Interactive Peritoneum in a Haptic Surgery Illustration Environment

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Abstract. We describe a fully interactive, low-overhead and robust peritoneum representation allowing for probing and cutting. The peritoneum implementation has been tested within a surgical illustration environment.

Keywords. Peritoneum, Surgical procedure illustration, interactive, haptic, TIPS.

Introduction

Modeling peritoneum in a 3D surgical simulation, i.e. a membrane that stays close to yet *strictly to one side* of non-statically positioned organs, vessels and possibly deforming fatty tissue, is non-trivial. Haptic feedback that allows probing organs, vessels and haptic feedback and cutting and tearing the peritonium (in preparation for clamping and/or ligation) adds another level of complication for real-time deployment. Efficiency and accuracy are further challenged when organs, vessels and tissue are deployed in an interactive session of an illustration environment such as TIPS [1] (Toolkit for Illustration of Procedures in Surgery) since the relations between the geometric entities are not known beforehand and have to be established on the fly.

Figure 1: (*left*) Semi-transparent peritoneum membrane covering the adrenal gland; (*right*) section of the scene on the *left* to show proximity of peritoneum and underlying anatomical features.

Here we describe a fully interactive *low-overhead* and robust peritoneum representation verified by deploying it within TIPS. To date no such interactive surface representation exists since cloth modeling, the closest paradigm borrowed from computer graphics is based on detailed triangulations and is too expensive at haptic-interactive rates.

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1. Challenge, Tools and Methods

Challenge. To create an enclosing membrane, requires solving a *one-sided best fit* problem. This class of problems can be formulated as a quadratic minimization problem subject to inequality constraints. In isolation, using state-of-the art tools, such a problem can be re-solved for changing position of enclosed anatomical features (organ, vessel and fatty tissue) position, in real time even when the surface consists of several thousand triangles. But concurrently with many other real-time processes requiring CPU and GPU cycles (see Table 1), such a minimization problem is too expensive to solve since the peritoneum membrane is not static, but has to adjust to the underlying features.

Tools. Our membrane class is based on tight sharp estimates on the location of a *spline* relative to its coefficients (control points) [2]. These estimates guarantee a fast, near-optimally tight, one-sided approximation (see Figure 1) without assembling and solving large constrained optimization problems. The approach is faster than computing the (local) convex hull of the control structure and trying to shift it to avoid intersection of the peritoneum with anatomical features

Methods. *Probing* feedback (via an Omni device) is based on the feedback from the dynamic model of the underlying anatomical feature. *Cutting* the peritoneum (e.g. to dissect the underlying fatty tissue) requires that the peritoneum retract under its own tension by an amount that varies with tissue properties. We addressed this challenge by translating the (virtual) tool's motion into a curve in the (u, v) domain of the spline surface that represents the peritoneum. Given this u, v curve one can in principle use NURBS 'trimming' along a lens-shape offset from the central u, v curve. Its image then defines the boundaries of the incision in the peritoneum. Trimming of NURBS surfaces is well-understood in off-line geometric design. However, the standard (OpenGL API) implementations are too slow or too coarse to provide the appearance and feedback of the peritoneum. To simulate the retraction of the peritoneum after incision, we instead, on the GPU, mark the region between the two offset curves so that the fragment shader can discard the surface corresponding to the lens-shaped cut in the peritoneum. When implemented within TIPS (Figure 2,*bottom*), the default shape of the lense can be varied by the TIPS author to illustrate different amounts of tension.

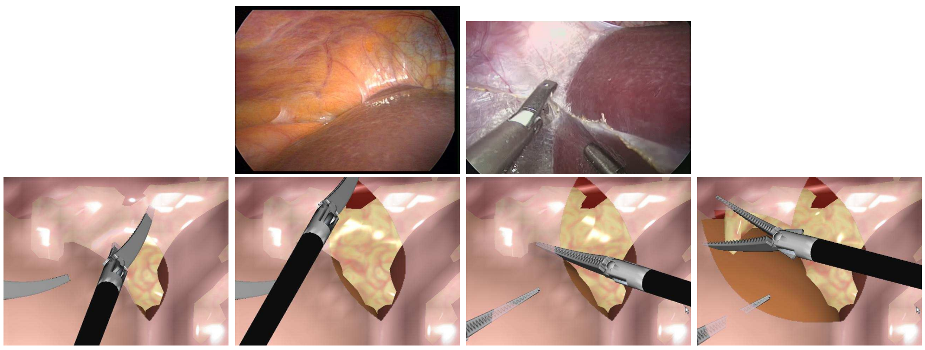

Figure 2 (*top*) Photo of peritoneum. (*bottom*) Cutting virtual peritoneum to expose the fatty tissue.

Anatomical Features	Features only	Features + peritoneum	Features + incision
vena cava & aorta	61	60	58
. . . + kidney	60	59	56
. . . + adrenal gland	55	53	52
. . . + adrenal vein	48	47	45
. . . + fatty tissue	19	17	17

Table 1 Frames per second on a 2Ghz dual-core CPU with 2GB RAM and NVidia GeForce 8800GTX GPU using OpenGL. (*left* column) Anatomical features are added and (*top* row) peritoneum and incision capability are added. The vena cava, aorta, kidney and adrenal vein are triangulated surfaces, the fatty tissue is a dynamically computed volumetric representation; all features have haptic feedback enabled.

2. Results and Discussion

Table 1 illustrates that our peritoneum implementation, including incisions, complements an existing real-time framework (with two-handed haptic interaction, real-time deformable and dissectable fatty tissue, blood vessels and organs, deployed on a laptop) with minimal additional computational cost. Since the resolution of the peritoneum does not depend on the number and complexity of the underlying anatomical features, the approach can interactively, one-sidedly cover any number of anatomical features in the scene. (Re)generation is instantaneous. As opposed to standard OpenGL trimming, this approach can deal also with several overlapping incisions (Figure 2, *bottom right*).

Our peritoneum class mimics probing and incision of the membrane both haptically and visually, but it does not physically simulate the membrane. Apparent tension, i.e. retraction radius and haptic feedback can be set by the TIPS author. The effect was deemed sufficient by our surgeon-authors in the context of laparoscopic adrenalectomy where the peritoneum, once cut to provide access to the underlying fatty tissue, plays no further role.

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References

[1] Minho Kim, Tianyun Ni, Juan Cendan, Sergei Kurenov, and Jörg Peters. A haptic-enabled toolkit for illustration of procedures in surgery (TIPS). *MMVR 15*, 209–214, 2007.

[2] A. Myles and J. Peters. Fast safe spline surrogates for large point clouds. In *Proceedings Third International Symposium on 3D Data Processing, Visualization and Transmission, UNC, Chapel Hill, USA*, pages 61–69, June 14-16 2006.

[3] Sukitti Punak, Minho Kim, Ashish Myles, Juan Cendan, Sergei Kurenov, and Jörg Peters. Fatty tissue in a haptic illustration environment. *MMVR 16*, 384–386, 2008.