Interacive Cutting Simulation System of Physics-based Electrosurgery

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ABSTRACT

Foregoing studies have never proposed the physics-based real-time electrosurgery simulation, because of the complexity of the phenomena and computational costs. The aim of this study is to construct an interactive surgical simulator with a unified physics-based modeling of electrosurgery. In this paper, we proposed an interactive simulation system of physics-based electrosurgical cutting. Especially, pre-processing independent of contact information reduced real-time calculation time of electrical potential. The proposed system allowed a user to cut a 3D mesh with a virtual electrosurgical tool interactively.

Keywords: virtual reality, medical information systems, finite element methods.

Index Terms: I.6.3 [Simulation and Modeling]: Applications; C.3 [Special-purpose and Application-based Systems]: Real-time and embedded systems—

1 INTRODUCTION

Virtual reality-based electrosurgical simulators are demanded for training of the major skills in laparoscopic surgery to reduce complications. However, foregoing electrosurgery simulators ignored underlying physical phenomena, due to their complexity and required update rates for graphics and haptics. Thus, the conventional simulators removed the material when the temperature reached 100 °C [1], although stress concentration is closely-linked to tissue destruction. The temperature-based cutting cannot take into account the effect of the tension given to the tissue by grasping or pulling.

The aim of this study is to construct an interactive surgical simulator with a unified physics-based modeling of electrosurgery. In this study, we simulate interactive physics-based electrosurgery cutting.

2 INTERACTIVE ELECTROSURGICAL CUTTING SIMULATION

An electrosurgical unit is a device for cutting soft tissue by Joule heat caused by the current of high frequency. The electrical phase determines the current density distribution caused by the contact between the electrosurgical tool and the object. The thermal phase determines the temperature distribution caused by Joule heating and temperature conduction. The governing equations of electric conduction and heat transfer are given by Laplace and heat equations.

$$\nabla^2 V = 0 \tag{1}$$

$$c\rho \frac{\partial T}{\partial t} = \lambda \nabla^2 T + \mathbf{J} \cdot \mathbf{E} \tag{2}$$

where V is voltage, T is absolute temperature, $\mathbf{J}$ is current density, $\mathbf{E}$ is electric field, and c, ρ, λ are specific heat, density, and thermal conductivity, respectively. The structural phase determines the structural change caused by vaporization and stress concentration. The stress is derived from the expansion of the volume caused by water vaporization.

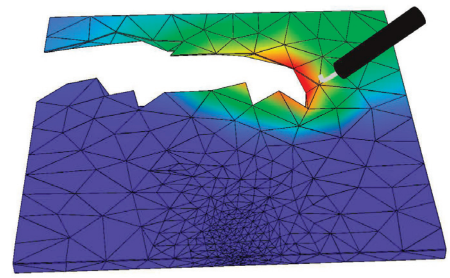

Figure 1: Interactive cutting simulation

Our approach is to reduce the computational cost in real-time processing by pre-processing independent of prior contact information. The proposed system inverts the whole coefficient matrix for linear simultaneous equation of electric potential, before the contact nodes by an electrosurgical tool are given. The conventional method requires the contact information in the high-cost matrix operation, such as the matrix inversion and factorization, while the proposed method does not require the contact information in the high-cost matrix operation. Thus, the proposed method excludes the high-cost matrix operation from real-time processing to pre-processing.

3 SYSTEM

The simulation system was equipped with Intel CPU (Core i7 3.07GHz), 12GB main memory, a PHANToM Omni haptic device, and an nVidia GeForce GTX 580 graphics board. The object used in the simulation had 1013 nodes (tetrahedral mesh). The object size was 100 mm × 100 mm × 10 mm. Fig. 1 shows the temperature distribution and the cut region by a user's manipulation. The electrical potential was calculated with consideration of interactive manipulation of the electrosurgical tool. The temperature of the nodes was increased by the Joule's heat, while the temperature was diffused in the object as time progressed. The stress increased after the vaporization of water in the elements. The elements whose stress was over the criteria were removed.

4 CONCLUSION

The simulation results showed that the proposed system enabled an interactive simulation with consideration of a series of physical phases: electrical, thermal, and structural phases.

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