Tessellation of NURBS Surfaces for use in Tactile Physics Simulations

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1. Background

- **Tactile Internet** allows for long range manipulation of robotic devices with ***haptic feedback*** [1].
- **Low Latency** is required for convincing haptics
- Network latency can be avoided through a **Local Physics Model** (see Fig. 1).
- A **suitable representation for curved objects** inside the model is needed.
- **NURBS Surfaces** can be used for this, but must first be tessellated to a mesh (see Fig. 2).

2. Research Question

- How can the tessellation of NURBS surfaces for use in tactile physics engines best be performed?
- What tolerance is required for meshes to be perceived as smooth?

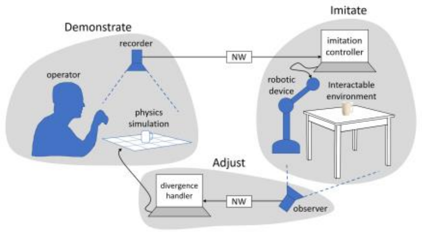

Figure 1: Example of the use of a local physics simulation for haptics generation in tactile internet.

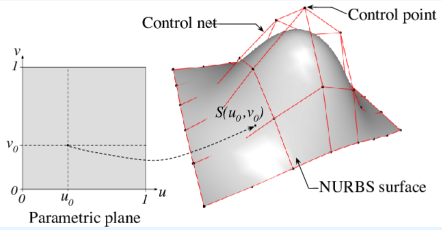

Figure 2: Example of NURBS surface [2]

3. Methodology

Global Spacing Tessellation Algorithm [3]:

1. Determine grid size λ for given tolerance ε
2. Sample points from uniform grid
3. Triangulate Vertices

- Hourglass, bullet, torus and sphere surface investigated
- Analysis of **mesh complexity**, **mesh error** and **geometry distribution**

Smoothness Perception User Study

- Through test setup in Fig. 3, participants could feel meshes
  - Sphere, Torus, Hourglass, Bullet
  - Tolerance ranging from 12.5mm to 0.05mm
- Meshes were rated as either **Angular, Coarse** or **Smooth**

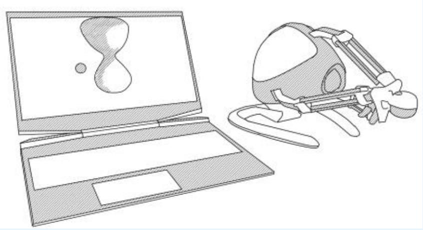

Figure 3: Illustration of the test setup used for conducting the mesh smoothness user study.

4. Results

Mesh Complexity

- Decreasing tolerance increased resemblence of mesh to original NURBS surface (Fig. 4)
- Mesh complexity increases dramatically if tolerance is lowered (Fig. 5)
- Irregular curvature leads to more complex meshes (Fig. 5)
- Mesh errors were within the tolerance (Fig. 6)
- Excessive geometry near top and bottom mesh (Fig. 7)

Perceived Smoothness

- n=21 participants surveyed, see figure 8
- Overwhemingly angular until tolerance of 2.5mm
- Tolerance of 0.25mm sufficient for exclusively coarse or smooth perception
- Tolerance of 0.05 mm gave majority of participants a perception of smoothness for all shapes

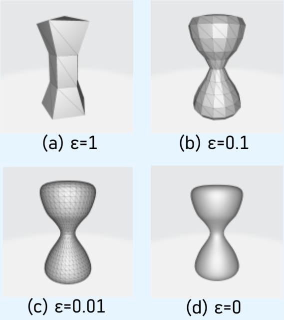

Figure 4: Hourglass surface tessellated at different tolerances ε

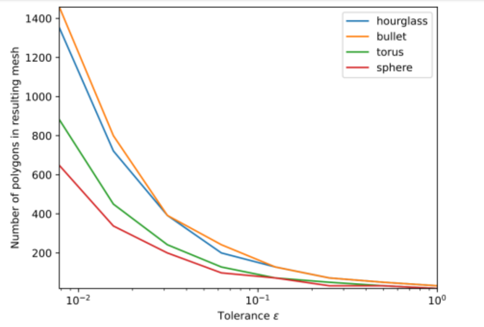

Figure 5: Mesh complexity as the tolerance is lowered

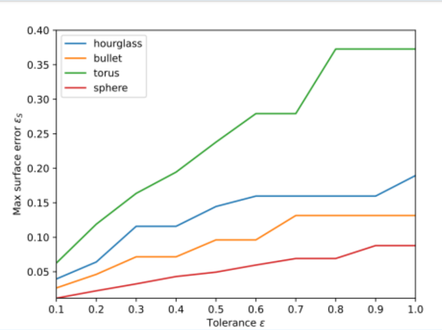

Figure 6: Maximum mesh error as the tolerance is lowered

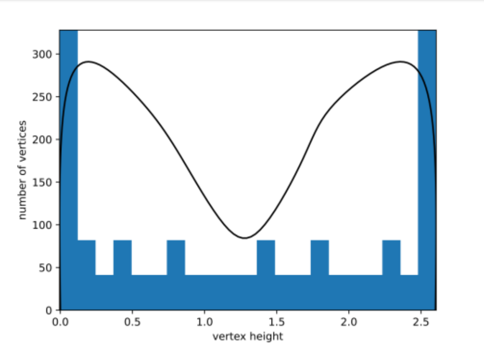

Figure 7: Geometry discribution within mesh of hourglass at ε=0.001

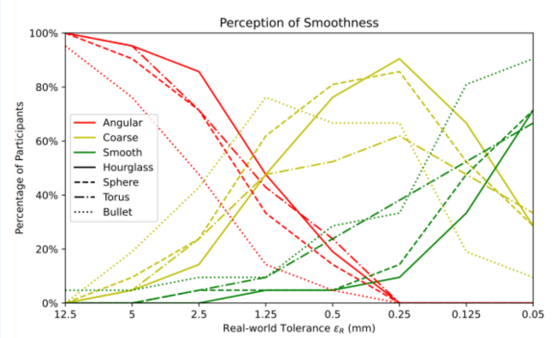

Figure 8: Smoothness perception survey results

5. Future Work

- **Force shading** could reduce necessary geometry for surfaces to be perceived as smooth
- **More realistic object shapes** to evaluate tessellation algorithm in realistic context
- **Alternative NURBS tessellation algorithms** might yield lower more efficient meshes

6. Conclusions

- The **global spacing tessellation algorithm** stays within the provided tolerance, but creates inefficient meshes for surfaces with non-uniform curvature
- A **tolerance of 0.05mm** is sufficient for most participants to perceive a mesh as **smooth**
- Lowering tolerance further should be done with care to avoid complex models and **overburdening the physics simulation**

[1] G. Fettweis, "The Tactile Internet: Applications and Challenges," *IEEE Vehicular Technology Magazine*, vol. 9, no. 1, pp. 64–70, Mar. 2014, doi: 10.1109/mvt.2013.2295069.
[2] Estratat, Mathieu & Greca, Raphael. (2023). An interfacing module using configuration for declarative design of nurbs surfaces.
[3] L. A. Piegl and A. M. Richard, "Tessellating trimmed nurbs surfaces," Computer-Aided Design, vol. 27, no. 1, pp. 16–26, Jan. 1995, doi: 10.1016/0010-4485(95)90749-6.