Research Based Tactile and Haptic Interaction Guidelines

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ABSTRACT

In this paper, we survey guidance on tactile and haptic interactions provided by various researchers who were not in attendance at GOTHI-05. Its main purpose is to identify potential guidelines that might be incorporated into an international standard on tactile and haptic interaction. This survey also identified a number of controversial areas that will need to be dealt with in developing such a standard. Results are presented in a manner consistent with a companion paper "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8].

Categories and Subject Descriptors

H.5.2 User Interfaces, *Ergonomics, Haptic I/O, Input devices and strategies,* D.2.0 Software Engineering General, *Standards*

General Terms

Human Factors, Standardization

Keywords

Tactile, haptic, interactions, interface object, reference model, standards.

1. INTRODUCTION

Tactile and haptic interaction is becoming increasingly important both in assistive technologies and in special purpose computing environments. While there is a very large body of research involving haptic and tactile interactions, there is a current lack of guidance relating to the particulars of tactile/haptic interactions that can be used by developers who are not also researchers in this field. ISO TC159 / SC4 Ergonomics of human - system interaction has recently initiated work to develop a set of ergonomic standards that will provide this guidance.

The Guidelines On Tactile and Haptic Interactions Conference (GOTHI-05) is a first step at accumulating potential guidance. The preparations for GOTHI-05 included identifying leading experts in the field and inviting them to submit papers focused on technology-transfer of their research findings into potential guidelines. While a number of experts accepted this invitation, it is with great regret that a number of others were unable to accept. This paper surveys the research of many of those not able to attend and starts the process of transforming their research findings into guidelines that can be used by a wider range of software developers.

1.1 Limitations of This Survey

Any survey of this nature is limited due to the particular research papers that it included. Since it was infeasible to examine all research papers in the area of tactile and haptic interaction, this survey limited itself to those papers which could be identified to include: guidance, guidelines, principles, recommendations, requirements, standards, or similar concepts.

Significant attempts were made to identify research including candidate guidance via a number of Web search engines and scholarly journal search engines. Further efforts were made to follow promising references in the papers which were examined.

This survey also did not consider any of the formal sets of standards and guidelines that were considered in the companion paper, "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8], which is also being presented at GOTHI-05.

It is recognized that these two papers present only a starting point, to be used along with the other papers of GOTHI-05 and much further research, along the road to developing a comprehensive set of guidance regarding the ergonomics of tactile and haptic interactions.

1.2 Structure of this Paper

This guidance and discussions presented in this paper are structured similarly to the guidance presented in "Initiating Guidance on Tactile and Haptic Interactions", by Fourney and Carter [8], for ease in the future consideration and combination of these two sets of guidance. However, due to the contents applicable to the two papers, there is not an exact correspondence between subsections. Each paper contains some subsections not found in the other.

2. HIGH LEVEL GUIDANCE

2.1 Layered Models of Haptic Interaction

In addition to the models presented in other GOTHI-05 papers, there are various models that can be applied to analyzing and developing haptic interactions. Popescu, Burdea, and Treffz [13] present a layered model that involves: applications, interaction tasks, interaction techniques, events, and input devices. Bowman [1] investigated a two level model involving interaction tasks and interaction techniques. Agreeing upon the appropriate layers to be considered is more important than the actual contents of any particular level. This is especially true, since the models investigated are all from the domain of virtual reality.

2.1.1 Interaction task models

Interaction tasks are the outcomes which the user is trying to accomplish on an object or a set of objects.

Popescu et. al. name, but do not explain, the following set of interaction tasks: "navigation, move, identification, selection, rotation, scale, modification". [13]

Bowman identified four general types of interaction tasks: (1) navigation, "which includes both the actual movement and the decision process involved in determining the desired direction and target of travel (wayfinding)"; (2) selection, "which involves the picking of one or more virtual objects for some purpose"; (3) manipulation, which "refers to the positioning and orienting of virtual objects"; and (4) system control, which "encompasses other commands that the user gives to accomplish work within the application". [1]

Stanney et. al. suggest that usability criteria associated with interaction can be classified as: wayfinding (i.e., locating and orienting oneself in an environment); navigation (i.e., moving from one location to another in an environment); and object selection and manipulation (i.e, targeting objects within an environment to reposition, reorient and/or query)". [16]

These different models can all be combined into a model consisting of three general tasks: navigation (including wayfinding) between objects, selection of a single object or group of objects, and manipulation (including activation) of the selected object(s).

The above only deal with interaction tasks from the user's perspective. However, there is at least one important interaction task from the system's perspective, that being feedback. Feedback is an important system task, as can be seen from the large amount of guidelines related to it that are presented later in this paper [4, 9, 11, 12, 13, 16].

2.1.2 Interaction technique Models

Interaction techniques are general types of user actions performed in order to accomplish interaction tasks. Bowman recognized that, "for each of these universal tasks, there are many proposed interaction techniques." [1] Popescu et. al. name the following set of interaction techniques: "grabbing, releasing, pointing, gesture language, 3D menu, speech commands", and further identified the following set of interaction events: "hand gestures, 3D motion, button click, force, 2-D motion, torque, spoken units". [13] It is unclear how they distinguish between these two sets.

While much work may be needed to develop a suitable set of interaction technique categories, it is expected that various items of guidance may uniquely apply to individual interaction techniques.

2.2 Definitions

2.2.1 Definitions of tactile and haptic

There is no consensus over the definitions of tactile and haptic interactions. Some authors use tactile as the main category and haptic as a special case of tactile, while other authors use haptic as the main category and use tactile as a subcomponent of haptic. In either case, tactile generally is used to refer to static aspects of touch while haptic includes dynamic aspects of touch.

While authors use the two terms in identifiable manners within their papers, few authors actually define either term explicitly. Stanney et. al. [16] define tactile as, "information received through nerve receptors in the skin which convey shapes and textures" and define kinesthetic as the active aspects of touch; "information sensed through movement and/or force to muscles and joints." Hale and Stanney [9] define haptic interaction as relating "to all aspects of touch and body movement and the application of these senses to computer interaction."

2.2.2 Definitions of specific interaction tasks

There is a need to organize the set of, and to define, individual interaction tasks and related concepts.

The area in which the most existing work was found relates to navigation. As already discussed, there are various definitions of what all that navigation involves. Stanney et. al. [16] define navigation as travel that, "is necessary to allow users to move into position to perform required tasks." Schomaker et. al. [14] have a somewhat broader concept of navigation, "as a process of movement and orientation, yielding a trajectory that is directed towards a given goal."

Darken and Sibert [6] identified three different types of navigation:

- Exploration is "where the primary goal is gaining familiarity with the environment'
- Naïve search is where the user is searching for a known object whose location is not known
- Informed search is where the user has 'some knowledge of the location of the object'

Stanney et. al. [16] define wayfinding as the ability to maintain knowledge of one's location and orientation while navigating throughout a designed space.

Selection, which is the most narrow concept, is the least controversial to define. Stanney et. al. [16] define object selection as involving "users designating one or more virtual objects for some purpose."

While manipulation is not defined, and may include a number of different specific tasks, Stanney et. al. recognize that, "object selection is followed by subsequent manipulation of specified objects." [16]

2.2.3 Definitions of tactile objects

Brewster and Brown define tactons or tactile icons as, "structured, abstract messages that can be used to communicate messages non-verbally." [3]

According to Brewster and Brown "Tactons have the potential to improve interaction in a range of different areas, particularly where the visual display is overloaded, limited in size or not available, such as in interfaces for blind people or in mobile and wearable devices." [3]

2.2.4 Definitions of perceptual effects

"Spatial masking means that the location of a stimulus is masked by another stimulus. Spatial masking may occur when stimuli overlap in time but not in location." [7]

"Apparent location is the percept of a single stimulus induced by the simultaneous activation of two stimuli at different locations. The apparent location is in between the two stimulus loci and depends on their relative magnitude. Both stimuli should be in phase to evoke a stable percept." [7]

Sensorial transposition is "the provision of feedback to the user through a different channel than the expected one." [13]

3. PROSPECTIVE GUIDELINES

3.1 Tactile/haptic inputs, outputs, and/or combinations

3.1.1 General guidance

3.1.1.1 Using appropriate interaction styles

"Interaction should be natural, efficient, and appropriate for target users, domains, and task goals." [16]

3.1.1.2 Using efficient movement controls

The system should enable users to interact with and control their movement throughout a virtual environment in a natural, streamlined fashion [16].

3.1.1.3 Flexibility of movement controls

The system should provide sufficient movement controls to support all aspects of the task. [16]

3.1.1.4 Using multimodal output

Where multimodal output is used, information presented in each modality should be readily understood, unambiguous, and necessary to complete the task. [16]

3.1.1.5 Use clear haptic output

Haptic information presented to users should be readily understood, unambiguous, and necessary to complete the task. [16]

3.1.1.6 Seamless integration of haptic output

Where the task allows, haptic output should be seamlessly integrated into the user's task. [16]

3.1.1.7 Preventing task display conflict

The system should avoid discord between the user's task and the haptic display. [16]

3.1.1.8 Using manageable haptic display

The system should avoid cumbersome, awkward haptic display. [16]

3.1.1.9 Providing reliable interaction

The system should provide consistent, accurate haptic interaction. [16]

3.1.1.10 Using intuitive haptic interaction

The system should provide intuitive haptic interaction. [16]

3.1.1.11 Avoiding minute, precise joint rotations

The system should avoid requiring minute, precise joint rotations, particularly at distal segments. [9]

3.1.1.12 Avoiding or Minimizing fatigue

a. The system should avoid causing user fatigue. [16]

b. The system should avoid requiring static positions at or near the end range of motion to minimize kinesthetic interaction fatigue. [9]

c. The system should ensure user comfort over extended periods of time. [7]

3.1.1.13 Using high spatial resolutions

The system should use very high spatial resolutions to increase haptic device ease of use. [16]

3.1.1.14 Effective presentation of haptic information

The system should encode haptic information using combinations of strength, speed, high-resolution force, and position that are effectively presented. [16]

3.1.2 Uni-modal use of tactile / haptic interaction

3.1.2.1 Using haptic feedback when other senses fail

The system should effectively use haptic feedback in areas where other senses are unusable. [16]

NOTE: Haptics is rarely used for spatial discrimination by itself (except in dark environments). [13]

3.1.3 Multi-modal use of tactile / haptic interaction

While the guidelines in all other subsections (other than 3.1.2) relate to both the uni-modal and the multi-modal use of tactile / haptic interactions, there is additional guidance that applies specifically to multi-modal use.

According to Popescu et. al., "multisensory feedback is not just the sum of visual, auditory and somatic feedback, since there is redundancy and transposition in the human sensorial process." [13]

3.1.3.1 Complex haptic object presentation

The system should use multimedia information when presenting complex haptic objects.

NOTE Users may not understand complex objects when only presented haptic information. [7]

3.1.3.2 Using multiple senses to support haptic tasks

The system may enhance haptic tasks by using other senses and vibratory cues. [16]

3.1.3.3 Using haptics during non-haptic tasks

The system may make use of tactile stimuli to convey additional information, beyond that presented via other modalities. [9]

EXAMPLE A user performing a visual spatial attention task uses tactile information to communicate warnings. [9]

3.1.3.4 Using of cross-modal cueing effects in multimodal displays

Cross-modal cueing effects in multimodal displays should follow an external spatial frame of reference. [9]

NOTE Information received visually can be used to reorient tactile perception and information received tactilely can be used to accurately reorient visual attention. [9]

3.1.3.5 Using haptics to minimize visual modality overload

If the visual modality is overloaded, the system may provide object identification information haptically. [9]

NOTE Although switching from tactile to visual stimulus does not seem to increase visual load, switching from visual to tactile stimulus can. [9]

3.1.3.6 Consistent combinations of vision and haptics

The system should maintain consistency of combinations of vision and haptics across modalities, for tasks involving size, shape, or position judgment. [9]

NOTE Vision will often dominate the integrated percept. [9]

3.1.3.7 Maintaining coherence between modalities

The system should impose the coherence of spatio-temporal representations for tactile and kinesthetic channels. [13]

EXAMPLE A user of a multimodal visual/haptic display finds the roughness of a surface evaluated through the visual display haptically matched by the rugosity information provided by the tactile display. [13]

3.1.3.8 Maintaining conceptual coherence

The system should maintain coherence in the haptic and visual displays of information related to the physical properties of a virtual environment. [13]

3.1.3.9 Avoiding time lags between modalities

The system should avoid time lags between visual and haptic loops in multimodal displays. [9, 13]

NOTE Time lags can causes confusion and control instabilities in multimodal systems. [9, 13]

3.1.3.10 Using cognitively linked vision and touch stimuli with care

If touch is potentially response-relevant, the system should ensure that vision and touch stimuli are not cognitively linked. [9]

NOTE 1 If vision and touch stimuli become cognitively linked, the effectiveness of conveying additional tactile information can be hindered. [9]

NOTE 2 During spatial attention tasks, it is possible to decouple tactile stimuli from other modalities but only when the tactile signals are considered irrelevant. [9]

3.1.3.11 Combining vision and haptics to enhance location memory

The system may add haptic location information to a visual display to enhance target placement memory. [9]

3.1.3.11.1 Using sensorial transposition

The system may use sensorial transposition to provide sensorial redundancy. [13]

EXAMPLE A multimodal system communicates the same feedback information through multiple channels to reinforce the original message. [13]

3.1.3.11.2 Mapping sensorially redundant feedback

The system should ensure that mapping feedback information through different channels avoids causing sensorial contradictions, sensorial overload, or an increased task completion time. [13]

3.1.4 User perceptions

According to Popescu et. al., "haptic channels constitute by themselves complex coupled systems. There is a very tight coupling between force and touch feedback." [13]

3.1.4.1 Enabling user perception of roughness variation

The system should enable the detection of physical variation in roughness of virtual textures. [5]

NOTE Virtual textures may not be perceived in the same way as their real counterparts. [5]

3.1.4.2 Assisting users in virtual texture detection

The system should enable users to adjust the size of the differences they can detect in their perception of virtual textures.

NOTE Users “vary in their perception of virtual texture in terms of the size of the differences which they can detect.” [5]

3.1.4.3 Supporting accurate size perception

Where accurate perception of size is required, the system should allow virtual objects to deviate from their real world dimensions. [5]

NOTE 1 “Users may perceive the sizes of larger virtual objects more accurately than those of smaller virtual objects.” [5]

NOTE 2 “Users may feel virtual objects to be bigger from the inside and smaller from the outside (the "Tardis" effect).” [5]

3.1.4.4 Helping users find virtual space

The system should enable users to determine where virtual space is located. [5]

NOTE It is possible for users to “have differing mental models of where virtual space is located.” [5]

NOTE Users' mental models may vary in relation to what part of the device is "touching" a virtual object. [5]

3.1.4.5 Violating the laws of physics

The system should avoid violating the laws of physics, unless such violation is necessary to the task. [5]

NOTE Although being able to push through the surfaces of objects does not greatly disturb users, care is needed when violating other laws of physics. [5]

3.1.4.6 Helping users understand the virtual environment

The system should allow users to move about the virtual environment to obtain different views and acquire an accurate “mental map” of their surroundings. [16]

3.1.4.7 Making complex haptic information easy to perceive

The system should ensure that the simultaneous presentation of complex haptic patterns, sensations, and objects is easy to perceive. [16]

3.1.4.8 Multiple haptic intensity levels
The system should avoid presenting and semantically binding a large number of haptic intensity levels. [16]

3.1.4.9 Ensuring accurate limb position
The system should use active movement to ensure more accurate limb position. [9]

NOTE Active movement of limb position is more accurate than passive movement. [9]

3.2 Tactile/haptic encoding of information

3.2.1 General encoding guidance
Brewster and Brown [3] identified the following general basic parameters that can be used for encoding information in *tactons*: frequency, amplitude, waveform, duration, rhythm, body location, and spatio-temporal patterns.

3.2.1.1 Using self-explaining tactile messages
Tactile messages should be self-explaining. [7]

3.2.1.2 Mapping sensorial transpositions

3.2.1.2.1 Allowing easy user adaptation when using sensorial transposition
To produce easy user adaptation, the system should use sensorial mappings that are as simple as possible. [13]

NOTE The level of user adaptation needed in the mappings involved in the sensorial transposition may feel "natural" or require user training. [13]

3.2.1.2.2 Using strong sensorial transposition mapping domains
The system should provide sensorial mappings that use the strongest representation domains (visual-spatial domain, auditory-temporal, frequency, tactile-temporal, etc.) of the transposed channel. [13]

NOTE Sensorial mapping needs that is as simple as possible helps to produce easy user adaptation. [13]

3.2.2 Spatial Encoding

3.2.2.1 Gestures
The system should minimize requirements for frequent, awkward, or precise gestures. [9]

NOTE 1 Such gestures, if used too often, can promote user fatigue. [9]

NOTE 2 Making accurate or repeatable gestures without tactile feedback is difficult. [9]

3.2.2.2 Intuitive and simple gestures
Gestures should be intuitive and simple. [9]

3.2.3 Sensory Encoding

3.2.3.1 Force

3.2.3.1.1 Control resolution
The forces displayed by the device should be controllable to at least the level at which humans can sense and control force. [2]

3.2.3.1.2 Considering target skin location sensitivity to stimuli
Haptic devices that are to be used across various skin locations should adjustable to take into account differences to stimuli sensitivity. [9]

NOTE The two-point threshold grows smaller from palm to fingertips. Spatial resolution is about 2.5mm on the index fingertip. [9]

3.2.3.1.3 Activating cutaneous pressure sensors
The force exerted on a target skin location should be greater than 0.06 to 0.2 Newtons per cm^2 in order for users to detect it. [9]

3.2.3.1.4 Haptic information transfer
To effectively promote haptic information transfer, the system should:

a) use a surface stillness of 400 Newtons per meter, [9] or
b) use an end-point force of 3 to 4 Newtons. [9]

3.2.3.1.5 Allowing pressure limit individualization
The system should enable the user to individualize pressure limits. [9]

NOTE: The gender of the user can impact the allowable pressure limit. [9]

EXAMPLE 1 A woman's face has a just noticeable difference pressure limit of 5 mg. [9]

EXAMPLE 2 A man's big toe has a just noticeable difference pressure limit of 355 mg. [9]

3.2.3.1.6 Encoding information using intensity
When encoding information using different intensity levels, the system should use not more than four (4) different levels between the detection threshold and the comfort / pain threshold. [7]

3.2.3.1.7 Direction of tactile force
The system should vary the direction of the tactile force based upon the direction the user moves the device. [4]

NOTE In effect, the tactile force applied by a device is "user-inspired".

3.2.3.1.8 Supporting high bandwidth force reflection
The system should support high bandwidth force reflection with high stiffness between master and slave devices. [16]

3.2.3.2 Vibrations

3.2.3.2.1 Using vibratory feedback
High frequency vibratory feedback may be important for haptic tasks involving: inspection, exploration, and direct manipulation. [13]

3.2.3.2.2 Using vibration with force feedback
Force feedback systems should include vibratory feedback. [13]

NOTE The addition of vibration to force feedback systems can increase performance in manipulation tasks. [13]

3.2.3.2.3 Coding information by frequency
When coding information by frequency, the system should:

a) use not more than nine (9) different levels of frequency, and
b) use a difference of at least twenty percent (20%) between levels. [7]

NOTE If presented with the same amplitude, the different levels of frequency will also lead to different subjective magnitudes. [7]

3.2.3.2.4 Vibratory probe perception

The vibration from any single probe should exceed 28 decibels (relative to a 1-microsecond peak) for 0.4 – 3 Hz frequencies. [9]

3.2.3.2.5 Preventing spatial masking

When presenting simultaneous stimuli in different loci, the system should use stimuli with different frequencies (one below 80 Hz and one above 100Hz). [7]

NOTE: This may prevent spatial masking. [7]

3.2.3.2.6 Maintaining control of virtual objects

The maximum level of vibration should allow the user to easily control an object without corrupting the user's perception of the virtual environment. [2]

3.2.4 Temporal Encoding

3.2.4.1 Haptic display frame rate and latency

The system should use high frame rates and low latency for haptic outputs. [16]

3.2.4.1.1 Perception of distinct signals

The stimuli of individual signals should be at east 5.5 ms apart. [9]

3.2.4.2 Coding information by temporal pattern

When using a single actuator of a tactile display to encode information in a temporal pattern, the time between signals should be at least 10 ms. [7]

NOTE The temporal sensitivity of the skin is very high, 10 ms pulses and 10 ms gaps can be detected. [7]

3.2.4.3 Effects of temporal coding

The system should avoid presenting two stimuli closely in time. [7]

NOTE This helps avoid the percept being altered (i.e., by temporal masking, temporal enhancement, and/or adaptation). [7]

3.2.4.4 Spatial-temporal interactions

The system should avoid presenting stimuli too closely in time and space. [7]

NOTE This helps avoid creation of unintended percepts. [7]

3.2.5 Composite Encodings

3.2.5.1 Graphical and haptic object behavior implementation and display

The system should implement and synchronously display to the user virtual object physical behavior both in graphics and haptics. [13]

3.2.5.2 Synchronizing surface deformation with force calculation

To provide immersion in the virtual environment, the system should synchronize object surface deformation with force calculation. [13]

3.2.5.3 Behavior of "soft" balls

"A "soft" ball (small forces applied to the user's finger when squeezing) should also be highly deformable." [13]

3.2.5.4 Virtual wall behavior

The system should provide virtual walls that resist very high forces and have no visual surface deformation when being pushed. [13]

3.2.5.5 Plastically-deformed object behavior

The system should allow plastically-deformed objects to present a hysteresis behavior both in shape deformation and in the associated force profile. [13]

3.2.5.6 Matching force resolution with human sensing resolution

The force resolution that a system is capable of producing should match or exceed human sensing resolution. [2]

NOTE Matching or exceeding human sensing resolution helps users to perceive the force displayed by the device. [2]

3.2.5.7 Varying force according to speed

The system should vary force according to speed. [12]

NOTE Slow motions require low forces. [12]

3.2.5.8 Size and density effects on object strength

"The maximum strength used for any widget, or set of widgets, should be dependent on both the size of the widgets and density of arrangement that they are presented in." [12]

NOTE "A dense arrangement of small widgets requires small forces, as large forces will severely hamper motion from one widget to an adjacent one." [12]

3.2.5.9 Supporting virtual object targeting

The system should increase the strength of forces applied to match increases in approach speeds to maximize targeting. [12]

NOTE Users often approach large spatially distributed widgets at considerable speed. [12]

3.2.5.10 Maintaining similar strength ratios across users

The system should keep the general strength ratios between different sizes and densities of widgets the same for all users. [12]

NOTE "Irrespective of the maximum strength a user chooses, the proportions between the magnitude of the forces applied over a large target, and of that applied over a small target seem likely to remain the same." [12]

3.3 Content-specific Encoding

3.3.1 General tactile / haptic encoding

3.3.1.1 Using haptics to represent both physical and spatio-temporal object properties

The system may use haptics to represent information related to the physical properties of the virtual object as well as their spatio-temporal properties. [13]

3.3.2 Encoding and using textual data

No text specific guidance was found in the sources surveyed.

3.3.3 Encoding and using graphical data

3.3.3.1 Using rounded edges and corners

The system should use rounded shapes rather than sharp edges and corners. [15]

NOTE: When felt from the “outside”, sharp edges and corners are more difficult to feel and understand than rounded shapes. [15]

Sharp edges and corners are much more difficult to feel and understand than rounded shapes when they are felt from the "outside". [15]

3.3.3.2 Maintaining separation between walls
Objects should be sufficiently separated so that the user is able to perceive the boundaries between individual ocjects. [15]

NOTE If walls or edges are very close there is a risk that the finger passing through a wall or edge, will also unintentionally pass through an adjacent wall or edge. [15]

3.3.3.3 Using kinesthetic information to enhance spatial location
The system may use kinesthetic information to enhance the spatial location of a virtual object. [9]

3.3.3.4 Accurately reorient attention

3.3.3.4.1 Using tactile information to draw visual attention
The system may use dynamic tactile information to accurately reorient visual attention. [9]

3.3.3.4.2 Using visual information to draw tactile attention
The system may use dynamic visual information to accurately reorient tactile attention. [9]

3.3.4 Encoding textural data

3.3.4.1 Encoding hard surfaces
The system should maintain active pressure after initial contact when users feel a "hard" surface. [9]

3.3.4.2 Encoding soft surfaces
The system should maintain a slight positive reaction against the skin after initial contact when users feel a "soft" surface. [9]

3.3.4.3 Using relative motion to display texture
The system should use relative motion between the haptic surface and the skin to accurately display texture. [9]

3.3.5 Encoding and using controls

3.3.5.1 Haptic pushbutton design
A haptic pushbutton should consist of an initial springy region where the force increases linearly with displacement, followed by a sudden decrease in resistive force and transition to a deadband where the resistive force is constant, followed by a hard stop where the resistive force approximates that of a hard surface. [10]

3.4 User Individualization of Tactile / Haptic Interfaces

3.4.1 Intentional Individualization

3.4.1.1 Enabling force feedback override
The system should allow any force feedback applied to a user to be overridable. [12]

NOTE User override of tactile force can be achieved by “fighting through” or “sidestepping” a constraint. [4]

3.4.1.2 Enabling individualization of force
The system should enable the user to individualize the amount of force applied. [4, 12]

NOTE Users vary in the amount of force that can overpower or “be too strong” for them. [4]

3.4.1.3 Enabling stimulus intensity individualization
The system should enable the user to individualize stimulus intensity. [7]

NOTE 1 There is a high variation in thresholds of sensation and pain both among individuals. [7]

NOTE 2 Since spatial and temporary acuity degrades with aging, an individual’s variation in thresholds of sensation and pain will vary over the life span. [7]

3.5 Interaction Tasks

3.5.1 Navigation
Navigation techniques and actions may be dependent on the size and density of the real or virtual space through which the user must navigate. According to Darken and Sibert [6]:

- A small world is a world in which all or most of the world can be seen from a single viewpoint such that important differences among objects in the world can be discerned.
- A large world is one where there is no vantage point from which the entire world can bee seen in detail.
- An infinite world is one in which we can travel along a dimension forever without encountering the 'edge of the world'.
- A sparse world has large open spaces in which there are few objects or clues to help in navigation.
- A dense world is characterized by a relatively large number of objects and cues in the space.
- A cluttered world is one in which the number of objects is so great that it obscures important landmarks or cues.
- As the distribution approaches uniformity, the positions of objects become more predictable.

3.5.1.1 Allowing path planning based on current view
The system should enable the user to use the current view to plan the shortest path to a target. [16]

3.5.1.2 Providing well designed paths
The system should ensure that paths between objects have a clear structure and clear start/end points. [16]

3.5.1.3 Making landmarks easy to identify and recognize
The system should ensure that landmarks are easily identifiable and recognizable with a prominent spatial location. [16]

3.5.1.4 Providing navigation
The system should provide navigation mechanisms that allow users to move into position to perform tasks. [16]

3.5.1.5 Providing easy to use navigation techniques
The system should provide navigation techniques that are easy to use and not cognitively cumbersome or obtrusive. [16]

3.5.1.6 Physical interaction and touch

3.5.1.6.1 Enabling virtual environment search and survey via touch

The system should enable users to actively search and survey the virtual environment through touch. [5]

3.5.1.6.2 Enabling easy identification of objects via haptics

The system should enable users to easily identify objects through physical interaction. [5]

3.5.2 System Feedback

3.5.2.1 Providing haptic feedback

The system should provide haptic feedback. [12]

NOTE Haptic feedback reduces errors through guidance and provides forces to support the motions that a user is undertaking. [12]

3.5.2.2 Providing natural kinesthetic feedback

The system should integrate "tools with mass". [16]

NOTE: This is one way to provide users with natural, gravitational, and inertial kinesthetic feedback. [16]

3.5.2.3 Providing feedback of impending transitions

The system should use feedback to indicate, not preclude, an impending transition. [11]

3.5.2.4 Using applied forces as feedback

The system should use the forces applied as a means of feedback. [12]

3.5.2.5 Providing force as feedback based on user's input

The force of feedback should be based on, but control, the user's input." [11]

3.5.2.6 Providing force feedback in proportion to user input

The system should provide only force feedback that is directly proportional to the input forces applied by the user. [11]

3.5.2.7 Haptic menu navigation

When navigating a menu haptically, the system should provide a slight counter-force as the user moves from one menu item to another. [4]

NOTE This technique gives the effect of "ridges" separating menu items. [4]

3.5.2.8 Direct manipulation task haptic feedback

The system should accompany tactile feedback with force feedback during direct manipulation tasks. [13]

3.5.2.9 Manipulation task vibratory feedback

The system should provide vibratory feedback for manipulation tasks. [13]

3.5.2.10 Using tactile cues as alerts

The system should use tactile cues as simple alerts. [9]

EXAMPLE Tactile cues created via vibrations or varying pressures alert the user to changes in the interface that were made by the system.

3.5.2.11 Haptic target behavior

The system may use a "snap-to" behavior to actively capture the cursor as it passes over a target and that requires the user to exert effort to move beyond the target. [12]

NOTE Haptic targets are often presented as walled areas or wells of attractive force. [12]

3.5.2.12 Using augmented haptic widgets

Haptic widgets may be augmented with attractive basins or haptically walled areas. [12]

NOTE Such augmentations typically provide performance improvements. [12]

3.5.2.13 Haptic feedback for a widget

Widget haptic feedback design should consider the:

a) shape of the widget, and

b) likely path a user will take over the widget. [12]

3.5.2.14 "Anticipation" haptic feedback

The system may use haptics to provide a "breakable" force resisting the user's motion and indicating the imminence of a qualitative change in the user's input before the user makes such a change. [10]

NOTE 1 This mechanism allows the user to retreat from the change if it is not desired. [10]

NOTE 2 The term "breakable" describes a force that the user can overcome to "break though" it. [10]

3.5.2.15 "Follow-through" haptic feedback

The system may use haptics to indicate that an attempted qualitative change has actually been accomplished. [10]

NOTE This mechanism allows a user an opportunity to correct their motion if they do not get this feedback. [10]

3.5.2.16 "Indication" haptic feedback

The system may use haptics to provide an indication that a continuing condition remains in effect, possibly with quantitative information about the condition. [10]

3.5.2.17 "Guidance" haptic feedback

The system may use haptics to adapt the user's input with a bias towards some set of possible inputs. [10]

3.5.2.18 Using anticipation and guidance feedback to distinguish direction

The system may use haptics to allow the user to make a clear distinction between locally orthogonal directions. [10]

NOTE This technique can be used to map different (but possibly related) controls onto different dimensions of the same input mechanism. [10]

4. FURTHER INFORMATION OF POTENTIAL STANDARDS USE

The potential guidelines above contain some physical measurements [7, 16]. However, Bresciani, Drewing, and Ernst provide tables of useful physical information for:

- thresholds for different physical parameters in different modalities

- the range of force of human performance for actions involving arm', hand' and finger's joints
- the control resolution of human performance for actions involving arm', hand' and finger's joints

5. CONCLUSION

This paper identifies guidance in a number of areas not covered by the existing standards surveyed by Fourney and Carter [8]. It also attests to the large amount of potential guidance that can be obtained from existing published research. It is expected that a much more thorough analysis of the literature will identify a number of further guidelines that should be considered in the development of the new ISO standard on Guidance on Tactile and Haptic Interactions.

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