

Physics-based Real Time Laparoscopic Electrosurgery Simulation

Anderson MACIEL¹, Suvranu DE

*Department of Mechanical, Aerospace & Nuclear Engineering,
Rensselaer Polytechnic Institute, Troy/NY*

Abstract. While physics-based modeling of electrosurgical procedures is essential for most laparoscopic simulation systems, we present such a system for the first time in this paper. We have implemented a physics-based model of electrosurgery to control the temperature distribution on the tissue as a function of time. Then, we evaluate the algorithm within a complete graphics-haptics-physics-based system.

Keywords. Computer Graphics, Interaction techniques, Simulation, Physics-based modeling

Introduction

The term electrosurgery designates the application of a high-frequency electric current to human tissue in order to staunch bleeding or cut tissue [1]. Unlike electrocautery, during which a heated wire comes in contact with tissue, in electrosurgery the patient is included in the circuit and current enters the patient's body. Alternating current is used to directly heat the tissue itself (diathermy), while the probe tip remains relatively cool. By varying the voltage and the waveform, the electrosurgical generator controls the rate at which heat is produced. High heat produced rapidly causes tissue vaporization (cut), and low heat produced more slowly creates a coagulum. Electrosurgery tasks are an essential part of many surgical procedures, especially those performed in a minimally invasive manner. Digital surgery is being used more and more by the medical community as an important training tool and for pre-operative planning. Though surgical simulators exist today, accurately simulating all the steps of a surgical procedure is difficult, and so far, all implementations of the electrosurgical process are nonphysical, based primarily on computer graphics techniques of rendering the burnt tissue [2]. In this paper we develop, for the first time, a real time physics-based virtual electrosurgical simulation tool in which heat generation in the tissue is linked to the applied electric potential.

1. Tools and Methods

Electrosurgical cutting, unlike scalpel cutting, actually removes mass of the tissue by vaporization. The amount of tissue to be removed depends on the rate of heat generation

¹Corresponding Author: Anderson Maciel, MANE-RPI, 110 8th st. Troy, NY 12180, USA; E-mail: maciea@rpi.edu.

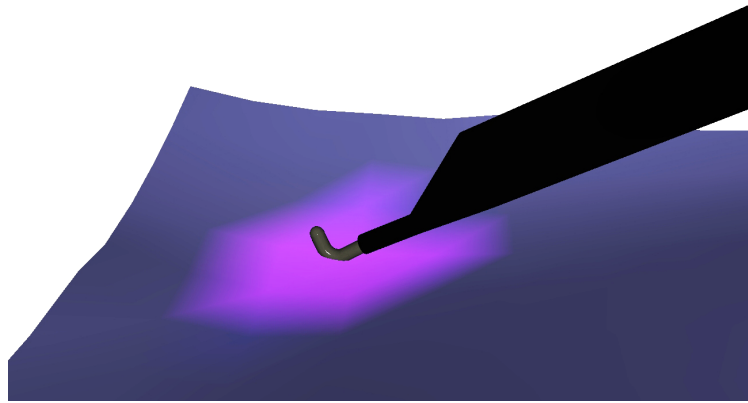


Figure 1. Color map of the temperature distribution.

and may have different effects on membranous or massive tissues. We have modeled two distinct situations using 3D surface triangle meshes to represent both membranous tissue (fascia, ligament and skin) and bulk tissue (muscle, liver and kidney). The user interacts with the models using a virtual L-hook electrode associated to a Phantom Omni™ force feedback device. The force feedback is computed using a mass-spring model. As the heat production rate determines how the tissue will be vaporized and cut, a first approach to a physics-based model of electrosurgery is to control the temperature distribution on the tissue as a function of time. The contact of the electrode with the tissue results in a rise in temperature in its vicinity. This is a transient process and the rate of temperature rise is dictated by the thermal conductivity of the soft tissue and the coefficient of thermal diffusivity. Figure 1 presents a color map of the temperature distribution. When the tool is withdrawn, the flow of electricity ceases resulting in rapid decline of temperature levels back to the body temperature.

2. Results

As case studies for this part of the research, we consider two scenarios: (1) electrosurgical cutting of a thin membranous tissue and (2) ablation of portion of a massive organ. In both cases, a temperature model is implemented, and the complete system - including deformation, interaction, rendering and force-feedback - runs in real time, i.e., graphics update of over 30 Hz and haptics update of over 1000 Hz. Figure 2 illustrates these scenarios. It is observed, that for the membranous tissue, the process of burning causes the tissue to open up due to initial tension, which requires triangle removal on the surface as well as update of the topological information of the mass-spring system. For the massive tissue, on the other hand, surface triangles are not removed but are displaced by a certain distance from the electrode tip, exposing the underlying tissue. The color texture mapped to the burnt region is also modified, using images of burnt tissues obtained from actual experiments, to provide realism of the burnt surface.

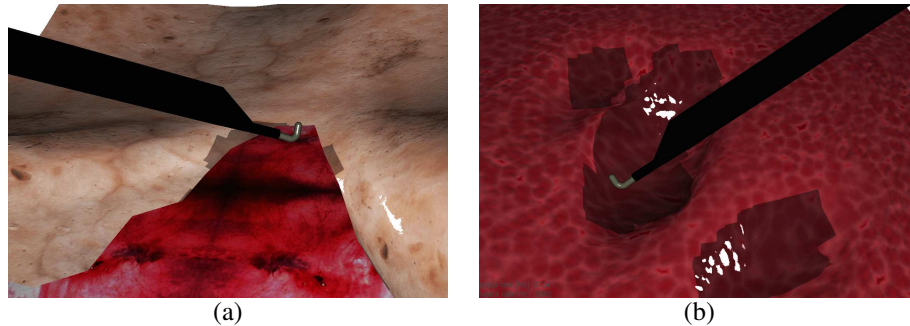


Figure 2. Virtual electro-surgical cutting of a membranous tissue (a) and ablation of a liver model (b).

3. Conclusions/Discussion

While physics-based modeling of electro-surgical procedures is essential for most laparoscopic simulation systems, we present such a system for the first time in this paper. We have implemented and evaluated the algorithm within a complete graphics-haptics-physics-based system. We have considered both membranous and bulk tissues and the difference in their response to electro-surgical processes. This is coupled with a newly developed dynamic point algorithm for efficient line-based collision detection [3]. Excellent performance is achieved allowing force-feedback rendering at a frequency of several kHz. It is anticipated that this will become an essential component of laparoscopic surgical simulators of the future.

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