Plane-Shape Perception Using Point-Contact Type Force Feedback Device

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Introduction

Force (haptic) feedback devices (FFD) form an important field of research in virtual reality. They are especially promising in such application fields that require three-dimensional I/O, including CAD systems and surgical simulators. While haptic rendering requires very high control rate (~kHz), CAD modelling and physics-based simulation processes are often 100 times slower; to bridge the gap, haptic rendering must be separated from other processes. We proposed Feature-Based Haptic Rendering and its communication protocol [1] to exchange shape information as *features* -- shape fragments, haptic characteristics, control commands, etc. (Fig. 1) between processes. Modelling/simulation process selects and sends out features, which will be rendered haptically using FFD. Here, the latency gap between processes requires interpolation of features for smooth haptic rendering. Features can be interpolated on both the space domain and the time domain; spatial interpolation is important for smoothing polygonal surface, and temporal interpolation is necessary in shape deformation and moving objects. To develop less expensive, but effective interpolation algorithms, knowledge of human haptic characteristics is strongly needed. For example, modeler process can pre-fetch features before a time consuming work, and human sensory thresholds will define their resolution.

Given these, we have conducted an experiment on static plane-shape recognition threshold using PHANToM device [2] (SensAble Technologies, U.S.A.) as a FFD.

Experiment

(1) Subjects (11 adult Japanese, all right handed) touched a stimulus shape (Fig. 2) using a stylus-type probe and altered its height h with the up (or down) arrow key. The reaction magnitude f was calculated as $f = (G(x) - y) \cdot s$, where x, y are the coordinates of the cursor

position measured in mm and $s = 0.5$ is stiffness. The direction of reaction force was fixed in the upward, (0, 1, 0), the same as a flat plane, because varied reaction force directions cause haptic illusion [3].

In ascending experiments, the initial stimulus shape is a "flat" plane with a small height value, whose height will be increased by pressing the up arrow key until a subject feels it no longer flat. In descending experiments, a mountainous shape is presented initially and a subject decrease the *h* with the down arrow key until he feels it flat. In both cases, a subject hits return key to determine *h*. Three trials were performed for each of ascending / descending and 5 width *w* values (5, 10, 20, 30, and 40 mm). The height *h* changed by 0.5 mm ($w = 20$, 30, 40 mm) and 0.1 mm ($w = 5$, 10 mm) each time the arrow keys were pushed. To avoid the subject's remembering the number of hitting keys, the initial *h* value was altered in each trial. To avoid ordering effects, the order of the trials was randomized.

(2) To see the effect of stiffness, a preliminary experiment was conducted where stiffness $s = 0.25$ and width $w = 10$, 20, and 30 mm, with five subjects.

Results and Discussion

The median of the three *h* values obtained under each condition was picked up and the average of ascending and descending experiments was calculated for each *w* value. Fig. 3 shows f_h values, the force for the height *h* ($f_h = h \cdot s$), and Fig. 4 shows the force gradient f_h/w; thinner lines are the results of experiment #1 and thicker lines are the results of #2. Here, 95 percentile (%ile) value means that 95 % of subjects felt the stimulus shape flat below this value.

[Experiment #1] The resulting f_h for $w = 5$ and 10 mm are statistically not different (one-way ANOVA: $F(1, 20, 0.05) = 4.35 > F_0 = 0.06$), implying that human force sensitivity saturates around 0.2 - 0.3 N. With width larger than 10 mm, f_h/w is almost constant; one-way ANOVA gives $F(3, 40, 0.05) = 2.84 > F_0 = 0.75$, indicating that, when the direction of the reaction force is fixed, a shape will be felt flat if the force gradient is 0.02 - 0.03 N/mm or less ($w \in [10, 40]$).

[Experiment #2] Although it has small number of subjects, the results show a similar tendency to exp. #1, except that the force sensitivity saturation seems to begin at *w* of 10 - 20 mm. Further research on the effect of stiffness parameter is needed.

Conclusion and Future Work

Thresholds of human haptic shape perception using PHANToM device was shown: (1) Force gradient of 0.02 N/mm, and (2) minimum force of 0.2 N. Though further study on the effect of curvature is needed, a curved surface should as well be perceived smooth if this force gradient condition is satisfied. Future work includes investigating the threshold with smaller width values, effects of curvature and stiffness, and temporal perception characteristics.

References

[1] Yamashita, J., Y. Cai, and Y. Fukui: "Feature-Based Haptic Rendering -- Architecture, Protocol, and Application," in Visual Proc. of SIGGRAPH ’97, 1997. (Revised version of this paper can be obtained as http://www.aist.go.jp/NIBH/~b0621/Project/FBR97.ps.Z)

[2] Salisbury, K.et.al.: "Haptic Rendering: Programming Touch Interaction with Virtual Objects," in Proc. of ACM 1995 Symp. on Interactive 3D Graphics, 1995.

[3] Minsky, M. *et al.*: "Feeling and Seeing: Issues in Force Display," Computer Graphics, Vol. 24, No. 2, 1990.

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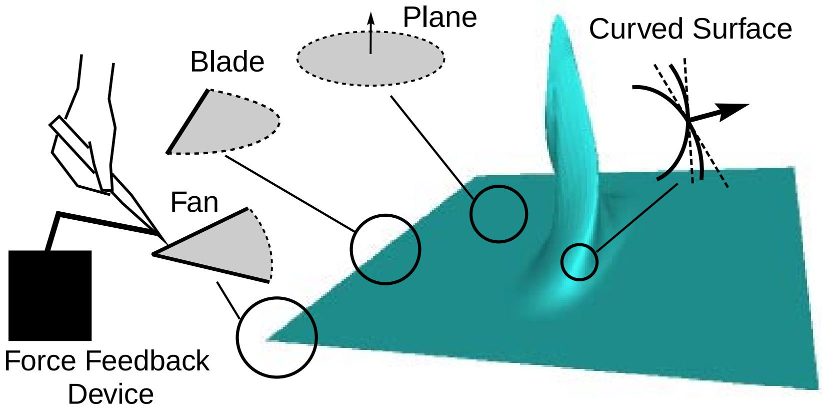

Fig. 1 Feature-Based Haptic Rendering
The user touches features selected and sent by the modelling process. Static shape is presented as spatially interpolated features. Motion and deformation require temporal interpolation.

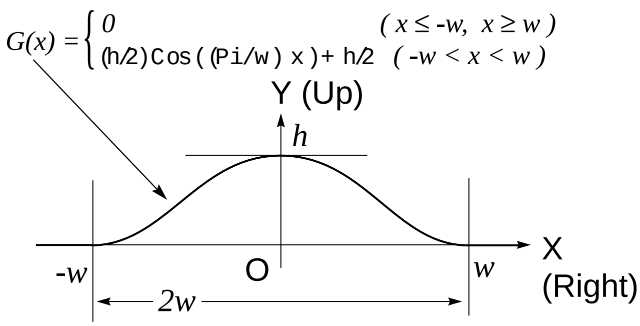

Fig. 2 Stimulus Shape
The

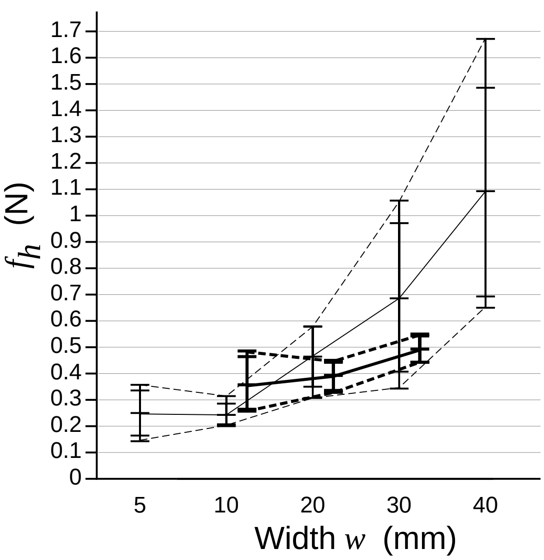

Fig. 3 Force for Height *h*

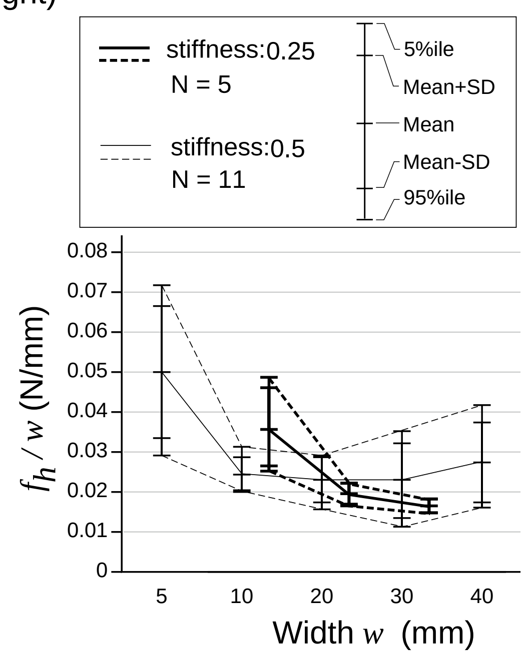

Fig. 4 Force Gradient