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Multisensory texture exploration at the tip of the pen ☆

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A B S T R A C T

A tool for the multisensory stylus-based exploration of virtual textures was used to investigate how different feedback modalities (static or dynamically deformed images, vibration, sound) affect exploratory gestures. To this end, we ran an experiment where participants had to steer a path with the stylus through a curved corridor on the surface of a graphic tablet/display, and we measured steering time, dispersion of trajectories, and applied force. Despite the variety of subjective impressions elicited by the different feedback conditions, we found that only nonvisual feedback induced significant variations in trajectories and an increase in movement time. In a post-experiment, using a paper-and-wood physical realization of the same texture, we recorded a variety of gestural behaviors markedly different from those found with the virtual texture. With the physical setup, movement time was shorter and texture-dependent lateral accelerations could be observed. This work highlights the limits of multisensory pseudo-haptic techniques in the exploration of surface textures.

1. Introduction

In everyday interaction with the environment, we experience surface textures mostly through touch and vision, although audition can also contribute to forming multisensory percepts (Klatzky and Lederman, 2010). The importance of haptics for conveying a similar experience in virtual and augmented environments has been widely advocated (Robles-De-La-Torre, 2006), although force-feedback devices are impractical or expensive in many contexts. This explains the emergence of pseudo-haptics (Lécuyer, 2009; Mensvoort et al., 2010), that is the exploitation of multisensory illusions to render forces through alternative sensory channels. The present work belongs to the area of experimental pseudo-haptics, as it seeks evidence of the effectiveness of image, sound and vibration as sensory substitutes of lateral forces in texture exploration tasks. As opposed to most existing works in this area – which rely on physical separation between the pointing device and the locus of visual interaction – we consider interactions where action and feedback are co-located, though mediated by a tool (stylus). This is indeed the typical situation of many manual activities that afford the development of expressiveness and virtuosism, such as painting or drawing.

To show if and how modulations of visual, auditory, and vibratory feedback differently affect the perceived lateral forces during surface exploration, we designed a system based on a vibroacoustically augmented graphic tablet and on real-time physics-based simulation of contact mechanics. This apparatus can render surface textures by means of visual, auditory, and vibratory feedback. An experiment was designed to look for behavioral evidence of the effects of different kinds of feedback on constrained gestures. For this purpose, the trajectories and forces were measured by using the digitizing tablet itself. The assumption that these forces and trajectories may be affected by perceived (illusory) shear stresses was experimentally tested. The proposed experiment is markedly different from prior assessments of pseudo-haptic techniques, which were based on subjective estimation or magnitude production. It gives the possibility to further validate or to refute previous claims on the effectiveness of pseudo-haptics.

The proposed tool for the multisensory exploration of virtual surface textures qualifies as an abstract interactive object, that is an object designed with the goal of improving our understanding of some interaction primitives (Svanæs, 2013). In particular, we used a constrained steering task to quantify how the feedback in different sensory modalities affects the same surface-rubbing gesture. Since it has been shown that lateral forces do affect accuracy in steering tasks over physical textures (Sun et al., 2012), we looked for similar behavioral effects when multi-sensory pseudo-haptic feedback is used to substitute the actual lateral forces. A qualitative evaluation of the interaction under different

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combinations of sensory feedback was also made possible by comparison with the physical, real-world realization of such stylus-surface interaction.

2. Related literature

2.1. Forces for on-screen textures

It has been shown that forces are dominant over geometric features to convey information about surface profiles through active touch (Robles-De-La-Torre and Hayward, 2001). Based on this evidence, attempts have been made to substitute lateral forces by visual vibrations of the mouse cursor and by vibratory feedback at the mouse manipulation point (Hachisu et al., 2011). The frequency of these vibrations would mirror the changes in the speed of the cursor, as they are introduced in the pseudo-haptic paradigm proposed by Lécuyer (2009). This kind of substitution, however, is not trivially transferable to surface-based interactions such as those with touchscreens, since it relies on dynamic changes of the control/display ratio of the input device. Local and dynamic image deformations were also proposed to convey a sensation of stiffness (Argelaguet et al., 2013), and it was shown that they can render several levels of apparent stiffness in manipulations through pointing devices. The effectiveness of these techniques in touchscreens and tablet-based interactions has not been ascertained yet.

In order to overcome the difficulties of using sensory illusions in more direct manipulations, such as those found in tablets, some researchers have proposed to stretch a rubber membrane over a frame on top of the touchscreen (Lefebvre and Pusch, 2012). This increases the perceived sense of physicality in the continuous deformation of virtual objects. In this case, the control/display ratio is used to alter the perceived level of resistance of the virtual object, by controlling the extent to which finger movement is translated into object deformation.

Bau et al. (2010) proposed TeslaTouch, a tactile feedback for touch interfaces based on electrovibration at the bare finger tip.

Harrison and Hudson (2012) demonstrated how shear can expand the range of possible interactions at the touchscreen, and how it can be used to implement a variable control/display ratio, without sacrificing any screen real estate. What they proposed is equivalent to having an isometric pointing stick at the point of touch. Their experimental apparatus was built by mounting a capacitive touchscreen on top of a LCD display. Operating between the display and touchscreen were two analog joysticks. Shear-sensitive touchscreens may be suitable for pseudo-haptic feedback enhancement for texture exploration.

McDonald and Kuchenbecker (2013) proposed a haptic simulation model for tool-mediated texture interaction, that is surface texture exploration mediated by a handheld stylus provided with sensors and a vibrotactile actuator. Their measurements show that lateral and axial accelerations at the probe form trains of complex pulses, each corresponding to a contact event between the tip of the tool and a ridge in the texture grating. In their setup, a dynamic model is used for impacts, and forces are transferred from the normal to the transversal plane via friction.

2.2. Sound out of texture exploration

In sound synthesis, several models exist that describe the contact phenomena occurring at the interface between an object and a surface. Friction is one such phenomenon based on stick-slip commutation (Avanzini et al., 2005). Other salient phenomena such as rolling are rendered by patterns of impacts (Rath and Rocchesso, 2005). In those studies and models, surfaces are often specified as one-dimensional height profiles, either sampled or generated algorithmically.

A flexible sound synthesizer for scratching, rubbing, and rolling sounds has been developed by Conan et al. (2013, 2014): sound generation is based on a dynamic impact model, and impacts are distributed in time and controlled in amplitude according to stochastic models of scratching, rubbing, and rolling. Another synthesis engine is the Sound Design Toolkit (Delle Monache et al., 2010), which offers a set of physics-based sound models organized according to an ecological taxonomy of everyday sounds.

A remarkable work that uses the exploration of physical textures for sound-generation purposes is that of Merrill et al. (2008). They proposed to use physical textures as affordances for brushing, scraping, striking, etc., and these gestural actions could be exploited for continuous playback and modification of prerecorded audio samples.

Only a few studies have investigated if and how texture sounds can affect motor behavior. Castiello et al. (2010) showed that the sound of fingers on different material textures affects movement duration in a reaching-to-grasp task, with sounds that are congruent with the visual appearance producing shorter movement durations. Moreover, their experiments provided evidence that the contact sound is used by both the planning and the on-line control systems at the neural level. In an experiment aimed at revealing how sound may affect materiality and behavior in the use of touch screens, Tajadura-Jiménez et al. (2014) sensed finger gestures of free exploration and linear displacement to drive synthesized textural sounds of controllable nature and frequency content. They found very small effects of sound quality on movement speed and finger pressure, for blindfolded subjects.

2.3. Trajectory-based interactions

Stylus-mediated exploration of a surface can be seen as a trajectory-based task (Accot and Zhai, 1997). The steering-law model, as derived by Accot and Zhai, was proposed to predict the performance of different devices when used for steering constrained paths on a surface (Accot and Zhai, 1999; Kulikov et al., 2005). The typical goal for those tasks, however, is quite different from free exploration, as participants were not free to wander. Conversely, they were usually requested to perform a stroke as quickly and as accurately as possible, without crossing the boundaries of a prescribed corridor.

It has been shown that different kinds of error feedback (visual, tactile, auditory, none) have no effect on movement time (Sun et al., 2010). Conversely, the same research showed that accuracy seems to improve with tactile feedback. However, it should be noted that error feedback is not ecological, and is very different from the multisensory feedback that one would get when steering a path with a stylus on a textured surface. In the specific application context of cascading menu selection, the effect of superimposed visual force fields on selection time was measured (Ahlström, 2005). This pseudo-haptic artifice, which manipulates the pointer's movement, was shown to reduce selection time.

Sun et al. (2012) had the intuition that, when steering a path using a pen, the physical quality of the surface may play a role in the performance. They superimposed sheets of different materials on a graphic tablet and used the steering-law experimental paradigm. Although they did not observe any effect on movement time, they did find that different surfaces affected accuracy and applied force. This provides evidence that people approach the stroke differently, depending on the surface they are drawing on.

Andersen and Zhai (2008) checked how handwriting and pen gestures may be affected by different kinds of feedback (no feedback, visual, audiovisual, auditory). Audio-only (continuous