The use of haptic virtual environments by blind people

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ABSTRACT

This paper describes two studies concerning the use of haptic virtual environments for blind people. The studies investigated the perception of virtual textures and the perception of the size and angles of virtual objects. In both studies, differences in perception by blind and sighted people were also explored. The results have implications for the future design of VEs in that it cannot be assumed that virtual textures and objects will feel to users, whether blind or sighted, as the designer intends.

1. INTRODUCTION

The research presented here concerns the perceptual aspects of the development of haptic VEs for blind people. It is important to know how blind users haptically perceive virtual objects, so that such objects can be incorporated appropriately into large scale VEs. Haptic perception incorporates both kinaesthetic sensing, (i.e. of the position and movement of joints and limbs), and tactile sensing, (i.e. through the skin) (Loomis and Lederman, 1986). At present, most VEs use visual displays, with some use of auditory and very little haptic information. The development of haptic, kinaesthetic and tactile devices offer a new dimension of realism to VEs for sighted users and has particular potential for blind users.

1.1 The Impulse Engine 3000 ™

The device used in the current studies was the Impulse Engine 3000 (Figure 1). This force-feedback device was developed by the Immersion Corporation and was used with software written by Andrew Hardwick. The device can display virtual textures and objects which users can feel using a probe. The probe is the length and diameter of a thick pen and has 3 degrees of freedom of motion, i.e. it can move in 3 spatial dimensions: forwards and backwards, up and down, and left and right. The system provides force-feedback to users by monitoring the position of their hand and altering the force accordingly (Hardwick, Furner and Rush, 1997). The force is created by three motors which exert resistance against the probe. This gives users the impression that a texture or object is present.

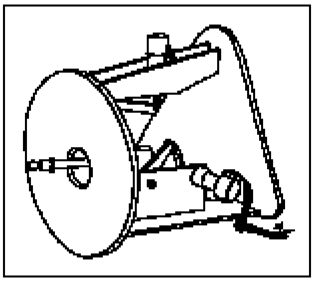

Figure 1. *The Impulse Engine 3000 ™.*

Two types of virtual stimuli were used in the current studies: textured surfaces and simple 3-dimensional objects such as cubes and spheres. The cubes and spheres could be felt from both the inside and the outside of the object. When exploring the inside of an object, it is as if the user is inside the object and they cannot feel the outside of the

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object. An example from the real world might be exploring the outside of a closed box but not being able to explore inside it and then getting inside the box, closing it, and exploring the inside of it.

Twenty-two participants took part in both studies, 9 were blind and 13 were sighted. Six of the sighted participants were female and all the other participants were male. The sighted participants were all university students, from different disciplines. The blind participants were all employed in computer-related jobs or on a computer science course except one, who was a retired audio engineer. Six of the 9 blind participants were either born without sight or lost their sight by the age of 30 months. The other 3 lost their sight between 8 and 26 years of age. The participants ranged in ages from 18 to 65; the average age being 32.

2. THE PERCEPTION OF VIRTUAL TEXTURES

The first study involved virtual textures with varying groove widths. The dimensions of the virtual textures were as close as possible to those used in the investigations of the perception of real textures by Lederman (1974; 1981; Lederman and Taylor, 1972), the only difference being that those real textures involved grooves with a rectangular profile whereas the textures used in the current study involved sinusoidal shaped grooves. This difference was unavoidable, as Lederman was unable to produce grooves with a sinusoidal profile (although she would have preferred to use such a form) whereas with the Impulse Engine it was not possible to simulate usable rectangular profile textures (preliminary simulations showed that the probe of the device became “caught” in the corners of the grooves). The widths of the grooves varied from 0.375 mm to 1.5 mm in steps of 0.125 mm and had a fixed amplitude of 0.0625 mm (Figure 2). There were no visual representations of the virtual textures. The magnitude estimation technique (Snodgrass, Levy-Berger and Haydon, 1985), widely accepted in studying psychophysics, was used to assess the roughness of ten textures. Initially, participants were given a standard stimulus (one of the textures from the middle of the range), to which they assigned for themselves an easily remembered number (e.g. 10), the “modulus”. They were then presented with a random sequence of 60 textures (the ten textures, each presented six times). For each presentation, they were asked to give a number which represented the texture of the new presentation relative to the modulus. So, if the texture seemed twice as rough, they would give the number 20, if it seemed half as rough, they would give the number 5. Participants find this method difficult, but for many physical stimuli it has been shown to reveal the relationships between physical parameters and psychological sensation.

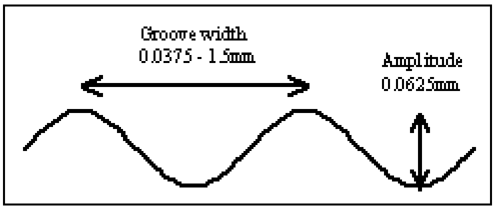

Figure 2. Dimensions of the sinusoidal grooves used in the virtual textures study.

The data were analysed by calculating the power function between physical texture parameter (i.e. groove width) and psychological sensation (i.e. the magnitude estimates) for each participant. Regression analyses were also conducted to determine how much of the variation in the sensation of the textures could be accounted for by the variations in the groove width. Regression analyses were conducted for each participant individually and on the massed data which allowed a comparison of the performance of blind and sighted people.

Overall, there was a highly significant relationship between the perception of virtual texture and its simulated physical characteristics ($F_{1,216} = 12.09$, $p < 0.001$). All nine blind participants also individually showed a significant relationship between perception of virtual texture and its simulated physical characteristics. For three of these participants the exponent was positive, meaning that they perceived the narrower grooves to be rougher than the wider grooves. This was in contrast to the other six participants for whom the exponent was negative, meaning that they perceived the wider grooves to be rougher than the narrower grooves. Only five of the thirteen sighted participants showed a significant relationship between perception of virtual texture and its simulated physical characteristics. For all the sighted participants the exponent was negative. The magnitude of the exponents ranged from 0.51 to 0.84, making them higher than those obtained by Lederman for the closely corresponding real textures.

The results from this study showed that more blind people were more discriminating than sighted people in their assessment of the roughness of the textures. Most of the twenty-two participants perceived the wider groove widths to be more rough than the narrower groove widths, although three participants perceived the narrower grooves to be rougher.

3. THE RECOGNITION OF VIRTUAL OBJECTS

For the second study a range of virtual objects was presented in various ways. The Impulse Engine 3000 allows virtual objects to be explored from both inside and outside the object, so for some of the virtual objects used, both inside and outside presentation were given to investigate any differences this factor produced. The virtual objects used were: cubes (inside and outside presentation), spheres (inside and outside presentation), rotated cubes (outside presentation only), sheared cubes (inside presentation only). Three sizes of each type of virtual object were presented: cubes with edges ranging from 1.0 cm to 2.5 cm (Table 1), spheres with diameters ranging from 1.5 cm to 2.5 cm. The amount of rotation of the cubes varied between 30 degrees and 70 degrees and the amount of shear between 18 degrees and 64 degrees. Since this was an initial exploratory study, a full factorial design was not used. Each type of virtual object was presented three times, with a range of different sizes and angles of rotation and shear. A multiple choice matching response method was used. Participants were asked to feel an object and then choose from a set of four objects of varying size the one they thought they had felt. Sighted participants were shown scale drawings and blind participants were shown scale tactile 2-D representations.

Table 1. *Mean perceived size/angle of virtual objects with percent over- and under-estimation (data from blind and sighted participants combined).*

Object Type	**Actual Size/Angle (cm/degrees)**	**Perceived Size/Angle Inside presentation**		**Perceived Size/Angle Outside presentation**	
		Mean and standard deviation (cm/degrees)	**Over/Under estimation (Percent of actual)**	**Mean and standard deviation (cm/degrees)**	**Over/Under estimation (Percent of actual)**
Cube	1.0	1.8 (0.40)	+ 80%	See Note 1.	
	1.5	1.7 (0.30)	+ 13	1.6 (0.50)	+ 7%
	2.0	2.4 (0.20)	+ 20	2.0 (0.50)	0
	2.5	See Note 2.	-	2.4 (0.20)	- 7
Sphere	1.5	2.1 (0.1)	+ 27	1.2 (0.40)	- 20
	2.0	2.3 (0.1)	+15	1.8 (0.50)	- 10
	2.5	2.5 (0.1)	0	2.3 (0.30)	- 8
Rotated	30°	-	-	40° (12.0)	+ 33
Cube	50°	-	-	52° (12.0)	+ 4
	70°	-	-	45° (18.0)	- 36
Sheared	18°	20° (11.0)	+ 11%	-	-
Cube	41°	37° (11.0)	- 10%	-	-
	64°	59° (9.7)	- 8%	-	-

Since a full factorial design was not employed, a series of analyses of variance were used to analyse different components of the data. Mean perceived sizes/angles for the various objects used are shown in Table 1. No significant difference was found between the perceptions of sighted and blind participants, except that the sighted participants judged the sheared cubes more accurately than the blind participants. Both groups were significantly more accurate in their perception of larger objects than of smaller objects. For example, the 1.0 cm edge cube was perceived on average to have a 1.8 cm edge when explored from the inside, an overestimate of 80%, whereas the 2.0 cm cube was perceived on average to have a 2.4 cm edge, an overestimate of only 20%. The size of the objects felt from the inside tended to be overestimated, the mean overestimation across all sizes of cubes and spheres being 25.8%. However, the size of objects felt from the outside tended to be underestimated, with a corresponding mean underestimation of 6.3%. Finally, the angles of the rotated cubes seemed to be difficult to judge, although this may have been due to the lack of a reference point for judging the rotation in the VE.

4. DISCUSSION

The way in which a user of the Impulse Engine 3000™ can explore virtual objects differs from the way in which real objects are felt in several ways. An example is that the device currently requires the user to feel textures and objects with the probe. This is not a particularly intuitive way of interacting with objects and several participants said they would rather use their hands because they are more used to feeling their environment in this way. A further example is that if the user pushes hard enough they can have the sensation of pushing through the surface of an object. This is because the Impulse Engine 3000 motors are capable of withstanding only 8 Newtons (approximately 2 lbf) of force from the user.

Hardwick, Rush, Furner & Seton (1996) observed an interesting phenomenon associated with the Impulse Engine 3000, whereby people differ in terms of where they think the virtual space is located in real space. Some people have a mental image of the virtual space being outside the device, so that virtual objects are felt to be near the hand and are touched by the end of the probe that they hold (Figure 3a). In contrast, others imagine the virtual space to be within the device, so that virtual objects are touched by the other end of the probe (Figure 3b).

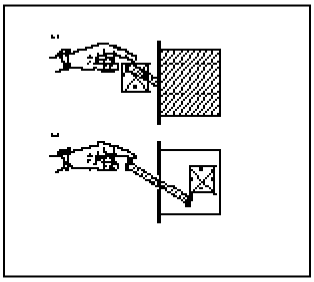

Figure 3. Representation of different mental models of the location of a virtual object.
(a) outside the device. (b) inside the device.

This phenomenon was explored further during the current studies asking each participant where in real space they thought the object was located, and to point to this location. Data on this phenomenon were collected from 19 of the participants. 14 (74%) imagined the objects to be located inside the device, 4 (21%) imagined the objects to be outside, and 1 (5%) imagined them to be half-way. Three (33%) of the blind participants imagined the objects to be located outside of the device, compared to only 1 (8%) of the sighted participants. Of the participants who imagined the objects to be outside the device, 3 were blind and 1 was sighted. Therefore, this phenomenon may be more prevalent amongst blind people than sighted people, but is worthy of further investigation.

5. CONCLUSIONS

This paper has presented two studies exploring the perception of virtual textures and objects using the Impulse Engine 3000 haptic device. These studies have illustrated both the potential and some of the problems of using current haptic technology to simulate real world objects or to create totally virtual objects. In designing haptic interfaces, designers need to exercise care and not assume that the virtual world will be perceived in exactly the same ways as the real world, particularly given the current limitations of haptic devices which use probes and joysticks. However, the current devices do provide realistic feeling textures and objects which replicate the psychophysical properties of real textures and can be judged like real objects. These virtual objects and textures have enormous potential for enhancing VEs for both sighted and blind people.

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