Haptic and Tactile Feedback in Directed Movements

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ABSTRACT
Directed movements with a user's arms and hands are the basis of many types of human-computer interaction. Several previous research projects have proposed or studied the idea of haptic and tactile feedback in directed movement-based interaction with computer systems. In this paper we collect and review existing recommendations for haptic feedback in both single-user and collaborative situations, and derive a design space for haptics in this area.

Categories and Subject Descriptors
H.5 [**Information Interfaces And Presentation**]: H.5.2 User Interfaces: Haptic I/O.

General Terms
Performance, Design, Experimentation, Human Factors.

Keywords
Haptic and tactile feedback, tangible computing, directed movement, target acquisition, handoff.

1. INTRODUCTION
Current mouse-and-windows interfaces involve several types of low-level actions that involve the mouse pointer. These directed movements have to date used only visual means to assist the user in the completion of the movement. However, other modes of feedback are possible: in particular, tactile and audio feedback.

Previous research has shown that extra-visual feedback is useful in some circumstances, but for normally-sighted users in normal viewing conditions, the benefits are not large. Therefore, designers should consider the user, the situation, and the task carefully before deciding to use additional feedback. In this paper, we gather a set of possible guidelines from our own and others' previous experience with haptic and tactile feedback.

Before stating the guidelines, we summarize basic issues in the design space for extra-visual feedback, including definitions for haptic and tactile feedback, the basics of directed movement, and a discussion of the idea of interaction bandwidth.

2. BACKGROUND
There are several different types of feedback that are possible in the domain of haptic and tactile computing. In this paper, we will use *tactile feedback* to refer to information that can be interpreted by the skin's sense of touch (e.g., texture, vibration, and pressure); *force feedback* to refer to information that is interpreted by larger-scale body senses (muscular, skeletal, and proprioceptive senses); and *tangible media* to refer to the use of real-world objects in a computational setting. Tangible computing brings in many types of tactile feedback as part of the real-world nature of the object, but in most cases force feedback is not part of these objects.

2.1 Directed Movement
Directed movements in window-and-pointer systems are those where the user carries out some action using the spatial location of the pointer. There are two main types of directed movement: targeting, and steering; in addition, we also discuss handoff, a composite type of motion seen in shared environments.

2.1.1 Targeting
Targeting is the act of moving the pointer to a particular location on the screen. Many direct manipulation actions in graphical interfaces begin with a targeting task, such as pressing a button or dragging a file to a folder icon, all begin with the same user action of moving and positioning the mouse pointer. When the pointing device in the interface has an on-screen pointer (as opposed to a touchscreen or a light pen), we can divide targeting into three distinct stages: *locating*, *moving*, and *acquiring*. Locating is the act of finding the mouse pointer on the computer screen when its position is unknown. Moving is the act of bringing the pointer to the general vicinity of the target, and requires the user to track the pointer as it travels across the screen. Acquiring is the final stage, and is the act of precisely setting the pointer over the target and determining that the pointer is correctly positioned.

Targeting performance is governed by Fitts' Law, which determines a relationship between targeting difficulty and the size of a target and its distance from the starting point (Mackenzie 1992). The way that a user carries out the directed motion in a targeting action is similarly governed by principles of human motor control. Targeting motions are usually a series of submovements of decreasing size: the first movement is large and fast, and subsequent motions (as the pointer nears the target) are smaller.

The details of this kinematic process are summarized by McGuffin and Balakrishnan (2002): the movement involves "an initial, open-loop, ballistic impulse; followed by a corrective, closed-loop, 'current control' phase; [these] later, corrective submovements are performed under closed-loop control." McGuffin and Balakrishnan showed that people are able to make use of sensory input (visual) during these late-stage open-loop motions, suggesting also that other forms of feedback, such as tactile information, may also be of use.

Targeting motions are slightly simpler in absolute-positioning environments, either those that use pointing devices such as touch screens, or environments that use tangible blocks as the work artifacts, and thus allow real direct manipulation by the user's arms and hands. In absolute environments, locating is less of a problem, and the user needs only to move their hand directly to the target. Although the same kinematic process occurs, people are generally faster and more accurate with their hands than they are with a relative positioning devices such as a mouse.

When considering tactile exploration in the absence of a visual channel, Fitts' law no longer accurately predicts the targeting task. Unlike the visual task, the user must identify any intermediate objects encountered during the approach to the target. These objects must be internalized by the user and serve as landmarks in the search process, indicating the relative distance from the starting position and to the final target. Due to the time required to digest this information, a linear model such as that proposed by Friedlander et al. (1991) better characterizes the targeting task under these conditions.

2.1.2 Steering.

Steering, like targeting, is a basic component of many interactive tasks in 2D workspaces. Steering is integral to tracing, drawing, freehand selecting, gesturing, navigating menus, and pursuit tracking. The mechanics of 2D steering have been studied extensively by Accot and Zhai (e.g., 1999, 2000, 2004), who showed that performance can be predicted by an extension to Fitts' Law called the Steering Law. The Steering Law relates completion time to two factors: the length and width of the path. The steering law has been shown to accurately predict completion time over several path types, input devices, and task scales.

Where there are three stages to targeting, there is really only one stage in a steering motion: the user moves their pointer along the path, making sure that they do not stray outside the boundaries. The kinematics of steering tasks are similar to those of targeting, but the user spends almost all of their time in closed-loop motion, where they are continuously evaluating whether the pointer is still within the path boundaries.

2.1.3 Handoff

Object transfer is one of the low-level actions that allows people to carry out a shared task as a group (Pinelle *et al.*, 2003). Handoffs occur for two reasons: first, because people cannot reach all parts of the workspace, and it is easier to divide the task of reaching an object than it is to walk around the table; and second, because when a space is divided into territories (Scott *et al.*, 2004), it is often more polite to ask for an object from another person's work area than it is to reach in and take it yourself.

Handoff can be characterized as a multi-person target acquisition task. The first person brings the object or tool towards the second person, and holds it in position until the second person grabs it. The second person then moves the object to a target region somewhere in their work area. The target for the first person, however, is variable, and may change based on the table or the activities of the receiver.

2.2 Types of Feedback

Based on two main types of feedback (tactile and force), two types of directed motion (targeting and steering), and three possible stages of motion (locating, moving, acquiring), we can set out a number of possible types of feedback.

Feedback Description	Type of Motion	Type of Haptic Feedback
Pointer crosses target boundary	Acquisition	Tactile
Pointer crosses path boundary	Steering	Tactile
Feedback mapped to screen areas	Location	Tactile gradient
Texture trail	Motion	Tactile
Gravity wells	Acquisition	Force
Gravity paths	Steering	Force
Use of tangible blocks for targeting	Location, Motion, Acquisition	Tactile

Table 1. Types of tactile and force feedback in various forms of directed motion.

2.3 Interaction Bandwidth

Haptic, tactile and tangible information constitute a very interesting alternative to the visual and auditory channels. Although most of the human perceptual channels are interrelated, the touch channel is perceived by humans as an independent source of input, just as sound is clearly distinguished from vision. This leads us to think that using the touch channel could help us reduce clutter in either the visual or auditory spaces, allowing for an increased number of simultaneous distinguishable signals to be perceived by the user.

However, the tactile channel's particularities should be taken into account when designing interaction. For example, although tactile feedback is readily perceived by humans without much delay, it is not able to communicate large numbers of different symbols or many fast changes (i.e., the bandwidth of the haptic channel is low). This will restrict the use of haptic, tactile and tangible feedback to represent variables that do not change rapidly and that do not have many different states. Besides, tactile and haptic signals can potentially interfere with muscular and proprioceptive functions associated with control, resulting in undesired side effects. A clear example of this is using vibratory cues in a mouse that could affect accuracy in pointing and selecting tasks. The signals should be thus placed and designed with care not to hinder other aspects of interaction.

In the field of direct manipulation interaction techniques, the use of haptic, tactile and tangible feedback provides a very valuable alternative means to give information to the user when the primary perceptive spaces (visual and auditory) are already cluttered or when the visual and auditory spaces cannot be used at all.

A very simple example is the signaling of mode changes or state in interaction techniques with several modes or in systems that use potentially overlapping interaction techniques. A good representative of this is using haptic feedback to indicate mode in pen-based tabletPCs (Li *et al*., 2005). When using pen-based devices there are two main modes of interaction with the pen: electronic ink and commands. The transition between those two is problematic, among others, because it is difficult for the user to know in which mode they are, issuing commands to the system (e.g., cut, copy, paste, go to the top, scroll) or drawing content (i.e., electronic ink). Using visual information to tell the user the current mode by, for example, changing the properties of the strokes of the pen, will interfere with the graphical nature of drawing tasks. If, instead, we provide a feel of different surfaces for each mode, the user will instinctively know if she changed the mode correctly or not, and it could prevent errors.

Another set of situations in which touch-based feedback could be invaluable are those where attention has to be split into several loci. For example, when driving a car, we can perceive haptic information about the steering of the car (or any other) while remaining attentive to possible hazards in the roadway. In a similar way, we can use haptic or tactile feedback when it is not possible to provide coherent visual feedback. For example, in a multi-display system, tactile information can be used to tell the user if the cursor is in a visible position or not.

3. PROPOSED GUIDELINES

Based on an analysis of previous work, and our own experiences and experiments, we propose several guidelines that can be used to aid the design of haptic and tactile feedback for directed movements. We organize the guidelines into three groups, following the three types of directed movement introduced above; in addition, we include a general category where guidelines apply to more than one type of motion.

3.1 General

1. *Haptic and tactile feedback are best used to inform about narrow bandwidth signals.*

The nature of the human touch perceptive system makes it difficult and/or annoying to convey large amounts of information through the touch channel, however, touch signals are very salient and have the potential to very easily draw attention. Haptic and tactile signals should thus be used mainly to represent variables that don't change very often, but that require attention.

2. *Tactile feedback is of particular use in visually stressed conditions or for visually impaired users.*

When the bandwidth of the visual channel is reduced, the value of having another channel is increased. For users with visual impairments, tactile and other forms of non-visual feedback should be effective in many more cases than for normally-sighted users; similarly, tactile feedback should be effective in difficult environments (e.g., outdoors, variable lighting, high glare, etc.).

3. *Tactile representations can be abstract.*

Users can be trained to recognize abstract representations of complex information through the sense of touch in the same way that the visual sense processes iconic information. The most recent example of this can be seen in the experiments by Brewster and Brown (2004) involving tactile icon representations.

4. *Tactile feedback can be used on the torso.*

Several researchers have studied the use of high-resolution vibrotactile feedback to augment the reduced visual fields common in many high-stress tasks. On most occasions vibrotactile cues were provided to the users' torso since the users' hands could be occupied in other tasks. The results of these studies suggest that feedback to the torso can be effective in improving users' spatial awareness (Weinstein, 1968; Veen *et al*., 2000). The research also found that users are more sensitive to feedback in the front of the torso than in the back.

5. *Maintain stimulus-response compatibility.*

A general principle in applying tactile feedback has been the stimulus-response (SR) compatibility. Akamatsu *et al* (1995) note that when a cursor moves over a target the correct way to convey this sense to the operator is through a touch sensation in the controlling limb. In an experimental comparison of target selection tasks with tactile, visual and auditory feedback [5] the authors found that tactile feedback allowed users to use a wider area of the target and to select targets more quickly once the cursor is inside the target.

6. *Haptic and tactile feedback should be avoided when they can interfere with control functions.*

Haptic and tactile feedback signals can affect motor abilities and should be carefully designed so that they don't interfere with other tasks in the system, for example, by detaching the location of feedback from the parts of the body that exert control of the system or by providing a very subtle signal.

7. *Haptic and tactile feedback should be considered when splitting of attention is required or when the primary feedback channels are unavailable or busy.*

The distinctive, distributed quality of touch perception makes it the ideal channel for situations where the attention has to be divided. The visual channel has a very broad bandwidth, but it is constrained to one spatial attention location at the same time. This limitation can be overcome by using the tactile or haptic feedback channel concurrently or instead of the visual channel provided that the information conveyed by these corresponds to the user's touch perception bandwidth.

8. *Haptic and tactile feedback in isolation are insufficient for object identification.*

When visual information is not available, it has been shown that exploration of complex objects in the scene through touch alone does not lead to an adequate conceptual model to identify real world objects. As a result, all tactile/haptic exploration tasks should be augmented through either visual or audio stimuli (Colwell *et al*., 1998).

3.2 Targeting

9. *In normal viewing conditions, extra-visual feedback may not improve targeting performance.*

As discussed above, in situations where there is adequate visual feedback, and the user is able to attend to the signal, additional feedback is unlikely to improve speed or accuracy (Akamatsu *et al*., 1995). However, users do not generally dislike the extra feedback, and it does not detract from performance, at least in sparse target environments.

10. *The effects of feedback in multiple-target environments are not well understood.*

Most studies have taken place on sparse target environments (one or a few targets), and those that have used more cluttered presentations show mixed results for targeting feedback. In general, the additional information from other targets reduces the salience of the feedback for the target.

11. *Buttons on tangible objects can interfere with positioning.*

The Heisenberg effect of spatial interaction (Bowman, 2002) refers to the phenomenon that on any tracked tangible or tactile input device, using a discrete button will disturb the position of the input device. In the case of using a wand, stick or TractorBeam (Parker *et al*., 2005) to position cursors on a remote display placing a selection button on the positioning device can lead to errors in target selection.

12. *Gravity wells are useful aids for motion-impaired users*

Computer users with hand or upper body tremors such as cerebral palsy or Parkinson's disease find gravity wells as useful aids for target selection (Hwang *et al*., 2003). Gravity wells are attractor-forces situated at the center of targets. When the cursor approaches the target area the haptic device pulls the cursor towards its center allowing the users to perform the act of clicking whilst the cursor is held steady.

3.3 Steering

13. *Haptic and tactile feedback are useful as aids in general steering tasks.*

When considering navigation through a narrow channel, forces pushing from the boundary areas can serve to correct erroneous movement which would lead the user out of the channel. In this case, a delicate balance must be struck to ensure that the forces are strong enough to correct errors, but not so strong as to limit the movement of the user (Dennerlein *et al*., 2000).

3.4 Handoff

14. *Use tangible representations for objects that need to be transferred frequently or quickly.*

Previous research shows that handoff is considerably faster and easier with tangible techniques than for digital pointing techniques (Liu *et al*., 2005). When sender and receiver coordinate together to handoff object by digital representation, the handoff process requires considerable hand-eye coordination for both the sender and the receiver. The sender and the receiver rely on visual information to accomplish the handoff. By using tangible representations, the users benefited greatly from the haptic feedback. This advantage suggests the designers that they are going to use tangible representations for objects, if they design a system which handoff activity happened frequently.

15. *The difficulty of the receiver's task in handoff motions influences the handoff location more than the difficulty of the sender's task.*

For smaller target sizes, the handoff location is closer to the receiver than for larger target sizes – that is, users automatically adjust the handoff location to balance the workload between the sender and the receiver. Designers should understand that the handoff location will alter if they design different size of targets for sender and receiver to acquire.

16. *Both sender and receiver should be able to perceive when and where the handoff action is going to occur.*

Compare with the inner-handoff when single user transfers object from his one hand to another, extern-handoff takes more time for sender and receiver to negotiate to transfer the object. It is because the sender can not predict where receiver is going to get the object, and receiver can not predict where the sender will move the object for him to pick it up. Designing a system which can give both sender and receiver perceptions about when and where the collaborators are going to transfer object will help users to achieve handoff task much easier.

4. CONCLUSION

Directed movements make up a large fraction of a user's interaction with a graphical interface. As direct-manipulation interfaces become more common, and as input devices become more powerful, haptic and tactile feedback for directed motions will likely become commonplace. Although the costs and benefits of adding haptic feedback are not yet fully understood, there is already a reasonable body of literature that can suggest design guidelines in this area. In this paper, we have collected sixteen principles from previous research and from our own experiments. These principles can be used to inform the design of feedback for targeting, steering, and handoff interaction techniques. However, it is clear that much more research needs to be done – particularly in studying the effects of haptic feedback in cluttered environments (such as many everyday interfaces).

5. ACKNOWLEDGMENTS

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