

Haptic Rendering for Laparoscopic Surgery Simulation and Related Studies

Ryan McColl

Monash University, Australia

Ian Brown

Monash University, Australia

Cory Seligman

Monash University, Australia

Fabian Lim

Monash University, Australia

Amer Alsaraira

Monash University, Australia

INTRODUCTION

This project concerns the application of haptic feedback to a virtual reality laparoscopic surgery simulator. It investigates the hardware required to display haptic forces, and the software required to generate realistic and stable haptic properties. A number of surgery-based studies are undertaken using the developed haptic device.

The human sense of touch, or haptic sensory system, is investigated in the context of laparoscopic surgery, where the long laparoscopic instruments reduce haptic sensation. Nonetheless, the sense of touch plays a vital role in navigation, palpation, cutting, tissue manipulation, and pathology detection in surgery. The overall haptic effect has been decomposed into a finite number of haptic attributes. The haptic attributes of mass, friction, stiction, elasticity, and viscosity are individually modeled, validated, and applied to virtual anatomical objects in visual simulations.

There are times in surgery when the view from the camera cannot be depended upon. When visual feedback is impeded, haptic feedback must be relied upon more by the surgeon. A realistic simulator should include some sort of visual impedance. Results from a simple tissue holding task suggested the inclusion of haptic feedback in a simulator aids the user when visual feedback is impeded.

BACKGROUND

Introduction to Haptic Feedback

Haptic perception is equivalent to humans' sense of touch, and incorporates both tactile and kinesthetic perception. Haptic feedback is present whenever the haptic receptors are engaged. All physical objects intrinsically display haptic feedback to humans when they interact with them, and include texture, weight, and heat. In relation to this document and simulators in general, haptic feedback is the term given to the forces displayed by a mechanical haptic device able to simulate an objects haptic information.

Surgery simulation and robotic surgery is an area where haptic feedback use is increasing. The sense of touch provides useful information to surgeons when orientating themselves, diagnosing pathologies, and manipulating tissue. Visual-only simulators can improve surgical training and education, but hands-on experience can only be achieved by including haptic feedback (Nudehi, Mukherjee, & Ghodoussi, 2003, p. 4563). To ensure a completely immersive and realistic VR simulator, haptic feedback must be included. Due to computing power issues in the past, the implementation and development of a haptic feedback system has come secondary to the highly computational visual graphic components. Improvements in technology and further research will lead to haptic feedback becoming more reliable, stable, and commonplace.

Haptic Perception

The sense of touch in human is extremely important and often underrated (Robles-De-La-Torre, 2006). A realistic surgery simulator must provide sufficient visual and haptic information to the user. Simulated haptics and graphics is not real life, but by exploiting the limitations of humans' senses, realism is created. To synthesise haptic feedback to such a level, an understanding of the biomechanical, sensorimotor, and cognitive abilities of the human is required (Tan, Srinivasan, Eberman, & Cheng, 1994, p. 353).

One way of testing and comparing humans' abilities is to use the Just-Noticeable-Difference (JND) measure. The Just-Noticeable-Difference (JND) describes the smallest amount of change of an arbitrary stimulus which can be detected, just as often as it cannot be detected. Therefore, the JND, in the context of force perception, is defined as being the minimum amount of force change to an initial force that a user can detect in 50% of trials (Wikipedia, 2006). It can be used to test many haptic attributes, and provides a means to validate hardware and software capabilities in a haptic system. This value lies mostly between 5% and 15% for humans, depending on the stimulus type and limb or joint where it is applied (Hinterseer & Steinbach, 2006).

Sense Perception During Laparoscopic Surgery

There is significant degradation and distortion of forces encountered by surgeons during laparoscopic procedures. The force feedback from tissue interaction, including tasks such as tissue palpation, is effected by friction at the trocar, weight of the instrument, and length of the instrument (Patkin & Isabel, 1995; Tavakoli, Patel, & Moallem, 2006). As a reference, a metal trocar can introduce about 0.4N of friction (Sallé, Gosseli, Bidaud, & Gravez, 2001), and the weight and length of a typical laparoscopic instrument are about 100grams (1N) and 400mm respectively.

Depth perception cues are lost, due to viewing the scene on a 2D monitor. Patkin and Isabel (1995) found that five out of 16 depth perception cues are lost including stereopsis, convergence, and texture fade. Also, the field of view reduces from 150° to 60°, and viewing distance reduces by 90%, compared to open surgery. Hand-eye coordination is reduced by

the indirect method of observing and manipulating tissue. Breedveld and Wentink (2001, p. 155) suggest this is due to a mislocation of the camera picture, and a misorientation of the instrument movements. The instruments movement on the monitor are different than expected, and the "effects are very confusing." They, however, make no mention on the role force feedback plays in compensating for the hand-eye coordination effect. Bingham et al. (2000) does consider haptic feedback in a hand-eye coordination experiment. It does not directly relate to laparoscopic surgery, but results suggest that distance and shape distortion created by visual illusions can be corrected somewhat by haptic feedback.

Training simulators should include haptic feedback to improve users' awareness of its role. Development of a surgeons' sense of touch can reduce damage to organs and tissues, and improve recognition of the slightest difference of tissue density, improving the ability to identify blood vessels and other structures merely by touch alone (Patkin, 2005; Patkin et al., 1995).

Haptic Hardware

An ideal mechanical interface acts as a transparent medium in which force is displayed to the user from the data calculated in the virtual anatomy model. It should be friction free, have zero mass and inertia, have zero backlash, and display a wide magnitude of forces without error. This ideal will never be realised in the real world, so we strive for a device as close to ideal as possible.

Haptic Modeling

Surgery simulation requires a force reflecting deformable model of the anatomy. The quality of visual and haptic information must be sufficient to simulate a high level of realism to the user. Accurate physical-based models are computationally demanding, whereas simple geometric models do not generate realistic information. A balance between realism and real-time operation is required.

Validation

In order to determine the effectiveness of various haptic models developed within this project, validation studies need to be undertaken. The hope is that haptics enable

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