The perception of texture, object size and angularity by touch in virtual environments with two haptic devices.

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Abstract

The incorporation of the sense of touch (haptic sense) into virtual reality (VR) has considerable potential to enhance the realism of virtual environments and make VR accessible to blind people. This paper summarises a series of investigations into the haptic perception of texture and object size/angularity in VR, with two haptic devices. Guidelines for the creation of haptic environments for blind and sighted individuals are also presented.

Introduction

Until recently interaction with virtual environments (VEs) was only viable via the visual and auditory senses. The absence of the haptic sense considerably limits the realism of VEs. As Loomis and Lederman (1986) noted “Touch facilitates or makes possible virtually all motor activity, and permits the perception of nearby objects and spatial layout”. (pp 31-2). Furthermore, the inclusion of haptic information in VR has great potential to improve blind peoples' access to virtual environments and improve the accessibility of Graphical User Interfaces (GUIs). This could be achieved by providing haptic alternatives to visual navigational cues, for example by using texture instead of colour or pattern; or by providing pictorial or symbolic indicators as to the endpoint of a link.

However, limitations of haptic VR devices mean that a user cannot simply interact with virtual objects in the same manner as its real counterpart; the device used to relay the haptic stimulation to the user dictates the nature of the interaction with the virtual object. Consequently, one cannot assume that the findings gained from experiments into real haptic perception will apply to virtual haptic perception without qualification. Prompted by this fact, Colwell et al (1998) conducted several experiments investigating the perception of three object dimensions in VR: texture, size and angularity using a 3 degree of freedom haptic interface, (i.e. one that permits three-dimensional interaction with virtual objects), known as the IE3000, (depicted in Figure 1).

Figure 1: The IE3000 haptic device

The work reported here represents an extension of this work using the same methodology, but a different device, namely the Phantom haptic interface, (depicted in figure two). The goal was to assess the impact of the specific device used on the perception of roughness, size and angularity in haptic VR.

Figure 2: The Phantom haptic device

The perception of virtual texture

The Methodology for Measuring Subjective Roughness

The methodology used to measure preceived roughness is based on a technique known as magnitude estimation, devised by Stevens (1962). With this technique observers first assign an arbitrary number of their own choice to the intensity of a baseline (standard) stimulus presented by the experimenter. They are then presented with a series of further stimuli and asked to assign an intensity number to each that reflects its perceived intensity relative to the baseline. So, for example, with texture stimuli if the participant assigned the baseline texture with a roughness value of 5 and thought the following texture to be twice as rough they would assign it a roughness value of 10. If on the other hand they thought it was half as rough they would assign it a value of 2.5. The psychological theory underpinning this method states that the relationship between the perceived intensity of a psychological characteristic e.g. roughness, is related to the actual intensity of a physical characteristic of the stimuli raised to some power. The power to which the stimuli is raised, referred to as the **exponent,** is critical as it describes the relationship between the perceived intensity and the actual intensity of the physical stimuli. For the purposes of this summary it suffices to point out that a positive exponent means that perceived roughness **increases** with increases in the physical intensity of the stimuli; while a negative exponent means that perceived roughness **decreases** with increases in the physical intensity of the stimuli.

Texture perception in reality

Lederman et al (1972-1999) have conducted most of the contemporary work on roughness perception for real surface texture. In these experiments the stimuli were metal plates with equally spaced grooves cut or etched lengthways into them. The depth profile of such plates is that of a periodic rectangular waveform. Such textures are composed of three elements: amplitude (groove depth), groove width (the width of the groove itself); and land width (the spacing between the grooves). Magnitude estimations of the roughness of such stimuli have indicated that groove width constitutes the actual intensity of such textured stimuli and is the most significant determinant of the perceived roughness of real textures. With such textures perceived roughness increases as a function of increasing groove width i.e. a positive exponent. (e.g. Lederman, 1972). Limitations of the hardware preclude a direct translation of Ledermans work into a VE; plates featuring a rectangular waveform were not adopted, as the haptic image quality was inadequate due to the infinitesimal size of the virtual contact point. Regular sinusoidal waveforms were possible however. Unlike rectangular waveform stimuli these are defined by two elements: groove width (i.e. peak to peak width) and amplitude.

The experimental procedure

In this experiment the stimuli consisted of ten virtual textures mounted on plates featuring an area of sinusoidal shaped parallel grooves running the entire length of the plate and measuring 4 cm. in width. The amplitude of the grooves (i.e. half the peak to peak height) was constant across the plates at .1125mm. The ten plates differed in terms of their respective sinusoidal groove widths, used to manipulate the participants’ judgements of their roughness. The groove widths utilised ranged between .675mm and 2.700mm in 10 equal increments of .225mm.

Interaction with the virtual textures with the Phantom device occurred via two endpoints, a stylus and a thimble. The IE3000 originally had a stylus, but this was removed for the experiment. A small cover was fitted to the connection point, which was then grasped by the participants.

The participants made magnitude estimates on the ten virtual textures, randomly ordered by the computer, by sweeping the stylus/thimble endpoint across the textured surface once. This procedure was repeated six times for both the thimble and stylus endpoints (the order in which the endpoints were used was counterbalanced between participants). White noise was relayed to the participants via headphones throughout the duration of the experiment to prevent them from obtaining any audio cues to the dimensions of the virtual textures. This procedure replicates Colwell et al (1998).

Summary of results: Virtual textures

Ease of discrimination for blind and sighted users between devices

Sighted participants found the same virtual textures more difficult to distinguish with the IE3000 device than with the Phantom device. Thus the same increment between virtual textures might not be sufficient for all users to distinguish between them across different devices.

Consistency of roughness perception between sighted and blind users

The rate (exponent) at which perceived roughness changed as a result of groove width variation did not significantly differ between blind and sighted participants with either the IE3000 or Phantom devices.

Direction of relationship between groove width and perceived roughness

The relationship between the perceived roughness of the virtual textures and the geometry of those textures was, for the majority of individuals, the opposite of that found for the real textures used by Lederman & her co-workers. They found that perceived roughness increased as a function of increasing groove width (positive exponent), whereas in our virtual reality studies perceived roughness increased as a function of decreasing groove width (negative exponent).

The effect of the endpoint device used

The endpoint used with a specific device can exert a significant effect on the rate (exponent) at which perceived roughness changes as a function of given increments in groove width. In effect, a given increase in a textures groove width can produce a greater or smaller increase in perceived roughness depending on the endpoint used. In the experiment involving the Phantom device it was found that the negative exponent was greater for the thimble than for the stylus endpoint for both blind and sighted participants.

Variation between individuals in perceived roughness

Although there was no reliable difference between blind and sighted people in the perceived roughness of the virtual textures, there was a good deal of variation in the rate (exponent) at which perceived roughness increased/decreased as a results of variation in groove width between individuals.

Replication of IE3000 results The results obtained with the Phantom device are very similar to those with the IE3000, indicating that the phenomena are quite general and likely to apply to any three degree of freedom haptic VR device.

Perception of size and angularity of three dimensional virtual objects

The methodology of the these experiments was somewhat novel, as research pertaining to the perception of object properties such as size tends to focus on the exploratory procedures (EPs) used when making such a judgement e.g.

Lederman et al (1987). EPs can be defined as the specific hand movements performed when examining a particular object property. The EPs used in arriving at estimations of size and angularity are a particularly pertinent variable in the context of HVR. The optimal EP for examining object size and angularity; that of **enclosure**, whereby one envelops all or part of the object with any number of fingers on one or both hands, is not possible with devices such as the IE 3000 and the Phantom. Instead the user is forced to explore virtual objects through single point interaction. The most analogous interaction in reality would be to explore an object using either a single finger or a pen, the implications of this EP for the accuracy of size/angularity perception are, as yet, unknown.

In our experiments, a total of 15 virtual objects were used: cubes and spheres were presented in three sizes: 2.7 cm, 3.6 cm and 4.5 cm. Each object and size permutation was presented in an **external** and **internal** exploration format; i.e. hollow variants of the shapes were explored from the inside. Three sheared cubes were used as the angular stimuli, all appearing in the internal, i.e. hollow exploration format and sheared at 18, 41 and 64 degrees respectively, their size was held constant at 3.6cm. The 15 virtual objects, randomly ordered by the experimenter were individually presented to the participants who gave their responses by using either an occluding sleeves ruler (pictured in Figure three) to make object size estimations or with an angular ruler (pictured in Figure four) to make degree of shear estimations. The sighted participants were blindfolded throughout the duration of the experiment to ensure a purely haptic judgement of the stimuli.

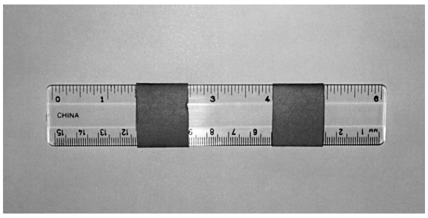

Figure 3: The occluding sleeves ruler

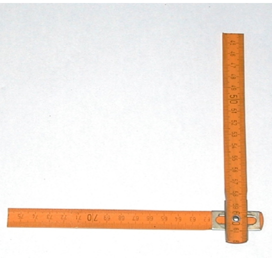

Figure 4: The angular ruler

This procedure was repeated for both the thimble and stylus endpoints (the order in which the endpoints were used was counterbalanced between participants). This also replicates procedure of Colwell et al (1998).

Summary of Results: Virtual objects size and angularity perception

Consistency of size estimates over different classes of objects between devices

In the experiment involving the Phantom device participants underestimation of the spheres was significantly more pronounced than their underestimates of the cubes, however no such difference was found with the IE3000 device.

Consistency of size estimates over different sizes of objects between devices

In the experiment involving the IE3000 device, accuracy decreased as a function of increasing size. This was the case with the spheres presented via the Phantom, but not the cubes, in which accuracy was similarly good for the smallest and largest cubes, but relatively poor for the intermediate sized cube.

The "Tardis[1] Effect" Internal vs. External exploration

A virtual object that is explored internally will be judged as being significantly bigger than its external explored counterpart. This effect, dubbed the "Tardis effect" has been evident in the reported experiments irrespective of the device used, visual status of the participants, type and size of the objects examined.

Consistency between blind and sighted users estimates of object angularity between devices

There was no statistically reliable difference between the blind and sighted individuals perception of object angularity with the Phantom device. However blind people gave significantly greater underestimates of the angularity of the sheared cubes than the sighted participants with the IE3000 device.

Consistency of angularity estimates between endpoints

The accuracy of the blind and sighted participants estimates of the angularity of the sheared cubes varied as a function of the endpoint used with the Phantom, with the stylus yielding more accurate estimates of shear than the thimble endpoint.

Guidelines for the Implementation of Texture and object size/angularity

The reported results have substantial implications for the implementation of touch in virtual reality. The fact that the results with two different end-points on the Phantom and the earlier study with the IE3000 are, on the whole, similar indicates their applicability to three degree of freedom haptic VR devices. The results yield the following guidelines for designers of haptic virtual environments:

Textures

1) **Provide an adjustment facility for groove widths:** Cross platform compatible applications will require the facility for the operator to adjust the increment between the virtual textures groove widths to reflect the discrimination that is achievable with the specific device.

2) **To increase perceived roughness, decrease groove width:** Designers must bare in mind that in haptic VR increases in the groove width of which a texture is composed is predominantly associated with reductions in perceived roughness.

3) **Groove widths should remain the same for blind and sighted users:** It is not necessary to incorporate further adjustments to the increments between virtual texture grooves to produce similar results between blind and sighted users.

4) **Sensitivity to virtual textures is optimal with thimble attachment:** If optimal sensitivity to the virtual textures is required for an application, designers should use the thimble attachment.

5) **Provide user adjustment of texture range:** Designers should implement a feature that permits the user to adjust the range of groove widths to reflect their discrimination ability

Size and Angularity

1) **Calibrate object size to compensate for differences in users perception between devices.** Cross platform environments in which size and gross object shape are relevant features must include a facility to assess the consistency of an individuals size judgements across the applicable object sizes and types.

2) **Calibrate object size to compensate for differences in user's perception of internal and external objects:** If the internal objects are to be used, designers must compensate for disparity in the perceived size of equivalent internal and external objects.

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[1] The Tardis was the name given to the time travel machine featured in the popular science fiction series Dr. Who. Externally the machine appeared to be no larger than a phone box, but was far greater in size internally.

3) **Include an adjustment facility for object angularity:** Designers must incorporate the facility for the operator to increase/decrease an object's actual angularity, so that similar angles will be perceived by both blind and sighted participants across devices.

4) **Accuracy of the perception of angularity is optimal with the stylus:** If the accuracy with which the users perceive the angularity of three-dimensional objects is paramount in an application, the stylus attachment should be used.

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