Feeling Rough:
Multimodal Perception of Virtual Roughness

Marilyn Rose McGee, Philip Gray, Stephen Brewster

Glasgow Interactive Systems Group
Department of Computing Science
University of Glasgow, Glasgow, G12 8QQ, UK

Tel: (0141) 330 3541
Email: {mcgeemr, pdg, stephen}@dcs.gla.ac.uk
Web: http://www.dcs.gla.ac.uk/~mcgeemr

Abstract

The texture of a real or virtual surface can both increase the sense of realism of an object as well as convey information about an object's identity, type, location, function, and so on. It is crucial therefore that interface designers know the range of textural information available to them through current interaction devices in virtual environments. We have examined roughness perception of a set of force feedback generated textures (conveyed via a PHANToM device) in order to better understand the range and resolution of textural information available through such interaction. We propose that the addition of audio stimuli will increase further the potential for conveying more varied and realistic texture percepts through force feedback interaction. We are currently examining roughness perception of a set of auditory stimuli and will use both sets of unimodal results to test the potential benefits of combining haptic and auditory textural stimuli.

Keywords

Haptic, auditory, force feedback, texture, roughness perception, multisensory, multimodal interaction.

Introduction

Despite the increasing prevalence of haptics in today's computing environments, the effective representation of such information is still a relatively new design problem for human computer interaction research. Force feedback interfaces in particular pose a variety of design questions such as what can and cannot be communicated convincingly via such devices.

In human sensing and manipulation of everyday objects, the perception of surface texture is fundamental to accurate identification of an object [5]. In a virtual world also, texture information can both increase the sense of realism of an object as well as convey information about what the object is, where it is, and what it is for [4]. Through force feedback interaction in particular we can provide textural information that we can literally feel through the haptic modality. Given that it is often argued that touch is the 'reality sense' [2], being able to feel the texture of a virtual object should surely lead to increased realism of the object.

Previous work investigating the perception of real surface textures has shown that the physical properties of textures are complex and that an overall understanding of texture perception remains somewhat elusive [e.g. 3,4,5]. Textures are therefore proving difficult to reproduce successfully in virtual environments. It has been accepted however that roughness (along with hardness) is certainly one of the primary properties of a surface used to identify and classify an object. We have chosen therefore to focus our research initially on this dimension of roughness of virtual surfaces.

Simulating textures with force feedback devices in particular has proved an interesting research problem. Force feedback devices convey texture by actuating kinesthetic forces on the users' finger, hand, or body. This type of interaction relies on forces created through kinesthetic movement or displacement of the device and user limbs or joints while much of the texture perception we are used to comes through tactile stimulation of the mechanoreceptors on or just below the surface of our skin [5]. We have found in our previous work that such 'gross' or large textures can perturb the users' movements so much that the ability to stay on the textured surface is adversely affected [7]. More careful design of such force feedback based textures is required if these devices are to reach their full potential.

High fidelity force feedback devices (such as the PHANToM) are becoming increasingly realistic interaction tools in a variety of applications where the texture of a virtual surface may be of great importance. Medical research for example can exploit such interaction in surgical and diagnostic simulations where the texture of tissue or organs may provide crucial information or feedback to the surgeon during a procedure.

Force feedback interaction is also improving the ability to design and prototype a variety of products ranging from the commercial (e.g. cars) to artistic and historical artifacts (e.g. sculptures and jewelry). E-Commerce will also benefit in that companies can provide their customers with a close representation of the feel of their products before they buy. The textile and fashion industry in particular could anticipate increased online sales if the texture of the clothing could be felt before purchasing [1].

It is crucial therefore that interaction designers know the potential range of textural information available through each modality and indeed each device available to them. With the increasing prevalence of force feedback interaction, it is particularly important to establish this for the haptic modality and high end of the range devices such as the PHANToM (SensAble Technologies).

Past research suggests that texture representation is possible through force feedback interaction but that the ideal solution is yet to be found. This is due in part to the mismatch between real texture perception (which involves both cutaneous and kinesthetic sensation) and virtual texture perception (which normally relies on either cutaneous sensation through tactile devices or kinesthetic sensation through force feedback devices). The problem could potentially be solved by advancing the currently available devices in order that the devices better suit real texture perception [e.g. 8]. This hardware-based solution is inevitable as the technology advances.

Another solution may be to improve the physical and mathematical modeling of real textures to produce the optimum algorithms for generating realistic virtual textures. This method currently has mixed results, as it cannot be assumed that the virtual exploration of texture matches that of real texture perception. Exact physical modeling therefore may be pointless if the interaction used to experience the texture differs significantly from that assumed by the physical model.

Proposed Solution

Our approach offers a cost-effective approach that makes use of the currently available devices and even the simplest physical models of texture. We propose a multimodal solution that exploits the human ability to combine and integrate information from multiple sensory modalities into a fused and meaningful and whole percept. We hypothesise that presenting combined haptic and audio percepts of roughness will increase the quantity and quality of textural information available through force feedback interaction alone.

Overview of Experiments

The current work involved: (1) the evaluation of the effect of texture frequency on perceived roughness of a set of force feedback generated textures, (2) a follow up study extending the range of frequencies used and examining the possibility that there were two distinct notions of roughness emerging from the range of textural stimuli used, and (3) the evaluation of the effect of texture frequency on perceived roughness of auditory textures created from the profiles of the force feedback textures. This perceptual classification process will serve as a basis from which to test the eventual effects of systematically combining the haptic and auditory texture stimuli.

The Force Feedback Device

The PHANToM 1.0 force feedback device by SensAble Technologies (Figure 1) was used to generate the virtual textures. Optical sensors detect changes in the device's configuration and mechanical actuators apply forces back to the user. Users interact with the device by holding a pen-like stylus attached to a passive gimbal on the device.

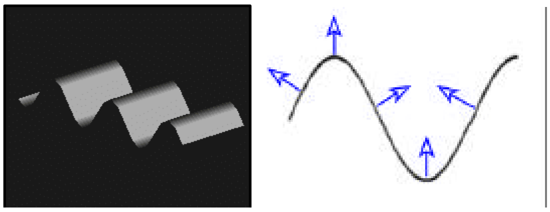
By scraping this stylus/probe back and forth across the

Figure 1: The PHANToM 3D force feedback device from SensAble Technologies.

textured area the appropriate forces can be calculated from the positional information of the tip of the probe and the stored algorithmic models of the textured surface with which the user is interacting.

Haptic Textures

Haptic textures were generated as sinusoidal waves or gratings on a rectangular patch on the back wall of the workspace. Figure 2 shows a diagrammatic view of the profile of a texture and the forces generated as a result of this profile.



(a) (b)

Figure 2: (a) diagrammatic view of the profile of the texture; (b) indication of forces resulting from amplitude and frequency of texture wave.

The resulting texture profiles depend therefore on the amplitude and frequency of the sinusoidal waves. The textures had fixed amplitude of 0.5mm and variable frequency (cycles per 30mm). The frequencies used varied from 5 – 45. Higher frequencies were more tightly packed waves and lower frequencies were more loosely packed waves. The result of these textures was a bump felt at the peak of each wave.

Auditory Textures

Auditory textures were generated from the same sinusoidal waves on a rectangular patch on the back wall of the workspace. The resulting profile still depended on the amplitude and frequency of the waves. The result of these textures was a single MIDI note generated from and heard at the peak of each wave. No experimental forces were experienced through the device.

Roughness Comparisons

Participants in Experiment 1 could rate the textures as the same, the one on the left as rougher, or the one on the right as rougher. Participants in Experiment 2 were given the same options but with the additional response option of rating the textures as not comparable on the same roughness scale. This set of responses allowed us to evaluate (a) whether the participant perceived the two textures as the same or as different in terms of roughness, and (b) the number of times each texture was rated as the roughest of the pair.

In addition, the added response in Experiment 2 allowed us to evaluate (c) which textures participants felt were different but not comparable along the same roughness scale. This was added as it was observed in experiment 1 that people often perceived a haptic difference but that they could not decide easily which one was in fact rougher.

Procedure

Participants (Experiment 1, N=12; Experiment 2, N=10, Experiment 3, N= 12) were instructed to drag the probe of the device over each of the indicated textured surfaces and make a judgment on the roughness of the pair of textures. Participants compared each texture to itself and to each of the others twice (in a random order). In experiment 1, subjects compared 6 textures. In experiment 2 the frequency range was extended to include 9 textures.

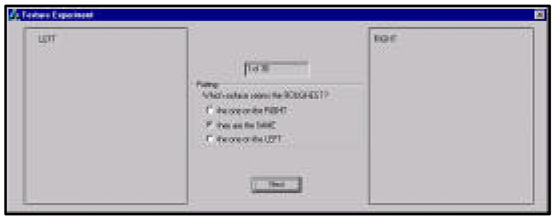


Figure 3: Interface for roughness comparisons

Participants were allowed to explore each of the textures during that trial for as often as they liked and could switch between exploring the one of the left to exploring the one on the right as often as they liked to compare the two textures. They were instructed however that it was their initial response to the textures that mattered most and that there were not necessarily right or wrong answers for each of the trials. Participants made their response by clicking the switch on the probe of the PHANToM to select the response that reflected their roughness judgment for each trial.

A training session identical to the experiment but with less trials allowed the participants to become familiar with the device and the interface. Importantly, it also allowed them to adopt an exploration strategy for experiencing the textures comfortably and successfully.

Hypotheses

Independent Variable: frequency of texture (cycles per 30mm).

Dependent Variable: Perceived roughness, operationalised as the number of times each texture was judged as the roughest of the pair.

Exp. 1: The frequency of the haptic texture (or number of bumps) will have an effect on the perceived roughness of the texture.

Exp. 2-a: Increasing frequency of haptic texture (or number of bumps) will lead to an increase in the perceived roughness of the texture.

Exp. 2-b: There may be a bimodal function of roughness with a frequency from either end of the scale being perceived as the roughest of the set.

Exp. 2-c: Textures compared from either end of the frequency range are more likely to be rated as not comparable on the same roughness scale than textures compared within the high range or within the low range.

Exp. 3: The effect of frequency of audio texture (or number of notes) will have an effect on the perceived roughness of the virtual texture.

Haptic Results (Experiment 1)

Effects of Frequency on Perceived Roughness

The frequency of the texture was shown to have a significant effect on perceived roughness. That is, there was a significant effect of frequency on the number of times a texture was judged as the roughest of a pair ($F=9.73$, $p<0.01$). The number of times each (frequency of) haptic texture was judged as roughest tended to increase as the frequency of the texture increased (see Figure 4).

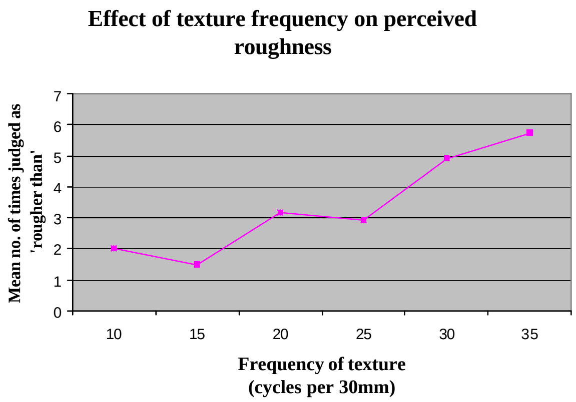


Figure 4: Effect of frequency on perceived roughness.

It is likely however that the range used in the experiment is only a sample from a more complex function. In fact, the graph shown may not be part of a simple monotonically increasing function at all. Instead it may be part of a quadratic function of perceived roughness as suggested by people such as Lederman *et al.* [6]. At the very least, it may be likely that there is more than one maximum roughness generated from the set of frequencies.

Two distinct notions of haptic virtual roughness?

Participant comments began to suggest that the lower frequency of 10 was considered very rough 'like corrugated material'. The higher frequencies of 30 and 35 however were also labeled as very rough but 'like sandpaper'. It is possible then that 2 frequencies from opposite ends of the scale can be perceived as equal in roughness magnitude but from different roughness scales.

Experiment 2 extended the range of textures (5-45 cycles) to evaluate whether the increasing frequency leading to increasing perceived roughness relationship still held beyond the range used in Experiment 1 and whether the bimodal peak roughness points emerged. This follow up study also evaluated our suggestion from Experiment 1 that comparing two textures from either end of the frequency range would increase the likelihood that they would be judged as different but also increase the likelihood that they would not be able to compare the textures on the same roughness scale. Final results from this evaluation will be presented at the workshop.

Identical Haptic Stimuli

Textures with equal frequency were judged as the same roughness on an average of 64% of the trials. It appeared that higher identical frequencies were more likely than lower identical frequencies to be successfully judged as the same. This could perhaps due to the interaction between probe size and texture-profile size - lower frequencies being more susceptible to differences in hand force and exploration speed. Further statistical analysis of exp.1 and exp.2 will investigate this hypothesis further.

Different Haptic Stimuli

A frequency separation of 5 cycles was not sufficient to significantly separate the perceived level of roughness for the haptic textures used. That is, textures separated by a frequency difference of 5 cycles were often judged as the same roughness. As frequency differences increased participants found it increasingly easy to decide whether the textures felt the same or different but increasingly difficult to decide which of the two was in fact the roughest. These results will be discussed in more detail at the workshop.

Auditory Roughness (Experiment 3)

The audio virtual roughness experiment is currently underway and the effects of frequency of notes on perceived roughness of the audio textures are being evaluated using the same experimental paradigm. The MIDI instrument being used is piano although this will be compared to other instruments in the future. Our main concern for the initial audio experiment was purely to explore the effects of frequency of an arbitrary sound or note on the perceived roughness of the auditory texture. Results from the auditory roughness experiment will also be presented at the workshop.

Future Work

The results of the haptic studies suggest that larger frequency differences lead to more easily distinguishable textures but also to difficulties in using the dimension of roughness in comparing textures. Large textures have also been found to throw users off of some textured areas [7]. The addition of audio information to such force feedback textures might ameliorate some of these restrictions.

We propose that the combined (multisensory) presentation of haptic and audio textural information will increase the range and/or resolution of textures available to the designer without disturbing interaction through force feedback devices. Results from the unimodal haptic and audio studies will be presented at the workshop. Our future multimodal (haptic – audio) experiment will also be discussed in more detail.

Acknowledgments

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