Haptic Cues: Texture as a Guide for Non-Visual Tangible Interaction.

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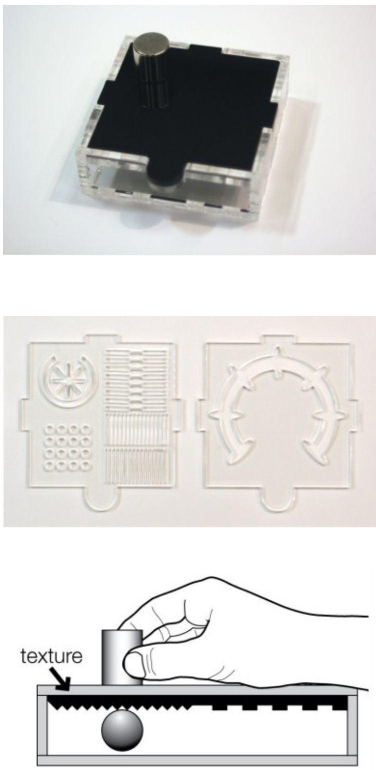

Figure 1. Setup for exploring texture perception using a (1) black box (2) consisting of changeable top with laser-cut haptic cues, a tangible magnet and a bearing ball, and finally a transparent bottom that allows for ball tracking (3) that is moved over the haptic cues inside the box through moving the tangible magnet.

Abstract

Tangible User Interfaces (*TUIs*) represent digital information via a number of sensory modalities including the haptic, visual and auditory senses. We suggest that interaction with tangible interfaces is commonly governed primarily through visual cues, despite the emphasis on tangible representation. We do not doubt that visual feedback offers rich interaction guidance, but argue that emphasis on haptic and auditory feedback could support or substitute vision in situations of visual distraction or impairment.

We have developed a series of simple TUIs that allows for the haptic and auditory exploration of visually hidden textures. Our technique is to transmit the force feedback of the texture to the user via the attraction of a ball bearing to a magnet that the user manipulates. This allows the detail of the texture to be presented to the user while visually presenting an entirely flat surface. The use of both opaque and transparent materials allows for controlling the texture visibility for comparative purposes. The resulting *Feelable User Interface* (FUI), shown in Fig. 1, allows for the exploration of which textures and structures are useful for haptic guidance. The findings of our haptic exploration shall provide basic understanding about the usage of haptic cues for interacting with tangible objects that are visually hidden or are in the user's visual periphery.

Keywords

Tangible User Interface; Guidance; Haptic; Texture.

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ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. - Input Devices and Strategies.

Inspiration

This work aims to explore two guidance parameters: *patterns* and *texture* for enriching Tangible User Interfaces [Ullmer 2001] through haptic feedback.

We are inspired by interfaces that rely on vision, such as common desktop GUI interfaces. These provide information about the users' point of interaction, which is represented through the mouse arrow, and the state of accessibility when the mouse arrow is represented above a GUI component, such as icons or menu items. That GUI structure is understood in this paper as *patterns*.

When a mouse arrow is moved over a GUI, different colored sections define different display areas, such as windows, menu bars, and icons. That visual distinguishability of GUI components by color can be translated for haptic interfaces through *texture*.

Both pattern and texture provide rich information that serve as guidance feedback for GUI interactions. This work aims to investigate the potential of pattern and texture for haptic interfaces.

Texture Perception

When scanning a surface with a finger as well as when moving a grasped object over a surface we perceive via the inner skin receptors rich information about the surface, for instance its shape, material, and texture. This paper addresses the texture perception of a surface where a grasped object is passed over rather than a surface that is perceived with a bare finger passing over.

Research has been done for simulating textures for guiding the finger [Bau 2010, Bau 2012] as well as for tangible [Marquardt 2009] interactions through haptic stimuli that are designed to refer to or even use analogue haptic experiences [Moussette 2012] . Our work differs from these prior studies as we explore the haptic perception of analogue texture as experienced through the coupling of a magnet to the tangible object. We are exploring the haptic expressiveness of analogue texture in order to undrerstand the texture patterns and parameters suitable for designing haptic cues. Thus, we aim extending the haptic design space for haptic cues through choosing an approach that uses analogue perception as inspiration.

Psychologists and cognitive scientists have conducted many studies on analogue texture perception, in particular on investigating the ability to differentiate texture roughness directly using ones finger [Lederman 1986, Connor 1990, Meftah 2000] or indirect via a stylus-like probe [Klatzky 1999, Klatzky 2003, Lawrence 2007]. Our approach is novel as we explore the analogue perception of texture patterns as experienced secondarily via a magnet coupled to an object on the textured surface.

Our approach is inspired by experiments of cognitive psychologists who explore texture perception; and we aim to describe based on that survey systematically the haptic design space of haptic guidance and feedback for tangible interacting with probes or for supporting common mouse interactions.

Background and motivation

There are many explorations of interfaces that compute texture for bare finger touch interaction [Bau 2010, Bau

2012] as well as tangible interaction [Marquardt 2009] in the domain of human-computer interaction. Moreover research on the perception of analogue texture with the bare finger [Lederman 1986, Connor 1990, Meftah 2000] or stylus-like probes [Klatzky 1999, Klatzky 2003, Lawrence 2007] has been done by cognitive scientists. A few haptic systems [Bianchi 2011] have combined vibrotactile output into a tangible tabletop system; however, so far (as to the authors' knowledge) no exploration of haptic perception of *analogue* texture as part of a tangible interface has been investigated. Three potential advantages of investigating analogue texture perception for guiding movements of tangible interfaces and mice motivate this work:

1. *Extending the expressiveness of texture.* Many tangible objects that are moved over surfaces, like 2D mice or tangible interfaces [Underkoffler 1999, Jordà 2005] are moved across smooth surfaces and therefore do not provide any haptic feedback. There are projects that simulate surface texture through computing haptic stimuli for touch [Bau 2010, Bau 2012] tangible [Marquardt 2009] interaction, and friction modulating mice [De Jong 2010]. The expressiveness of the haptic information that can be given through computed stimuli is limited by the technology used and is mainly designed as combinations of friction, roughness and vibration. Through exploring the perception of analogue texture, we aim to identify further texture parameters that have potential to increase the expressiveness as well as the design space for haptic guidance.

2. *Guidance through* t*exture perception.* Tangible interfaces and mice interfaces do not commonly combine active (modulated) haptic feedback gained from the texture that serves as physical surface for manual movements, which result in digital manipulation. *TeslaTouch* [Bau 2010] and *REVEL* [Bau 2012] provide haptic feedback to simulate surface structure when a finger is sliding above a touch screen through electric stimulation. The *Haptic Tabletop Puck* [Marquardt 2009] moves a stick towards and away from a fingertip of the hand that grasps the tangible object. We argue that the design space for haptic feedback of the mentioned interfaces, which is using the parameters stimulus strength and frequency, is limited by the capabilities of technology used. We aim to understand the perception of analogue texture for identifying a richer set of parameters that influence the perception of texture. Furthermore we aim to identify parameters that can confuse users sense of touch in order to develop interfaces capable of producing haptic illusions.

3. *Guidance through haptic pattern recognition.* We see a research gap in the topic of tactile perception of different texture patterns. In visual dominated interfaces, visual patterns guide interactions through present information that allow for distinguishing between different icons, images and display sections, such as windows. The presented work is addressing that topic through investigating how haptic patterns can be recognized based on which parameters and what parameters result in confusing haptic pattern recognition.

Exploration

For getting a fundamental understanding of perception of textures and haptic patterns, we built a *Feelable User Interface* (FUI [Wolf 2013]) that is an analogue setup that allows for moving a hidden ball bearing in a

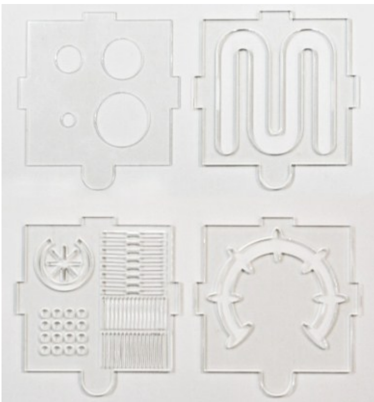

Figure 2. Set of changeable laser-cut patterns that are placed underneath top.

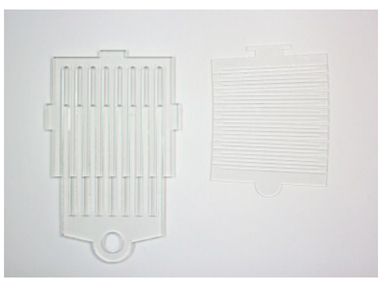

Figure 3. Set of changeable laser-cut textures that are placed underneath top and which can be changed in texture roughness through manually pulling a tiny handle.

box through the movement of a magnet on the top surface of the box.. The textures are placed on the underside of the top surface of the box and haptic patterns are felt by the vibrating movements of the ball as it moves across the textured surface. As the texture is located on the bottom side of the top plate, our setup provided the opportunity to hide the surface textures and patterns from the users if non-transparent material was used. In a hands-on session, volunteers had the possibility to explore hidden surface texture and patterns and they were asked to give think-aloud comments on their haptic exploration. The getting insights on the topics of our specific interest, we asked in the meanwhile or research questions that addressed the recognition of patterns and the ability to distinguish between textures, which we changed at that time.

Research question

1. What pattern do you recognize? (when moving the tangible magnet that moves the bearing ball over the textures shown in Fig. 2)
2. Does the pattern underneath the surface (see Fig. 2) allow for moving alongside?
3. What do you explore now? (while changing texture graduations with textures shown in Fig. 3)

Feelable User Interface

For exploring texture and haptic pattern perception, we built a *Feelable User Interface* (FUI [Wolf 2013]) that allows for the rapid prototyping of textures where the tangible control is coupled to the object on the textured surface by magnetism. This magnetic coupling allows computer controlled morphing of the surface texture without changing the outside visual appearance of the apparatus. Moreover, for exploring the effect of haptic cues on the interaction experience, we do not want to provide any visual cues. The apparatus, shown in figure 1, allows for dragging a single object above different surface structures without any visual information through adding a physical layer between the touch and the object. The object we are using is a solid steel ball bearing (of 20mm diameter) which acts as a physical mouse pointer. The actual action of ball movement is hidden inside a black-box-set-up and the texture of the surface is perceived through the grasped probe where the texture touches the bearing ball. All surfaces are made of the same material (acrylic) in order not to introduce other textures into the system.
We have chosen a magnet to transfer the kinetic energy of the user's hand to the object because that de-coupled layout is also a low-tech prototype of the one that allows for texture computation in further work. For computation, we think of using an electro-magnet that would allow us changing the force may give the illusion of changing surface friction. More frequently changing forces might fake the illusion of various surface structures, such as those we produced physically (see Fig. 2 and 3) and therefore allow for digitally mediated analogue interactions.

Procedure

For answering the research question 30 participants were asked to freely explore the interface and give think-aloud comments. For getting answers to our specific questions, we were asking those additionally in the meanwhile. As not all questions fit to all surfaces, we asked question 1 and 2, if the surface patterns (see Fig. 2) were explored; and question 3 was asked during interacting with changeable surface textures (see Fig. 3).

Results

The results of this explorative survey are qualitative and give basic insights into the expressiveness of haptic cues that refer to different textures and haptic patterns, which are feelable through a tangible object that is moved over the surface. In general users liked haptic cues while tangible interactions a lot. There was a sonic bias because moving a bearing ball above a haptic cue produces sounds. That sounds support haptic cues and should be considered as supporting and additional guidance modality.

The different hidden *patterns* were clearly distinguished. All hidden patterns that are shown in Fig. 2 were recognized to be different from each other. But pattern recognition was almost never possible. The holes (Fig. 2, top left) were recognised most easily, even though some participants guessed that the patterns would have ellipse shapes. Actually we observed that the bearing ball stops with little delay because inertia and its weight. That makes it harder to get a precise picture of the haptic explored pattern. However, exact pattern recognition seems to be difficult for the three other patterns (Fig. 2: top right, bottom left and right), users were able to move the ball along the pattern outlines. That ability is promising and inspires for designing haptic movement guidance. In contrast to the hidden patterns, haptic cues can be recognized much more easily if they are familiar through having been seen before; and in cases when we did not hide the surface but used transparent material, the haptic cues worked even much better for guiding to move the tangible object.

The changes of the textures (see Fig. 3) were recognized easily. The first texture (see Fig. 3: left) had just 2 states: almost smooth and linear gratings of 5mm. Users could easily distinguish between both states through the change in haptic perception. The second texture (see Fig. 3: right) allowed variable linear texture gratings, from 0 to 3mm, achieved by cutting a concertina pattern in the acrylic. We always increased the gratings to the possible maximum of 3mm, because smaller gratings could not be distinguish, and even a 3mm grating was not easily to distinguish for all participants. We also observed that people relied a lot on the frequency of the sonic output that automatically occurs when an object is moved across a textured surface.

Discussion

As noticed by participants' comments, movements of tangible objects above structured surfaces for both types: haptic patterns and texture results in haptic and sonic cues. These cues allow for recognizing the difference between textures and pattern elements. We found that texture gratings below 3mm hardly be detected, but at 5mm can easily be distinguished. Texture patterns are hard to recognize, but serve as haptic guidance and users are able to move an object along the pattern even if the pattern is hidden.

Any physical elements, such as a line or passing a cut out shape border results in a tactile and a sonic stimulus. However the presented results show that haptic cues contain information that serves for texture and pattern perception, as well as for being guided along textural cues; it is not completely clear whether the tactile or the sonic or both stimuli were giving the information that was necessary for the exploration. Another exploration is necessary and an experiment has to be conducted that controls the a) tactile and b) sonic stimuli. Audio can be avoided through playing load music via headsets. The tactile information can be hidden whilst still keeping the auditory signals that occur when the bearing ball is moving above the texture through recording the audio signals of exemplary interactions.

Conclusion and Future Work

This paper presents the first step to investigate whether or not changing surface structure effects perception when dragging objects above and shows that the surface change can serve for haptic guidance while moving a tangible object over the surface as well as for texture differentiation, which could serve as orientation at haptic displays. Dragging an object above a surface results also in sonic cues that support the pattern and texture perception.

This approach was explorative and aimed to result in a general understanding of the influence of haptic cues on surface perception. Future work will investigate the findings of this survey, such as linear grating ranges and the influence of sonic cues on surface perception in greater detail.

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