3D Haptic Shape Perception Using a 2D Device

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1 Introduction

Is a 2-dimensional (2D) force feedback device capable of presenting 3-dimensional (3D) shapes? The answer is a qualified “yes.” “Force shading”, a haptic counterpart of bump mapping in computer graphics, presents a non-flat shape on a nominally flat surface by varying the force vector direction in haptic rendering [Morgenbesser and Srinivasan 1996][Robles-De-La-Torre and Hayward 2001]. To our knowledge, such phenomena have been qualitatively measured only by 3D devices, and a quantitative comparison to 2D devices has not been made. We compare thresholds of human shape perception of the plane experimentally, using 2D and 3D force feedback devices.

2 Experiments

Apparatus: Our equipment included a Tangible Mouse (TM) (2D, Fuji Xerox Co., Ltd.)[TM URL] which conveys force to the user’s finger through a 2D flat actuator mounted on a mouse (Figure 1), and a PHANToM 1.0A (3D, SensAble Technologies, Inc.). The stimulus (Figure 2) was 2 visual control lines and a cursor that follows the haptic cursor. Haptically, a 2-polygon bump $h$ high and $w$ wide was located between the 2 control lines. In each trial of the experimental procedure, a pair of stimuli ($h = 0$ and $h > 0$) was presented, from which the subject was asked to choose a bump ($h > 0$). Subjects were 8 adults. Four heights at regular intervals were tested, 10 times each under a different experimental condition.

Parameters: $w/2$: 10, 20 and 30 mm; surface stiffness: 0.4 N/mm; haptic rendering conditions: (1) normal or (2) force shading. Basically, force $F = \text{stiffness} \cdot L \cdot \vec{N}$ was feedbacked. Under condition (1) (PHANToM alone), $L$ is the haptic cursor penetration depth into the stimulus and $\vec{N}$ the normal vector of the physical surface. Under condition (2), with TM, only horizontal component $F_x$ of $F$ ($L$ was set to 1mm) was output. With PHANToM, output force $F = (F_x, F_y)$, where $F_x = s \cdot L$ (L: penetration depth into the virtual plane) and $F_y = F_y \cdot (2h/w)$.

3 Results and Discussion

The plane shape perception threshold was estimated as a height yielding 75% correct detection for each of the subjects and conditions (Figure 3). Analysis of variance on the magnitude of “force gap” felt on the top of the bump (Figure 4) showed that (a) the difference between the two devices and widths in force shading was not statistically significant ($p < 0.4$), and (b) condition (1) with PHANToM was significantly different from others and width was an effective factor ($p < 0.05$). Result (a) strongly suggests that humans detect the force gap in force shading and the threshold is the same for the two devices, regardless of width or whether their coordinates are absolute (PHANToM) or relative (TM). Result (b) should represent the effect of positional feedback. Although this research is in an early stage, the results are promising in revealing physical parameters and their thresholds that define the fidelity of haptic rendering enabling different haptic displays to be compared. Projected work includes experiments with different shapes and stiffness.

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References


TM URL.  
http://www.fujixerox.co.jp/tangible_mouse/