Tangible 3D Haptics on Touch Surfaces: Virtual Compliance

Johan Kildal
Nokia Research Center
P.O. Box 407, FI-00045
Nokia Group
johan.kildal@nokia.com

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Abstract
Suitability of current haptic three-dimensional user interface (3D-UI) technologies is low for mobile interaction. 3D-Press in reviewed in this paper: a technique to create the haptic illusion that when pressing on a rigid surface is feels compliant. The fact that the illusion is intramodal (haptics only involved in creating it), and that the technology required is simple and with low energy demands, makes it ideal for mobile use. The parameters used in the implementation of 3D-Press influence the characteristics of the illusion. A research agenda is proposed to understand this relationship, as well as to learn how to integrate 3D-Press in multimodal interfaces for constantly-changing mobile use contexts.

Keywords
Haptic Illusions, 3D Interfaces, Mobile Interaction, Multimodal Interfaces.

ACM Classification Keywords
H.5.2 Information interfaces and presentation: User Interfaces: *Haptic I/O.*

General Terms
Design, Human Factors

Introduction

3D-UIs are entering the mainstream led by audio and visual technologies [1]. Even in mobile devices, flat displays rendering volumetric images combined with spatialised audio engines are a reality. In contrast, 3D haptic rendering seems to be lagging behind, particularly for mobile use.

The techniques that have been proposed to generate computer-controlled tangible surfaces outside the interaction plane involve either creating actual forces and displacement that the skin can feel, or evoking the illusion of such forces and displacements. Pin array displays and 3D force-feedback devices are examples of the first approach [2; 3]. Examples of the second type are lateral force fields, lateral skin deformation and visually-evoked pseudo-haptics [4-6]. Techniques combining both approaches have also been proposed, as in the case of tangible holograms [7].

All of the above examples present limitations for their implementation and use in mobile devices and mobile contexts. They sometimes involve cumbersome hardware, which is power-hungry and impractical to carry as a personal device. In other cases, the illusions created rely heavily on a visual representation, without which the illusion does not arise, thus making them inappropriate for sporadic non-visual interaction.

3D-Press [8] is a technique that was developed to create the haptic illusion of compliance when pressing on a surface that is actually rigid. When a user presses on a rigid surface (such as on a touch screen) he or she feels that the surface recedes as a result of the force applied (while it does not deform perceivably, in reality). This technique fulfils a set of characteristics that make it particularly appropriate for its implementation and use with mobile devices and in mobile contexts, as it is detailed below.

Principle of the Illusion in 3D-Press

As discussed further in [8], of the two types of cues (kinaesthetic and cutaneous) that we use to obtain information about compliance of a material [9], 3D-Press makes use of only a cue of the cutaneous type. The cue is presented to the user's hand that is applying force onto the surface (either by directly pressing on it with a finger or through a stylus). The cutaneous cue is a very brief vibration grain (18ms ramp-down-time inverted sawtooth envelope, with a base frequency of 156Hz, in the implementation used in [8]).

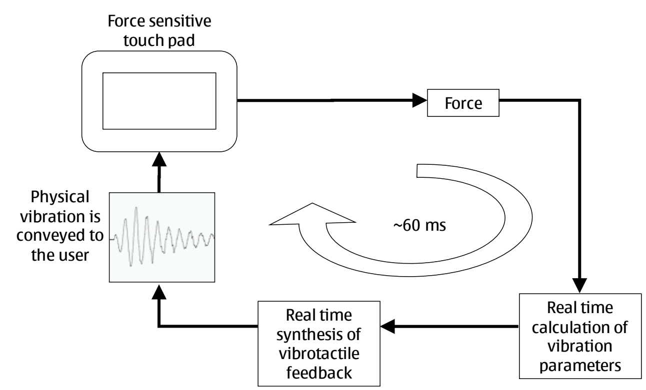

figure 1. Interaction loop: from the user modifying the force applied, to his or her skin being excited by a vibration grain at its maximum amplitude. The latency shown is a maximum for the illusion to emerge.

A displacement-with-friction model is imitated in 3D-Press. In this model, an increase in the force applied produces a displacement of the surface of contact, simulating the surface of some deformable material or mechanical assembly. In this model, the friction in the displacement is high enough to be perceived as vibration by the user applying the force. The model is further enhanced by its behaviour being such that friction is perceived both when the force applied increases and when it decreases. This suggests to the user an elastic behaviour with displacement inwards and outwards as a function of the variations in force.

In the implementation of this model, it is the vibration aspect of the friction that is presented to the user. The synthesis of the vibration grains is commanded by the variations in the force applied: for each pre-defined amount of variation in the force, a grain of vibration is produced, truncating previous grains that might be ongoing. If the complete interaction cycle is so fast that the user perceives the variations produced in the force and the vibration grains to be synchronous, a causal relationship is easily established. This perceived causality is necessary to create this illusion. A total latency of less than 60ms (between the user slightly varying the force, and the vibration reaching its maximum amplitude on the user's skin), is known to be short enough.

Suitability for Mobile Interaction

Although formal testing has so far only taken place on a desktop scenario, elements involved in the implementation and use of this technique (plus some evidence from initial piloting) indicate that 3D-Press fulfils all the important criteria to be a technique suitable for mobile use. The illusion is intramodal, meaning that only haptics are involved in its creation: proprioceptive and cutaneous perception of the voluntary changes in the force applied, and cutaneous vibrotactile stimulation, carefully synchronised in time. This haptics-only nature of the illusion is important for sporadic non-visual and non-auditory interaction, typical of mobile contexts of use. Another advantage of this technique is that it is compatible with both finger and stylus interaction on touch screens. Additionally, the hardware required (a force sensing touch display and a vibrotactile actuator) can be easily integrated in a personal mobile device, and the energy requirements are low enough for mobile use. Finally, it is possible to control the perceived characteristics of the illusion programmatically, in a simple way. The highest technical demand is on low latency, which would not be met by most mobile devices currently in the market. However, the latency requirements are perfectly achievable with current technology.

Validation

Sixteen variants of the basic model were implemented for a qualitative evaluation, already reported in [8]. They varied in design aspects like the number and distribution of friction grains along the virtual displacement distance of the model, the amplitude and the regularity of the vibration grains. Thirteen naïve participants were asked to press on a hard surface with a stylus and report verbally their experience as it took place. No hints were given to them as to the resulting illusion that was intended. The results revealed that the illusion of compliance (of displacement of the surface that was being pressed) arose spontaneously for every participant and with every implementation presented. Furthermore, the majority of the 13 naïve participants reported the illusion from their very first trial (on the second and on the third trial in two cases only). All this suggests that the haptic illusion of compliance is evoked strongly, without the need to suggest it visually or in words.

The analysis of the descriptions (through thematic analysis [10]) also identified a set of dimensions along which the experiences reported can be classified: depth vs. shallow displacement, rough vs. smooth displacement, and hard vs. soft material. In addition, a long array of metaphors borrowed from the physical world was provided, suggesting that the model of displacement with friction was successfully constructed. The most common metaphors related to pressing on rubbery or spongy material, pressing on springs or spring-mounted elements, and penetrating granular material, like sand.

Multimodal Modulation of the Illusion

Haptics alone are enough to evoke the illusion of compliance with 3D-press. This is an advantage for its use in mobile interaction, where the changing contexts often render the visual and auditory channels intermittently unusable, such as when walking on a busy street. It is equally true that there can be occasions in which the tactile channel is hindered while others are available, for instance during a bumpy ride on public transport. For this reason, some level of modality redundancy can be beneficial to help bridge the transitions between use contexts.

During the evaluation reported above, participants pressed on a physical surface that they could see and that it obviously did not deform. Still, the haptic illusion of compliance was extensively reported, showing that the incongruence between what was seen and felt did not pose much conflict. However, it can be expected that when all main sensory channels are available and the user can pay attention to all of them, preserving congruence can modulate the perceived experience by at least reinforcing it. Furthermore, such renderings can successfully modulate the basic illusion, enriching it with specific characteristics. For example, visually representing the displacement of the compliant material could reinforce the sensation of depth perceived on the hand, as in the case of the visually-evoked pseudo-haptic techniques reviewed in the introduction. At the same time, the auditory rendering of the friction that is felt in the hand can help the user judge aspects like the roughness of that friction [11].

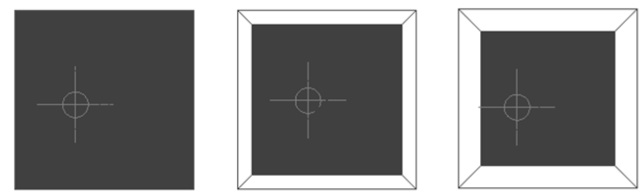

figure 2. Example of a simple visual representation of a spring-mounted push-button, in three different stages of its continuous movement: from not pressed on the left to fully pressed in on the right.

Thus, the haptic-only implementations done already could be modulated multimodally, so as to strengthen their identity as one of the metaphors reported in the study. For example, the behaviour of a spring-mounted push-button that travels for a certain distance under the action of the force applied on it could be evoked making use of very simple graphics. The graphic design in Figure 2 was used in a pilot test of this concept, conducted during an internal demonstration. The participants, who were also naïve to the purposes of the demonstrator, used a similar setup of graphics tablet with augmented stylus described earlier. In addition to this, the participants could see in this pilot study how a very schematic representation of a square button appeared to sink into a square cavity, responding to the variations in the force applied (figure 3). The participants pressed 12 buttons with identical visual behaviour but different implementation of the haptic feedback (the same set of haptic implementations as used in [8]).

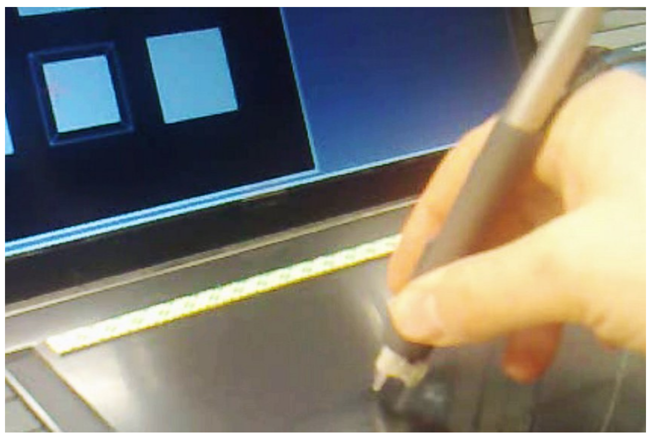

figure 3. User testing the illusion with 3D-Press augmented with a visual representation. While the user already perceives haptically that the rigid plastic surface is actually compliant when pressed with the augmented stylus, a visualization of the same model can reinforce and even model the illusion

This pilot study showed that, although no mention of a button was made to the naïve participants, this was almost the only metaphor mentioned by all of them, in contrast with the variety of metaphors that had been evoked by the same set of tactile feedback designs in the previous evaluation study. Additionally, while different characteristics of the buttons were mentioned with variations in hardness and smoothness among them, differences in depth of travel were less noticed, unlike in the haptics-only study in which the range of depths of displacement reported with the same set of stimuli was very broad.

These initial data suggest that if the same visual behaviour is presented with different tactile implementations, the scope of characteristics perceived in the illusion is reduced. This idea could be followed with the hypothesis that specifically-designed visual renderings could also modulate the perceived characteristics of this illusion in other ways. The same hypothesis could be formulated for the combination of 3D-Press with different designs of auditory behaviour, and combinations of all three modalities.

Research Agenda

The results from the evaluation and pilot reviewed in this paper indicate that systematic research needs to be conducted to properly understand the following questions:

- How the haptic design parameters used in the different implementations of 3D-Press influence the perceived qualities of the illusion.
- How other modalities can be incorporated to modulate and further enhance the illusion of compliance, with specific perceived physical and mechanical properties.

Researching these questions can offer considerable insight into multimodal perception and in how to apply such insight in interaction design, and particularly in the design of new interfaces for touch interaction.

Conclusions

3D-Press is a technique developed to create an illusion of compliance when pressing on a hard surface. As an intramodal haptic illusion that requires simple technology and low power consumption, it is a suitable technique for the design of tangible 3D-UIs that can be used in mobile interaction. Evidence that this illusion can create a range of different perceived mechanical properties has already been gathered. Now it is left to understand how to modulate these perceived properties in a controlled way. Learning how to combine this illusion with congruent auditory and visual representations is likely to assist in this task, as well as helping bridge its use across changing use contexts.

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