

# Haptic Rendering of Tissue Cutting with Scissors

David J. WEISS<sup>1</sup> and Allison M. OKAMURA<sup>2</sup>

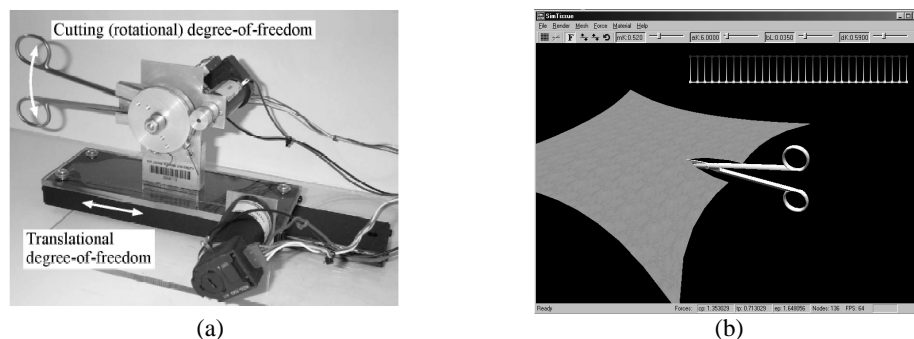
<sup>1</sup> Princeton University, Princeton, New Jersey 08544 USA

<sup>2</sup> Johns Hopkins University, Department of Mechanical Engineering, 125 Latrobe Hall, 3400 N. Charles Street, Baltimore, MD 21218 USA  
aokamura@jhu.edu, <http://www.haptics.me.jhu.edu>

**Abstract.** Current surgical simulations that involve cutting with scissors lack display of forces “between the fingers” of the operator. The objective of this work is to develop a fast, realistic haptic rendering technique for scissor cutting that can be easily integrated into soft tissue models commonly used in surgical simulators. A virtual environment was created for combined graphic and haptic display of cutting. Two 2-dimensional deformable mass-spring-damper models were developed: The first is a large mesh that is used to calculate translational forces. The second is a smaller, one-element-thick mesh that is used to calculate cutting (angular) forces. This technique was implemented on the haptic scissors, a haptic interface that allows motion and force feedback in translation and cutting.

## 1. Introduction

Realistic surgical simulations for medical training and planning should provide accurate haptic feedback to the operator. One aspect of surgical simulation that has received relatively little attention in the literature is cutting of virtual tissues, particularly haptic feedback using scissor-like instruments. Previous surgical simulations that involve cutting with scissors lack display of forces “between the fingers” of the operator [1,2,3]. Hence, we focus on the specific problem of haptic rendering of cutting forces during simulated surgery with scissors. Our previous work saw the development of a two degree-of-freedom pair of haptic scissors, and a basic cutting simulation capable of displaying haptic forces to the user [4-6]. Haptic forces were calculated using force data previously recorded during actual cutting of three types of tissues. The force data was smoothed, interpolated, and “played back” to the operator. Although playback of forces felt qualitatively “real,” the virtual



**Figure 1.** (a) The two degree-of-freedom haptic scissors. (b) The tissue cutting virtual environment. The large, stretched mesh is the tissue mesh, and the small, uniform mesh is the force mesh.

environment was limited because visual feedback was lacking in quality and realism, and contextual model changes were not possible because the material being cut was not truly modeled. The objective of this work is to develop a fast, realistic haptic rendering technique for scissor cutting that can be easily integrated into soft tissue models and visual displays commonly used in surgical simulators.

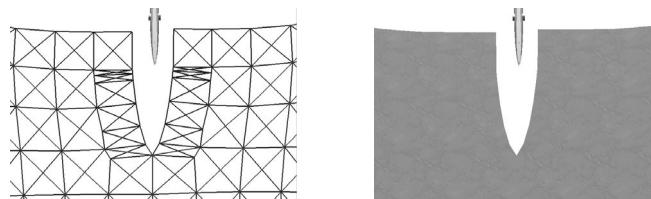
## 2. A Virtual Environment for Cutting

All calculations and haptic force calculations are performed in a haptic thread running at the target rate of 1000 Hz. Each iteration of the thread involves a four-step process: (1) read the position of the haptic scissors from the user; (2) calculate collisions/interactive forces between the scissors and the force mesh, and apply the forces to both the visual and tissue mesh; (3) update positions and forces in the tissue and force meshes; and (4) output haptic forces to the user.

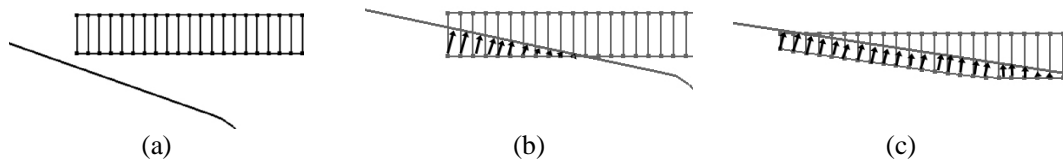
The “haptic scissors” (Figure 1a) is a two-degree-of-freedom haptic interface that allows motion and force feedback in translation (of the entire pair of scissors) and rotation (opening and closing of one blade). The scissors have one degree of freedom for cutting (rotational) forces, and one for translational forces. The rotational degree of freedom has an angular resolution of  $0.056^\circ$  and a maximum torque output of 280 mNm, which corresponds to a force output of 7.58 N at the handle. The translational degree of freedom has a resolution of 0.0152 mm and maximum force output of 159 N.

A virtual environment was created for combined graphic and haptic display of cutting with this device (Figure 1b). Two 2-D deformable mass-spring-damper models were implemented: The first is a large mesh that is used to calculate translational forces. The second is a smaller, one-element-thick mesh that is used to calculate cutting (angular) forces. The translational mesh is displayed in the virtual environment as an infinitely thin slab of tissue. A stiff virtual coupling [7] is used between the scissors and this mesh, and the force applied by the scissors at the contact point results in dynamic deformation of the mesh. At the end of each cut, the mesh is split and new nodes are formed. The cutting mesh is in the plane of the scissors and is invisible. It is created locally around the cutting start point when cutting begins, and is destroyed when cutting finishes. A cut is complete when the scissors are completely closed, the end of the translational mesh is reached, or the scissors change from closing to opening. Accurate collision detection is performed between the curved scissor blades and each mesh. The virtual environment designer can modify several physical parameters: the spring and damping constants of the meshes, and the amount deflection before breaking of the cutting mesh.

The slab of tissue to be cut is represented by a two-dimensional mesh comprised of  $n$  nodes, each with two degrees of freedom (Figure 2). The nodes are arranged in a grid over a user-specified area that represents the size of the slab of tissue, so that the  $i$ 'th node would have the coordinates  $(x_i, y_i)$ . Every node is “bonded” to each of its immediate neighbors, forming a pattern of trussed squares. Deformation of the mesh is calculated



**Figure 2.** On the deformed tissue mesh, red indicates strain and blue indicates equilibrium. A texture is then mapped onto the mesh. New nodes are created in the mesh as the tissue is cut.



**Figure 3.** (a) The scissors blade approaches the force mesh. (b) Forces are exerted on the mesh after initial contact. (c) As blade continues to penetrate, the force mesh is deformed.

using a simple iterative process. Every node has a position, velocity, net force, and external force vector; in one iteration, the net force for each node is calculated and acceleration is applied. After a constant damping is applied, the node is then displaced according to its velocity. Time steps in the calculations are specified by the user and remain constant.

When the scissor blade comes within a striking distance threshold of the mesh, a new force mesh is created at the border of the mesh and the simulation begins to check for collisions between the scissors blade and all the nodes of the mesh. The force mesh is created so that the origin of the force mesh's local coordinate system is always aligned with the coordinates in space of the exposed node along the cutting axis of mesh. Collisions are detected by comparing a node's  $y$  coordinate with the corresponding  $y$  coordinate along an equation that approximately describes the shape of the scissors blade (Figure 3).

### 3. Conclusions

This method for rendering cutting forces can be easily integrated with typical soft tissue models, and is computationally efficient because only a simple 2-D cutting mesh is required. On a typical PC, the, using a full-screen resolution of 800x600 pixels with 16-bit color depth, and without any special optimizations, the haptic update rate is approximately 333 Hz. Observations from both haptics experts and surgeons showed that the simulation is smooth and realistic. Future work will combine this haptic rendering method with parameter estimation for actual tissues.

### References

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