such systems give valuable feedback to the operator on the location of tissues and their characteristics. They can also provide guidance in the form of “virtual fixtures”, haptic pathways that guide the device to a target position under control of the operator, or prevent the device from going into an area that has been declared “off limits”.

Unique issues come from applications of remote operation with long time delays, e.g. “handshakes across the Atlantic”. Such simple applications can involve haptic loop operation without instability. Another example involves long-distance palpation of tissue, or needle insertion with the doctor in one continent and the patient in another.

On a smaller scale, tactile/haptic devices can be used with scanning probe microscopes to “feel” the atoms composing the surface of a crystal.

5.6 Medical

Virtual-reality-based tools in medical training have become common. Simulators allow students to practise skills before trying them on real patients. They can also practise procedures that are uncommon, and this has many safety benefits. Experts can also plan and rehearse particularly complex tasks before they begin practising on a patient. Simulators that only provide visual feedback miss many of the most important parts of performing an examination or surgical procedure and haptics can be used to allow touch-based skills to be learned in a safe way.

Minimally-invasive surgery (MIS), which is a very difficult skill to learn, can greatly benefit from haptics. Long, flexible tools are inserted through small incisions in the patient. Surgeons see what they are doing via small video cameras inserted along with the tools. The tools reduce the feeling that the surgeons get from open surgery, but touch is critical in identifying otherwise obscure tissue planes, blood vessels, abnormalities and gauging optimal forces to be applied for tissue manipulation. Coupling MIS tools to tactile/haptic devices and complex graphical models means that training can be given in a very realistic way. Surgeons can learn how to manipulate the tools without causing damage, the types of forces to be applied and the sensorimotor skills needed. Recordings can also be made of their virtual surgery that can then be played back for later analysis. All this can be done without any harm coming to patients during the learning process.

In the veterinary domain, researchers have developed simulators for teaching palpation and pregnancy diagnosis in horses and cows using force feedback. In these species, pregnancy diagnosis is an internal examination done purely through touch. It is difficult for students to learn and for teachers to teach; students cannot see what they are doing and teachers cannot easily tell if a student is performing the technique correctly. A mistake can have serious consequences for an animal. The simulators allow students to feel the animal's ovaries to learn what to feel for and how hard to press. They also allow the students to learn key landmarks within the animal so that they can find the correct locations to palpate.

Haptics has also been used for the patients themselves. Tactile/haptic devices can help people relearn control and movements after a stroke. The tactile/haptic device can initially help patients relearn by applying drag to an arm, e.g. to help the patient regain control and accuracy in movements. As the patient gets stronger, the device can offer increasing resistance, so that muscle strength can also be regained.

5.7 Gaming

Haptic interaction technology is widely used in game application interfaces. The mass marketing of games has led to a mass market for various types of tactile/haptic devices, many of which can be used for applications other than games. Haptic interaction technology is finding its way into games played with a computer. Whether games of chance or virtual adventure games, the sense of touch adds a new dimension of realism to the experience.