Juli Yamashita, Robert W. Lindeman, Yukio Fukui, Osamu Morikawa, Shigeru Sato. (2000). On Determining the Haptic Smoothness of Force-Shaded Surfaces, (Technical Sketch), *Conference Abstracts and Applications, ACM SIGGRAPH 2000*, p. 240.

On Determining the Haptic Smoothness of Force-Shaded Surfaces

Juli Yamashita, Robert W. Lindeman*, Yukio Fukui, Osamu Morikawa, and Shigeru Sato
National Institute of Bioscience and Human-Technology, Japan
{ juli | fukui | morikawa | sato }@nibh.go.jp
*The George Washington University (gogo@seas.gwu.edu)

Introduction

A force feedback device is an important 3D haptic display, especially applicable to Computer Aided Design (CAD), where 3D object manipulation is essential. Each haptic rendering [1] requires a high refresh rate (>1KHz) and collision detection between the cursor and an object, which can be very time consuming when the object has a complex free-form surface, such as a NURBS surface. For CAD applications, smooth haptic interpolation of polygonized surfaces using a technique called "force shading" [2, 3] is useful for maintaining high haptic-rendering rates by reducing the cost associated with computing the exact collision point.

Obviously, coarser polygonization is better, as long as the interpolated shape is felt as being smooth and not different from the original surface. But how coarse can it be? The polygonization resolution is defined by human sensory thresholds; however, no data are present on the absolute haptic threshold values of surface smoothness presented by a force feedback device. Therefore, we have conducted experiments designed to study the absolute thresholds of smoothly interpolated curved surface perception.

Experiments

Method: Method of limits. Subjects responded "yes" if the stimulus shape (Fig.1) was felt to be a smooth cylindrical surface, or "no" if not. Resolution angle α was varied in 1-degree increments. ***Equipment:*** PHANToM 1.0 (SensAble Technologies) was used. ***Parameters:*** (Experiment A) Reaction force direction was force shaded and continuous. Force magnitude was calculated by a simple spring model, multiplying surface stiffness and penetration depth to the nearest tangent plane, and displacement had C^0 continuity. (Experiment B) Non-interpolated condition and linear interpolation of the two force vectors calculated at the two nearest tangent planes were measured.

Results and Discussions

Exp. A (Fig.2): The absolute threshold angle is linearly defined by curvature (1/radius) and stiffness. The maximum difference *d* (Fig.1) for the results seems to be independent of radius (Fig.2 b).

Exp. B: Fig.3 compares the results of Exp. B and results of Exp. A of the same radius and stiffness. A statistically significant difference (5% level) exists between the non-interpolated condition and the two interpolated conditions, but not between interpolation methods. Without interpolation, reaction force direction is not continuous on tangent plane boarders, which explains the difference. These results imply that when reaction force direction is smoothly shaded, the smoothness threshold does not differ noticeably whether displacement continuity is C^2 or more; the smoothness threshold is determined mainly by the max difference between the approximated shape and the original. Although this research is still in its early stages, the presented threshold values should be useful in determining the polygonization resolution for force-shaded smooth haptic rendering of curved surfaces.

References

[1] Salisbury, K. et al.: Haptic Rendering: Programming Touch Interaction with Virtual Objects, ACM Symposium on Interactive 3D Graphics, 1995.
[2] Morgenbesser, H. B. and M. A. Srinivasan : Force Shading for Haptic Shape Perception, ASME Dynamics Systems and Control Division, 1996.
[3] Ruspini, D. et al.: The Haptic Display of Complex Graphical Environments, ACM SIGGRAPH97, 1997.

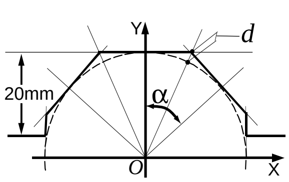

Fig.1 Sectional image of stimulus shape. A cylindrical surface, defined by resolution angle α, is interpolated in different ways. The axis of the cylinder is placed along the Z-axis, or toward the subject. *d*: Max. difference between the polygonal approximation and the true surface.

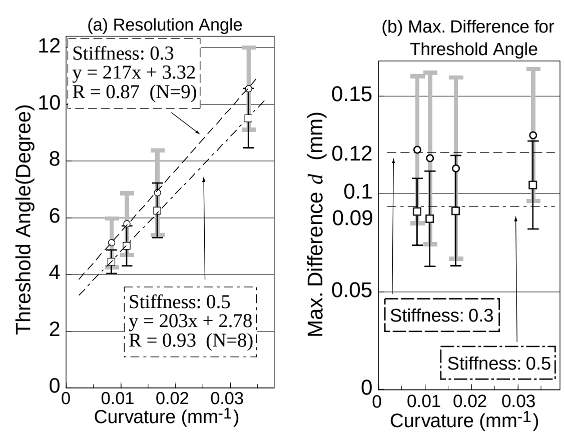

Fig.2 Results of Expriment A.

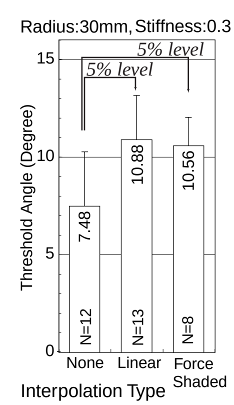

Fig.3 Comparison of interpolation methods.