Mixed Feelings:
Multimodal Perception of Virtual Roughness

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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 important therefore that interface designers understand the range of textural information available to them through current interaction devices in virtual environments. Previous work (e.g. [2]), has examined the perceived roughness of a set of force feedback generated textures (conveyed via a PHANToM device) in order to work towards such an understanding. In doing so, this work has highlighted the possible perceptual limitations involved in reliably and confidently judging the relative roughness of a set of haptic textures. How many textures can we distinguish between for example and how likely is it that we reliably judge any one as rougher than, less rough than or the same as the other?

The work presented here empirically investigates the effects of adding auditory textural cues to the existing haptic textures. Does the existence of an additional cue (in the auditory modality) change the answers to our questions above for example? We propose that the addition of auditory stimuli will increase the potential range and resolution of texture roughness percepts available through force feedback interaction.

Keywords

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

Introduction

In a virtual world 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 [2]. Through force feedback interaction in particular we can provide texture information in virtual environments that we can literally feel through our haptic (touch) modality.

Previous work investigating the perception of real surface textures has shown that an overall understanding of the physical properties of textures remains somewhat elusive [e.g. 2,3,4]. Virtual textures are therefore not necessarily straightforward to produce. Despite the complex nature of textures it has been accepted that roughness (along with perhaps hardness) is one of the primary properties of a surface used to identify and classify an object. We have chosen therefore to focus our research on the dimension of roughness of virtual surfaces.

Force feedback devices convey texture specifically 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 [3]. 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. The exact quantity and quality of textural information available through such devices must therefore be explored.

Previous unimodal studies of the perceived roughness of a set of force feedback generated textures have shown some possible limitations in reliable roughness discrimination (for full details see [5]). It was found for example that participants did not necessarily judge identical textures as the same roughness. Nor did they necessarily judge adjacent textures in a set as reliably different in terms of roughness. The current experiment examines the effects of multimodality (adding auditory cues) on the perceived roughness judgments of an equivalent set of force feedback textures.

This multimodal approach offers a cost-effective solution to overcoming the possible perceptual limitations of the currently available devices and texture models. Such a solution exploits the human ability to combine and integrate information from multiple sensory modalities into a fused, meaningful and whole percept. We hypothesise that presenting combined haptic and audio percepts of roughness will increase the reliability and confidence with which people can make comparative roughness judgements of force feedback textures.

Overview of Experiment

The Force Feedback Device

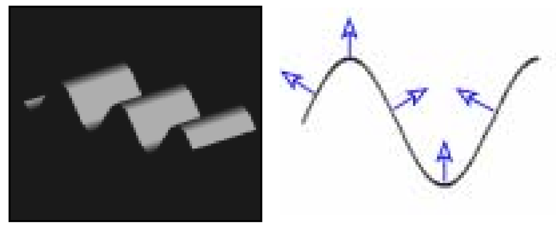
The PHANToM 1.0 force feedback device by SensAble Technologies (Fig. 1) was used to generate the virtual textures. Optical sensors detect changes in the device's configuration and mechanical actuators apply forces back to the user. Users interact with the device by holding a pen-like stylus attached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

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

By scraping this stylus/probe back and forth across the textured area the appropriate forces or sounds can be calculated from the positional information of the tip of the probe in combination with the stored algorithmic models of the textured surface. The device was placed beside the monitor, on the desktop in a similar position to that of the standard mouse.

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. The resulting texture profiles depended therefore on the amplitude and frequency of the sinusoidal waves. The textures had a fixed amplitude of 0.5mm and variable frequency (cycles per 30mm). Higher frequencies were more tightly packed waves and lower frequencies were more loosely packed waves. As a result these textures were felt as a bump at the peak of each wave.



(a) (b)

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

The frequencies that were used in the experiment varied from 10 – 35 cycles in increments of 5 cycles. These boundaries were selected due to observations from our previous work [5]. Participants previously commented that textures of 5 cycles felt more like individual bumps than texture elements and that those of 40 and 45 were more of a smooth buzzing vibration when compared with the other more 'corrugated' or 'jagged' textures. The perceived roughness scores also confirmed this. The range of frequencies sampled came therefore from the monotonically increasing section of the function found in the unimodal haptic roughness experiments [5].

Multimodal (Haptic-Auditory) Textures

Multimodal 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 as in the unimodal haptic case. The result of dragging the PHANToM pen across these textures however was a single MIDI note generated from and heard at or near the peak of every wave. This was in addition to the haptic forces as described above. Participants experienced these auditory cues via headphones in order to mask the motor-generated sounds from the device as far as possible.

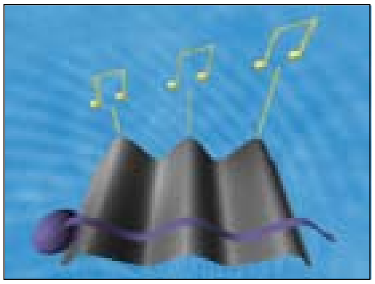


Figure 3: diagrammatic view of the profile of the multimodal texture for the congruent condition.

Modality of judgement

There were three conditions under which all participants experienced all combinations of the texture pairs including comparisons where the haptic frequencies were identical. All conditions involved comparing a unimodal haptic texture with another texture that could be (1) unimodal haptic, (2) multimodal and congruent, or (3) multimodal and incongruent. The definitions below explain further the notion of multimodality as well as the notion of congruency versus incongruency used in this experiment.

Haptic (H): a haptic texture is compared against another haptic texture. No auditory stimuli are presented in this condition.

Multimodal Congruent (MMC): every haptic texture is compared against every multimodal texture. The haptic frequency and auditory frequency are numerically identical. That is the number of haptic bumps matches the number of auditory bumps.

Multimodal Incongruent (MMI): every haptic texture is compared against every multimodal texture. The auditory frequency is 120% of the haptic frequency. That is, the number of auditory bumps is 20% greater than the number of haptic bumps.

Relative perceived roughness ratings

A modified forced choice paradigm was used to allow users to rate the perceived roughness of any two textures. Participants could rate the texture on the left as rougher, the texture on the right as rougher, or both as the same roughness. The 'same' option was included to examine how reliably two physically identical stimuli are perceived as the same roughness in addition to how rough each different (frequency of texture) is rated compared with each of the others.

The Design

A within subjects (N=18) design was used with two independent variables - Modality of judgment, and Frequency of texture. The dependent measure was the relative perceived roughness rating of each texture. This rating was gathered as a count of the number of times each of three possible responses was used: texture is the roughest of a pair; texture is least rough of a pair; and texture is the same roughness as the other texture in the pair. The effect of texture frequency on perceived roughness rating was evaluated as well as the effect of the modality of the judgments on those perceived roughness ratings.

Computing Science students with no prior experience of the PHANToM participated in the experiment. No participants reported any auditory or haptic sensory abnormalities that might affect their performance. All participants experienced all texture comparisons in all conditions. The order in which the modality conditions were experienced and the texture comparisons presented within each condition were counterbalanced.

Procedure

A standard Personal Computer set-up was used in a usability lab with the PHANToM device placed in a similar location to the normal mouse position. The keyboard and mouse were not used for any experimental interaction during the trials. The experimental interface resembled that of a Microsoft dialogue box with the textured areas indicated by 2 identical square patches to the left and right on the screen (Figure 4). Responses were made and recorded through stylus clicking over a radio button next to the response category of participants' choice. Participants 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).

Figure 4: Interface for roughness comparisons

Hypotheses

H1: Increasing haptic frequency will lead to increased perceived roughness in all modality conditions.

H2: The modality of the judgment will have an effect on the number of times haptically identical textures are judged as the same.

H3: The modality of the judgement will affect the likelihood that different textures are successfully judged as different.

H4: The incongruency of the multimodal textures will have an effect on the perceived roughness judgements.

Results and Discussion

A 2 factor fully crossed factorial ANOVA was used to determine the effects of (1*) Frequency* of the haptic texture *(6 levels*) on perceived roughness and (2) *Modality* of the judgement *(3 levels)* on perceived roughness as well as (3) the interaction between the two factors *Frequency* and *Modality.*

Effects of Frequency on Perceived Roughness

Results from the ANOVA show that there was a significant effect of haptic frequency of the texture on the number of times a texture was judged as the roughest of any pair across all the texture comparisons ($F_{5,85} = 16.22$; $p<0.01$). Pairwise comparisons showed that increasing frequency leads to increased perceived roughness for the range of textures compared.

H1 is therefore confirmed - increasing haptic frequency leads to increased perceived roughness in all three modality conditions.

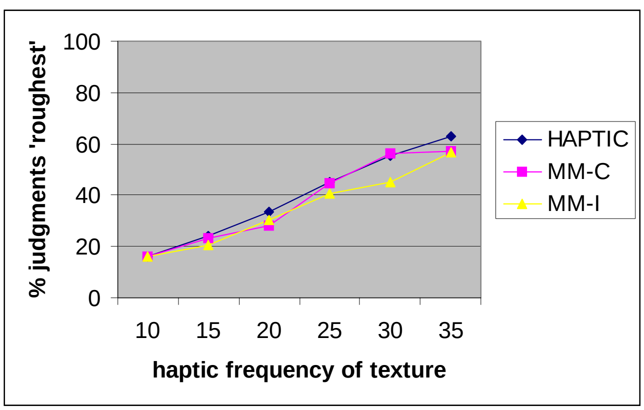


Figure 5: Effect of frequency of texture on likelihood that texture will be judged as roughest of any texture pair.

There was no significant effect of modality of judgement on the number of times any frequency of texture was judged as the roughest of any pair. In addition there was no significant interaction effect between the frequency factor and modality factor.

The 'perceived roughness' rating being considered in this evaluation was the overall likelihood that a texture will be judged as the roughest of *any* texture pair collapsed across the entire set of comparisons for each texture. Further analysis is being conducted to explore the perceived roughness ratings across the different frequency ranges. This is being considered because the perception of roughness at the different ends of the frequency range used may vary. That is, previous work has found that the range used invoked two possibly separate notions of roughness: that of 'corrugated roughness' at the lower levels of 10 and 15 cycles and that of 'sandpaper roughness' at the higher frequencies of 30 and 35. It is possible therefore that the modality of the judgment might have significant effects when the range of frequencies is analysed in finer detail.

The monotonically increasing function found in all modality conditions replicates the function found for unimodal haptic textures in our previous study [5]. It further confirms that people can successfully judge the relative roughness of a set of simple sinusoidal textures. It shows that, for the model of texture used and the range of frequencies sampled, varying the frequency (no. of waves per texture patch) is sufficient to enable people to rate the relative roughness of the set of textures. This is true regardless of the modality of the comparison. This does not, however, alter the likelihood that roughness has more defining parameters than frequency alone (wave cycles per patch) as defined in this experiment.

Identical Haptic Stimuli

The number of times a haptically identical pair of textures is judged as the same perceived roughness approaches 100% only in the haptic condition when the textures being compared both have a low frequency of 10. Even then, this likelihood is only 83%. Higher frequencies in the haptic condition have an even lower likelihood (mean = 50%) of being judged as perceptually the same in terms of perceived roughness.

In both multimodal conditions, the likelihood that haptically identical textures are perceived as the same roughness is significantly lower than in the haptic condition. This confirms the **H2** that the modality of the judgment will have an effect on the perceived roughness ratings.

The likelihood of haptically identical textures being judged as the same roughness decreases in the multimodal congruent condition and decreases further in the multimodal incongruent condition. This confirms both **H2** that multimodality will have an effect on the roughness judgments and **H4** that the incongruence within the multimodality will have an effect. There are frequencies at which the likelihood of the same response is equal regardless of condition. On the other hand, there are also frequencies at which the likelihood of same responses are dramatically different across conditions. The responses at individual frequencies may therefore need further exploration.

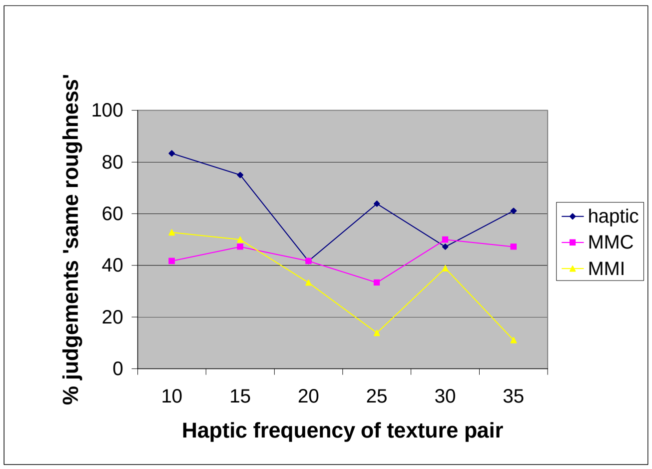


Figure 6: Effect of frequency of texture on likelihood that a texture will be judged the same as any other texture.

Different Haptic Stimuli

In our previous studies, a frequency separation of 5 cycles was not sufficient for participants to be able to decide that the textures were different in terms of roughness any more than they would for haptically identical textures. It is possible that making the decision at this resolution in the multimodal conditions would be different.

Fig.7 shows the likelihood that a texture pair is judged the same roughness at every possible frequency separation (or resolution) including the cases where they are haptically identical. When the textures are haptically identical, the modality of the judgement has an effect on the likelihood that these textures are judged as different. **H3** is therefore confirmed.

In the haptic condition, a frequency separation of zero means that the same physical stimuli were presented. We might expect a likelihood approaching zero for the probability of these identical textures being judged as perceptually different. In fact, the likelihood that identical stimuli are judged as different in the haptic condition is around chance level (33.3%) showing that people do not necessarily perceive physically identical force feedback stimuli as the same. This is perhaps not alarming given the freedom participants have to use as little or as much force in their exploration as well as their own exploration speed which in turn could vary within and between the trials. It does confirm that in practice, there is a strong chance of the haptic interaction affecting the perceptual and cognitive textural experience.

The likelihood of multimodal textures with identical haptic frequencies being judged as different is significantly higher than in the unimodal haptic condition. This shows that the additional auditory stimulus has an effect and that the incongruency in turn has an effect on the likelihood that haptically identical stimuli are judged as different. This would suggest that the auditory stimuli are in fact attended to and incorporated into the roughness judgement at this level.

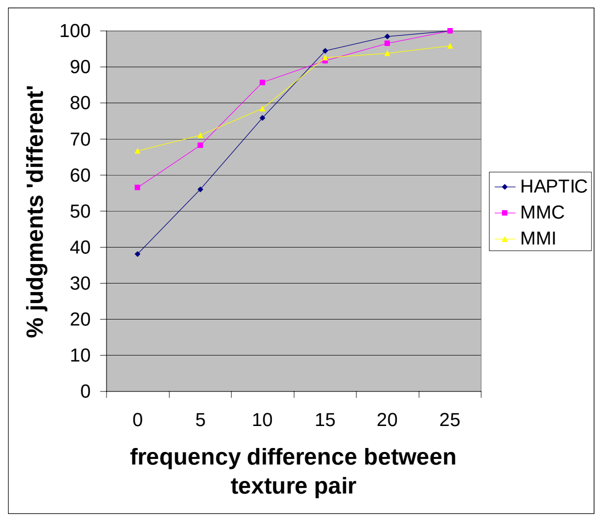


Figure 7: Effect of frequency *separation* on likelihood of two textures being judged as different.

As the frequency separation increases beyond 5 cycles the likelihood of the textures being judged as different increases towards 100% very rapidly. A frequency separation of 15 cycles (or more) in the range of frequencies and workspace used is sufficient to elicit reliable difference judgments between the two textures. Given the limited workspace available in many applications and the possibility that larger textures perturb users' movements it is still desirable to use auditory stimuli to improve the discriminability of these types of textures.

Conclusions and Future Work

More extensive analysis on the results from this experiment is currently being performed to determine the effects of multimodal (congruent and incongruent) judgements on the perceived roughness of force feedback textures more clearly. More work is needed on both the absolute and relative perceived roughness of force feedback textures at the perceptual level as well as in the context of a texture dependant task. Many applications require virtual objects to have realistic surface properties and therefore simulating convincing texture is important. Many haptic tasks may, in fact, require these surfaces or objects to be discriminable in terms of their relative roughness or to make them classifiable according to their perceived roughness. It is necessary therefore for haptic research to continue to perceptually classify the range and resolution of roughness (and other texture dimensions) available through current technology.

This work has argued that multimodal augmentation is a potential method for improving the simulation of force feedback textures. More research is needed to explore the ways in which multisensory or multimodal textures may improve the perception of and interaction with haptically textured surfaces and objects.

A final goal would be to develop design guidelines in computer haptics that equal or exceed those in the fields of computer graphics and audio. In particular, research should pay attention to the ways in which multimodal stimuli may provide richer information than any single device or modality is currently capable of. This will be a particularly useful solution while the current haptic technology and human haptic processing systems attempt to catch up with the visual and auditory domains.

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