Generalized Interactions Using Virtual Tools within the *Spring* Framework: *Probing, Piercing, Cauterizing and Ablating*

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Abstract

We present schemes for real-time generalized interactions such as probing, piercing, cauterizing and ablating virtual tissues. These methods have been implemented in a robust, real-time (haptic rate) surgical simulation environment allowing us to model procedures including animal dissection, microsurgery, hysteroscopy, and cleft lip repair.

1. Introduction

When trying to create a simulation environment, whether for surgical training, clothing design or manufacturing, it inevitably becomes necessary to model object to object interactions [1-3]. We have developed generalized methods for allowing a user to interact with patient-specific models using detailed virtual tools in a real-time virtual environment. These methods strive to provide a general method for interactions that can then be realized by many different virtual instruments.

2. Methods

When implementing a simulation system, many tasks are required to be performed at each timestep. Within our simulator, the basic simulation engine loop is deformable object solution, collision detection, collision response, and user interface information. For a detailed description of the simulation environment, the reader is directed to [4] and for a description tool behavior [5]. The goal of this paper is to describe the implementation of several forms of interactions common to surgical simulations. These interactions are implemented within each object's collision response routine. The result of each collision is determined by the object's interaction type. This paper briefly describes four such interactions: probing, piercing, cauterizing, and ablating. In each case, the collision resolution algorithm processes each of the elements in a collision pair list, performs their interaction function, and computes the resulting haptic force of that interaction upon the virtual tool performing the manipulation. Once this process is completed, the interaction forces are combined to calculate the overall force vector that should be realized upon the virtual instrument. This resultant interaction force is then rendered upon a haptic interface device.

Collision Detection

Each object in the virtual environment is partitioned into a bounding sphere hierarchy [6]. Currently we are storing intersection information as collision pairs with pointers to the objects that were in collision, the point at which collision occurred, and the primitives that were intersected (node, edge, or triangle). This list of collision pairs is then passed to the collision response method of the tool and provides the necessary information to perform a probing, piercing, ablating or cauterizing interaction.

Collision Response

Probing

When a virtual probing tool (such as a hand, pick, dilator, etc) has penetrated a deformable object, the deformable surface displaces itself until force within the springs becomes larger than the yield force of the deformable material being simulated [7]. To handle this displacement we compute the intersection of the object and the tool then, based on the direction the tool followed, we can determine which direction the deformable object should be moved. We resolve the collision in real-time by displacing nodes of the deformable object until the objects are no longer in collision.

Currently we are storing pairs of intersecting primitives, which determine the *boundary* of the subset of the surface that is interpenetrating, but not all of the faces that are in that subset. In order to resolve the interpenetration as fast as possible, it may be advantageous to determine all of the faces that are interpenetrating [8] and start collision response on the face that is farthest into the other object. However, in order to avoid additional computation, we force the faces of the deformable object to walk down the contour of the other object in order to resolve the object-to-object interpenetration. Figure 1 demonstrates the real-time probing interaction being implemented by a virtual hand composed of 3,000 triangles and a piece of virtual tissue composed of 5,000 triangles.

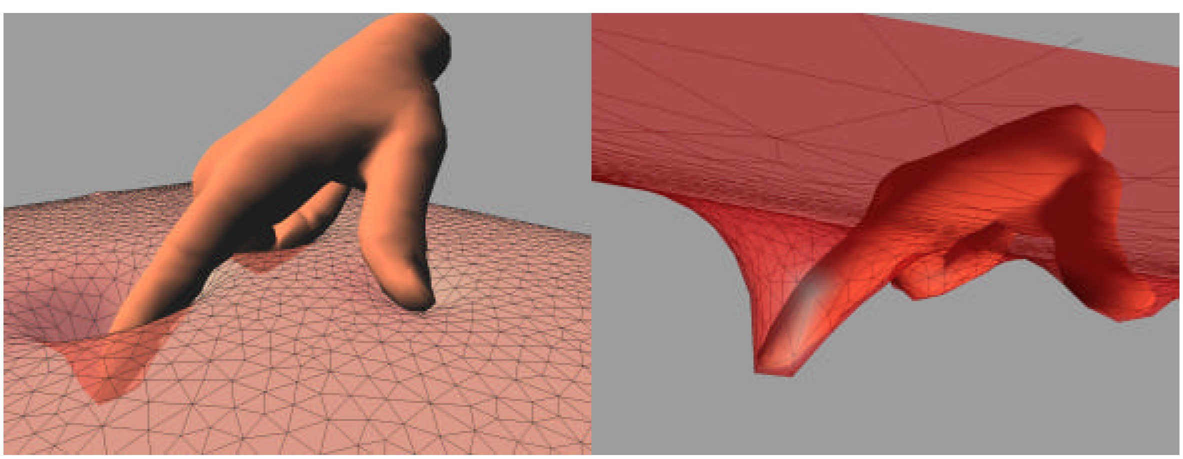

Figure 1. Pushing. [Left]: Top view. [Right]: Side view.

Piercing

For a piercing interaction (e.g., syringe, needle), the virtual instrument pierces through a surface, producing a local subdivision at the point of entry. The rest of the object merely has a probing interaction. In this way, the tip of the syringe is “sharp” and can pierce through tissue, while the rest of the syringe merely bumps the tissue upon interaction.

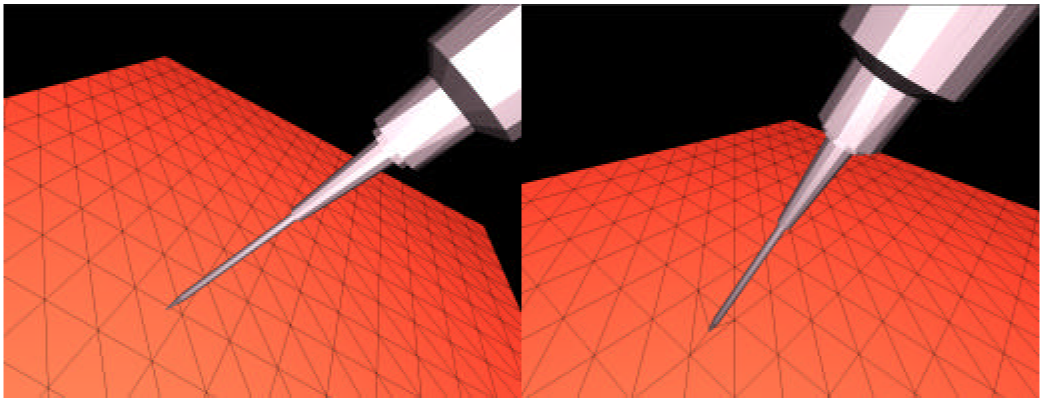

Figure 2. Piercing. [Left]: Before intersection. [Right]: After subdivision.

Ablation

An ablating instrument (roller ablator) when active and in contact with tissue, progressively yellows, browns, then blackens the area of contact. This interaction is performed by changing the color of the contacted faces and using blended textures to achieve the desired graphical result. Specifically, the underlying surface is originally set to completely white which, with an overlayed, blended texture, merely yields the original texture image. As the active cauterizing tool comes in contact with the surface, the triangles that are in collision with the “hot” part of the tool decrease their blue intensity (thereby leaving a more and more yellow color remaining). When the blue intensity is zero, then the red and green channels are also decreased, with the rate of decrease of the green channel being twice that of the red (thereby producing a brown color that fades toward black as both the red and green approach zero). By modifying the colors in this way, along with blended textures, the visual appearance of the texture is that of progressively yellowing, browning, and blackening as the tool remains in contact with the virtual tissue. Figure 3 demonstrates a roller ablator instrument composed of 200 triangles cauterizing a virtual tissue composed of 2000 triangles.

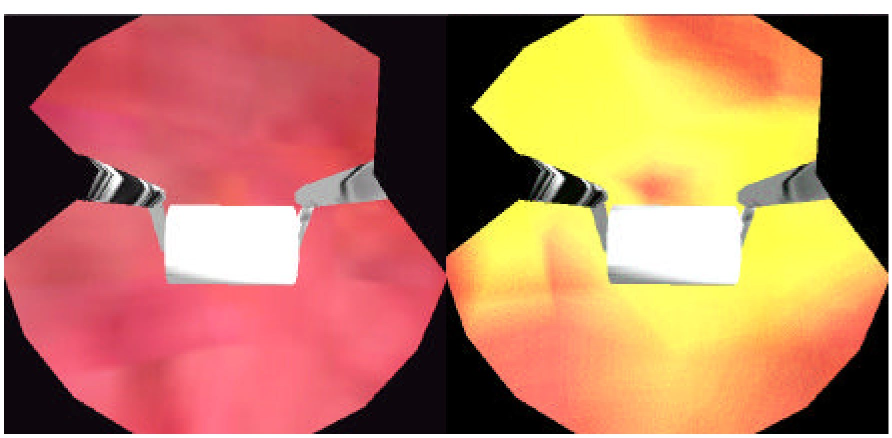

Figure 3. Cauterizing. [Left]: Before intersection. [Right]: Tissue is burned.

Cautery

When a virtual instrument (loop cautery) has been assigned the cauterizing interaction type, each object that it comes into contact with is eroded. Used in conjunction with an ablating interaction, this interaction is implemented by simply removing the triangles that are being intersected and ablating the boundary. Figure 4 demonstrates the use of an ablating tool composed of 200 triangles and a piece of virtual background tissue composed of 2000 triangles, with a polyp (foreground) of 881 faces.

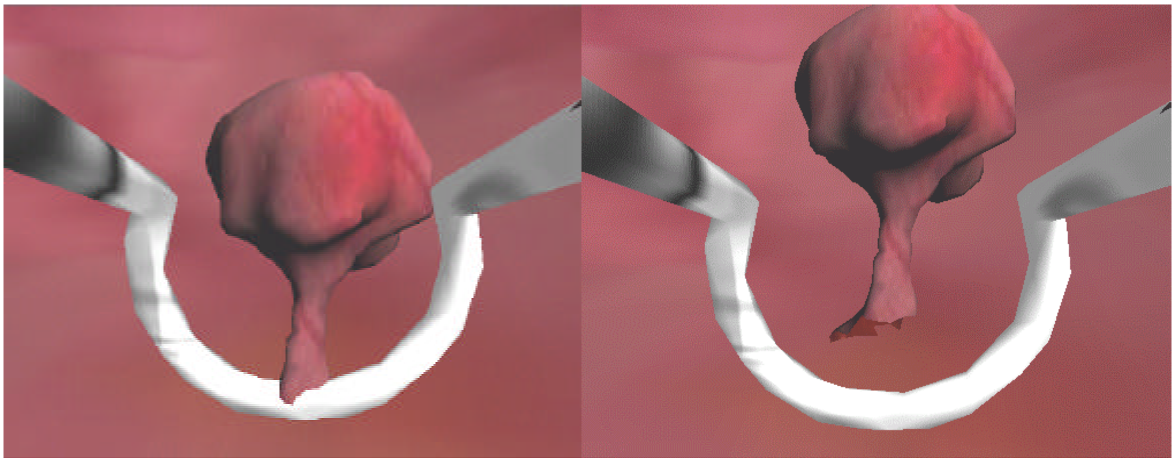

Figure 4. Cautery. [Left]: Searing through tissue. [Right]: Tissue disconnected after cautery.

A number of more abstract interactions are also implemented, such as selecting subparts of an object, coloring a subpart of an object, measuring distances and angles of an object, as well as texture manipulation.

3. Conclusions

We have demonstrated the implementation of several manipulations common to surgical simulation. These manipulations have been integrated into the *Spring* framework and are in use by several applications [9,10,11].

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References

[1] H. Delingette. Towards realistic soft tissue modeling in medical simulation. In *Proceedings of the IEEE: Special Issue on Surgery Simulation*, pages 512–523, Apr. 1998.

[2] C. Bosdogan, C. Ho, M.A. Srinivasan, S.D. Small, and S.L. Dawson. Force Interaction in Laparoscopic Simulation: Haptics Rendering of Soft Tissues. *Proc. Medicine Meets Virtual reality (MMVR'98)*, Jan. 1998, pp. 28-31.

[3] S. Cotin, H. Delingette, and N. Ayache. A Hybrid Elastic Model Allowing Real-Time Cutting, Deformation and Force Feedback for Surgery Training and Simulation. *The Visual Computer*, 16(8):437-452, 2000.

[4] Montgomery, K., Bruyns, C., Brown, J., Sorkin, S., Mazzella, F., Thonier, G., Tellier, A., Lerman, B., Menon, A.: Spring: A General Framework for Collaborative, Real-time Surgical Simulation, In: Westwood, J., et. al. (eds.): Medicine Meets Virtual Reality, IOS Press, Amsterdam, (2002).

[5] Bruyns, C., Senger, S., Wildermuth, S., Montgomery, K., Boyle, R.: Real-time Interactions Using Virtual Tools. In: Niessen, W.J., et .al. (eds.) MICCAI 2001, LNCS 2208, Springer, Berlin Heidelberg, (2001) pp. 1349-1351.

[6] Sorkin, S. Distance Computing Between Deformable Objects. Honors Thesis, Computer Science Department, Stanford University, June 2000.

[7] Terzpoulos, D., Fleischer, K.: Modeling inelastic deformation: Viscoelasticity, plasticity, fracture. Computer Graphics, 22, (1998) 269-278.

[8] Sundaraj, K., Laugier, C.: Fast Contact Localization of Moving Deformable Polyhedras. IEEE Conf. On Automation, Robotics, Control and Vision (ICARCV). Dec 5-8, 2000.

[9] Bruyns, C., Montgomery, K., Wildermuth, S.,: A Virtual Environment for Simulated Rat Dissection. In: Westwood, J., et. al. (eds.) Medicine Meets Virtual Reality, IOS Press, Amsterdam (2001) pp. 75-81.

[10] Wildermuth, S., Bruyns, C., Montgomery, K., Marincek, B., Virtual Colon Polyp Extraction (Simulation and Preoperative Planning), In: Niessen, W.J., et .al. (eds.) MICCAI 2001, LNCS 2208, Springer, Berlin Heidelberg, (2001) pp. 1347-1348.

[11] Montgomery, K.; Heinrichs, L., Bruyns, C., Wildermu th, S., Hasser, C., Ozenne, S., Bailey, D.,: Surgical Simulator for Operative Hysteroscopy and Endometrial Ablation, In: Lemke, H., et. al. (eds.) Computer-Aided Radiology and Surgery, Elsevier, Amsterdam (2001) pp. 79-84.