Illusion of Surface Changes induced by Tactile and Visual Touch Feedback

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Abstract
The work presented here aims to enrich material perception when touching interactive surfaces. This is realized through simulating changes in the perception of various material properties, such as softness and bendability. The thereby created perceptual illusions of surface changes are induced using electrotactile stimuli and texture projection as touch/pressure feedback. A metal plate with an embedded electrode was used to provide the user with electrotactile stimuli when touching the surface with a finger that is also equipped with an electrode. The distortion of material textures projected on the touched surface was used to visually simulate surface deformations. We show through an experiment that both, electrotactile and visual feedback can induce the illusion of surface deformation when provided separately. When tactile and visual touch feedback is presented at the same time, the perception of surface changes does not increase compared to just using one feedback modality only.

Author Keywords
Haptics, touch; material simulation; deformable; surface.

ACM Classification Keywords
H.5.2. User interfaces: Haptic I/O.

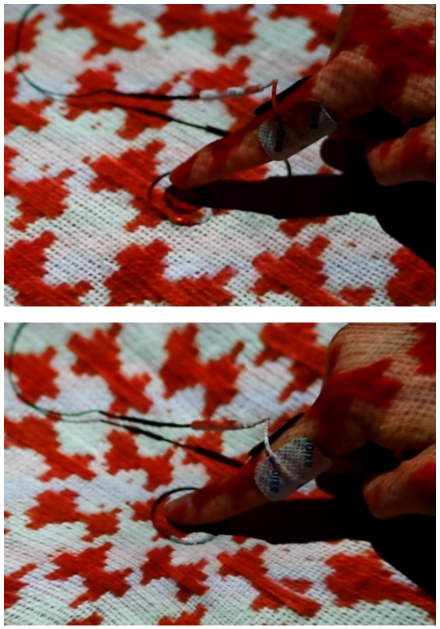

Figure 1. Texture is projected on a flat metal surface (top) and it is deformed when touched (bottom), which generates the illusion of surface deformation. Additionally or alternatively electro-tactile touch feedback can induce the illusion of touching a deforming surface. Electro-tactile stimuli are generated when touching an electrode embedded into a surface while another electrode is attached to the finger.

Background

While we are surrounded by many uneven and soft materials, touchscreens and touchpads are smooth and hard. When touching a soft surface, such as rubber or textiles, we perceive the surface properties through tactile as well as through visual sensation. For example, pressing on a soft surface causes skin stretching at the fingertip as well as visually perceivable texture deformation.

With the rise of touch-based interfaces, interactive screens are likely to become one of the most important ways in which we interact with computers, and as such will not only provide interfaces for devices, but also for smart surfaces built into furniture, walls, doors, cars, or clothes. Current touch-sensitive surfaces are constrained by the physical properties of the materials they are made from. Consequently, it is important that we strive to build better and more satisfying touch-based interfaces, that are reactive and which respond in intuitive ways based on our own sensory expectations.

Influencing (sometimes "overwriting") the perceptual experience of one or more senses when a surface is touched can create the illusion of touching a completely different surface. For example, electrovibration under a fingertip and the displayed image of sandpaper underneath can cause the illusion of touching real sandpaper [2]. Previous work induced the illusion of different surface materiality, namely roughness, when a finger was sliding across a surface using electrotactile touch feedback [1, 2]. Other research investigated how information from one sensory modality, such as audio or vision can simulate tactile perception [3, 4] or even can create a tactile surface illusion [5, 6].

The research proposed here however, aims to extend the range of surface illusions beyond what has done before (tactile illusions when sliding across a surface). We enrich the surface perception of static (or passive) touch through the use of visual and tactile feedback. We show that electrostatic tactile stimulation as well as simulated surface deformation using distorted projection effects the perceptions of various surface characteristics, e.g. softness and bendability.

Method

In an experiment, the effect of tactile, visual, and tactile-visual feedback on passive touch was investigated, while the tactile feedback was provided through an electrocutaneous display and the visual feedback was given through distortions of on-surface texture projections (see Figure 1).

Design

The experiment with 16 participants (4 females and 12 males, aged from 20 to 43 (mean=25.8, SD=5.75) had a within-subject design with two independent variables: electrotactile feedback (on/off) and projected texture deformation (on/off). As texture aimed to covered a broad range of natural materials to generate findings

Figure 2. The texture types represent ten different materials.

that can be generalized and applied to make all kinds of existing surfaces interactive. Thus, we selected material images representing very different surface properties, such as cardboard, cloth, corkboard, fur, styrofoam, grass, jam, leaf, sponge, and wood (see Figure 2).

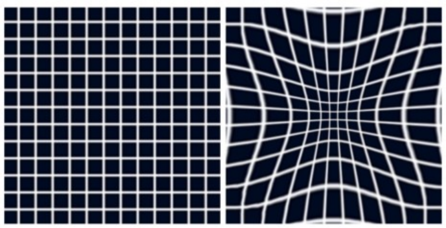

Figure 3. Texture distortion from 0.0 (left) to 1.2 (right). The grid is applied to each texture but not visible through the experiment.

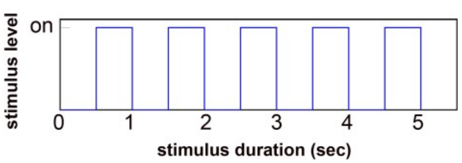

Figure 4. Electrotactile pattern that is changing in 0.5sec steps from on to off. The amplitude of the on-level is defined individually for each participant before the experiment.

The perception of the ten texture types, which we asked the participants to rate after each of the four feedback conditions, was measured using ten 7-item Likert scales. The Likert scales recorded the perceived strength of the following surface properties: softness, stretchability, smoothness, thickness, solidness, wetness, hardness, stickiness, viscosity, and bendability.

Apparatus

The experiment apparatus consisted of a 30x30cm white metal surface with an embedded electrode made out of copper, which was painted white to merge with the white surface. For activating and controlling the haptic stimuli, we used a Transcutaneous Electrical Nerve Stimulation (TENS) device as it is a save standard solution for electrotactile stimulation established in medical use. The electrode was connected to the Arduino controlled TENS device with 5.5-20mA and 0-80V. Another electrode that also was connected to the TENS device was attached to the participants' index finger using tape. A 4x4cm sized Interlink Electronics FSR 406² pressure sensor underneath the metal surface detected the time and the force when a participant touched the surface. A 25 lumen laser projector, mounted 1.1m above the surface, displayed the ten surface textures with 768x768 pixels on the white metal surface. The laboratory light was dimmed so that the texture projection was perfectly visible. During the conditions with surface deformation, the level of distortion (from 0.0 to 1.2, see Figure 3) was linearly mapped to the amount of pressure force (from 0.2N to 20N) measured with the pressure sensor. During the conditions with tactile feedback, an electrotactile pattern of 0.5 sec followed by a pause of 0.5 sec (defined by intensive pilot tests) was stimulating the participant's fingertip in a loop when a finger was touching the surface (Fig. 4).

Procedure and task

After a brief introduction into the purpose of the experiment, each participant was seated in front of the apparatus, and was equipped with an electrode on the middle index finger segment of the right hand. We did not attach it on the fingertip for not reducing the tactile sensation while touching the surface. The order of tactile feedback (on/off) was counterbalanced. Eight participants started with receiving tactile stimuli during the first 20 material projections, while each of the ten projections was once distorted and once not. Then the procedure was repeated without electrotactile feedback. The second eight participants, who were also equipped with the electrode in the beginning, did not receive additional tactile feedback during the first 20 material projections but during the second 20 projections. The order of the 20 projections of the ten material textures (once distorted and once not) was randomized.

During each of the 40 trials, the task was to touch the surface in the center (where the electrode was embedded into the while metal) and to apply pressure for one second. The start of the second was detected through the pressure sensor (threshold=0.2N), and the end of the second was announced through a short beep sound. The pressure force was self-paced.

Results

We analyzed if tactile or visual touch feedback influences the perception of surfaces. Friedman test was used to explore if the tested surface characteristics were affected by the use of tactile and visual touch feedback. We found that feedback over all materials had a significant effect on texture perception for softness ($\chi^2(3) = 32.745$, $p < 0.001$), stretchability ($\chi^2(3) = 28.087$, $p < 0.001$), thickness ($\chi^2(3) = 9.906$, $p = 0.019$), solidness ($\chi^2(3) = 25.774$, $p < 0.001$), hardness ($\chi^2(3) = 22.414$, $p < 0.001$), and bendability ($\chi^2(3) = 20.467$, $p < 0.001$). For these attributes, post hoc analysis with Wilcoxon signed-rank tests were conducted with an applied Bonferroni correction, resulting in a significance level of $p < 0.0125$.

Softness: When haptic feedback was not provided, the visual feedback of texture distortion significantly affected the participants' perception of softness. The surfaces were perceived to be softer when the texture was distorted (haptic feedback = off, distortion = 0.0 vs. distortion = 1.2: $Z = -3.517$, $p < 0.001$). Similarly, if the projection was not distorted, the perception of softness was significantly stronger when electrotactile feedback was provided versus when it was avoided (distortion = 0.0, $Z = -3.517$, $p < 0.001$). Interestingly, if haptic and visual feedback were provided at the same time, the softness perception did not change significantly compared to just perceiving one or the other feedback modality (distortion = 1.2 and varying haptic feedback: $Z = -0.284$, $p = 0.776$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

Stretchability: When no haptic feedback was provided, the texture deformation significantly increased the participant's perception of stretchability ($Z = -3.517$, $p < 0.001$). Similarly, if the texture was not distorted, the addition of haptic feedback significantly increased the participants' perception of stretchability ($Z = -3.414$, $p = 0.001$). Again, the combination of both feedback types, haptic stimuli and visual distortion, did not yield to significantly different perceived surface stretchability compared to just using one feedback modality (distortion = 1.2 and varying haptic feedback: $Z = -0.126$, $p = 0.900$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

Thickness: However, the Friedman test yielded significance for thickness, Wilcoxon signed-rank tests with a Bonferoni-corrected significance level of 0.0125, did not (haptic feedback = off: $Z = -2.138$, $p = 0.033$). Similarly, if the texture was not distorted, the addition of haptic feedback significantly increased the participants' perception of thickness (distortion = off: $Z = -2.106$, $p = 0.35$). Moreover, the combination of both feedback types, haptic stimuli and visual distortion, did also not yield to significantly different perceived surface thickness (distortion = 1.2 and varying haptic feedback: $Z = -0.829$, $p = 0.407$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

Solidness: When no haptic feedback was provided, the texture deformation significantly strengthened the participant's perception of solidness ($Z = -3.266$, $p = 0.001$). Similarly, if the texture was not distorted, the addition of haptic feedback significantly increased the participants' perception of solidness ($Z = -3.209$, $p = 0.001$). Again, the combination of both feedback types, haptic stimuli and visual distortion, did not yield to significantly different perceived surface solidness compared to just using one feedback modality (distortion = 1.2 and varying haptic feedback: $Z = -1.351$, $p = 0.177$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

Hardness: When no haptic feedback was provided, the texture deformation significantly increased the subject's perception of hardness ($Z = -3.238$, $p < 0.001$). Similarly, if the texture was not distorted, the addition of haptic feedback significantly increased the participants' perception of hardness ($Z = -3.238$, $p = 0.001$). Again, the combination of both feedback types, haptic stimuli and visual distortion, did not yield to significantly different perceived surface hardness compared to just using one feedback modality (distortion = 1.2 and varying haptic feedback: $Z = -1.454$, $p = 0.146$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

Bendability: When no haptic feedback was provided, the texture deformation significantly increased the participant's perception of bendability ($Z = -3.181$, $p = 0.001$). Similarly, if the texture was not distorted, the addition of haptic feedback significantly increased the participants' perception of bendability ($Z = -3.258$, $p = 0.001$). Again, the combination of both feedback types, haptic stimuli and visual distortion, did not yield to significantly different perceived surface bendability compared to just using one feedback modality (distortion = 1.2 and varying haptic feedback: $Z = -0.032$, $p = 0.975$; haptic feedback = on and varying visual distortion: $Z = 0.000$, $p = 1.000$).

In summary, electrohaptic stimuli and visual texture distortion influenced the perception of softness, stretchability, solidness, hardness, and bendability of a touched surface, while the perception of these attributes was not further enriched if both feedback modalities were provided at the same time. Thus, providing multimodal feedback, consisting of tactile and visual stimuli, did not significantly enrich the perception of surface changes compared to just provide feedback of either electrohaptic or visual stimuli.

Discussion

Both, electrotactile and visual feedback add to the perception of the surface properties stretchability, solidness, hardness, and bendability, even if presented solo. Thus electrotactile feedback and simulated visual surface distortion can extend the user experience of touch-based interaction on normal touchscreens or interactive projections, but also on GUI-free interfaces, such as furniture, walls, and other materials in our environment as long their allow for embedding electrodes to provide electrotactile stimuli.

Similar to Lécuyer and Lécuyer et al. [4, 5], we reported that visual information can create tactile illusions, in particular illusions of perceived changes of the surface materiality. Moreover, we can extend the work of researchers who showed that electrotactile stimuli can extend the tactile perception of active touch (sliding across a surface) [1, 2], as we have shown that such feedback can also enrich passive touch (pressure at a static point).

When the stimuli of both, tactile and visual modalities were given at the same time, the information was not strengthening the perception of certain surface properties, but the perceived change of surface properties was as strong as if only one modality was used. Thus, no intersensory effect was perceived by the participants, neither through a conflict of the information of both feedback modalities (which would have neglected the perceptual change [7]) nor through a stronger perceptual change when using two feedback modalities. A possible reason for the absence of an increase of perception for multimodal stimuli may be ceiling effects as the perception values were already very high when applying one modality only.

Conclusion and Future Work

While previous work mainly investigated active touch [1, 2, 3], we explored the perception of passive touch if electrotactile feedback is given. Regarding the surface perception, we found that the characteristics softness, stretchability, solidness, hardness, and bendability can be simulated through electrostatic stimulation of the touching fingertip or through distorting texture while it has been pressed.

For better understanding how the effect of surface perception can be strengthened through intersensory effects occurring if using two or more feedback modalities, the information given by each modality should be explored in greater detail. For instance, characteristics that are linked with the pure modality stimuli could be further explored and also how such information correlates with the expectation when touching/pressing certain materials (represented e.g. through projections).

In summary, our work extends the research body on triggering material perception through electrostatic stimulation as well as through visually simulated texture distortion. Simulating surface properties for passive touch and pressure enables richer touch feedback, which can lead to richer experience of touch-based interaction. Thus, enriching surface perception and thus creating more natural means of touch interaction through generating touch-based illusions can support the myriads of touch-based devices. That potentially enriches the experience when interacting with mobile phones, tablet devices, tabletop devices, and interactive surfaces that may have no built-in touchscreen but that potentially can use visual cues generated by projections.

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