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Suturing Simulation in Surgical Training Environment

Hans Fuhan Shi and Shahram Payandeh

Abstract— **In this video we present a physics-based haptic simulation designed to teach basic suturing techniques for simple skin or soft tissue wound closure. The pre-wound suturing target, skin or deformable tissue, is modeled as a modified mass-spring system. The suturing material is designed as a mechanics-based deformable linear object. Tools involved in the live suturing procedures are also simulated. Collisions between the soft tissue and the needle, the soft tissue and the suture are analyzed. In addition to modeling the detail steps involved in a typical suturing procedure, modeling approaches for evaluation of a stitch are also discussed.**

I. INTRODUCTION

SENSORY feedback including visual feedback and force feedback is a crucial requirement to make surgery simulations more realistic. There have been a number of developments in the past trying to address the modeling and implementation of this fundamental multi-modal interactive environment, e.g. see [1]. Mechanical knowledge of the soft tissue and the suture is required to compute interaction forces. We model both the soft tissue and the suture material based on continuum mechanics models. Through two haptic devices (Phantom Omni devices), our simulator can provide smooth force feedback and allow the user to perform different suturing patterns during training. Modeling approaches for evaluation of a stitch are also discussed. For example, if needle insertion points are too close from each other or from the edge of the wound, the suture will tear the soft tissue instead of suturing the incision together when the tension applied on the pierced nodes beyond a pre-set threshold. Experiment results show that our simulator can run on a standard personal computer and allow users to perform different suturing patterns with smooth haptic feedback. Figure 1 shows a example results of a typical wound closure which a trainee can form using two handed haptic interaction. This example can also be seen as a part of the accompanying video.

II. FACILITY DEMONSTRATED IN VIDEO

We use the same suture model as described in [2]. The suture is modeled as a sequence of mass points laying on the centreline of the suture (See Fig. 2).

In order to simulate the mechanical properties of a suture such as stretching, compressing, bending, and twisting, we calculate not only external forces such as gravity, user input force, and contact forces with obstacles, but also internal forces including the friction force, linear spring, linear damper, torsional spring, torsional damper, and swivel damper.This model also allows the user to tie any kinds of knots with interactions of haptic devices[2].

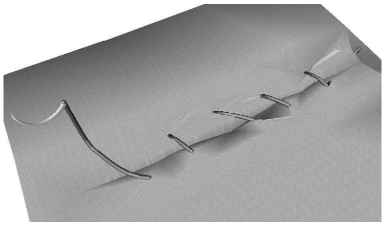

Fig. 1. A typical virtual suturing of a cut.

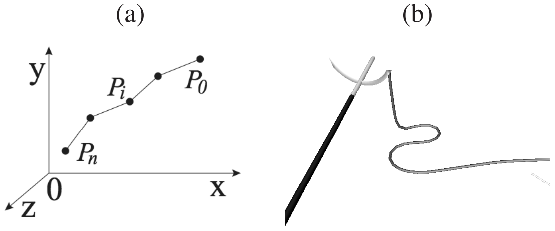

Fig. 2. (a) Linear FE model model of the suture. (b) A suture is attached on the end point of a needle during the simulation.

A Mass Spring System (MSS) can be applied to either volumetric elements such as tetrahedral, or polygonal surface elements such as triangles. In order to reduce computation load during the real-time simulation, we chose a surface mass-spring model based on the model described in [3]. Although a home spring has been added to each node to maintain the shape of the deformable object, the adjacent edges in small triangles still could bend to any angle if their common node is dragged by needle or suture. We add bending springs to each pierced vertex in our model to solve this issue.

We build our 3D models of pre-wound skin or soft tissue in 3D graphics applications such as Autodesk 3ds max, and then export out the model as VRML file. Our simulator imports these VRML files to build the virtual objects. In this way, we can simulate different kinds of cuts for suturing tasks.

To reduce the computation load at most to satisfy the high demand of haptic rendering, we select the simple iterative explicit Euler method to update the states of the soft tissue and the suture. Although the explicit method has some drawbacks comparing to the implicit method, our experiment results show that we can make the simulator stable enough

H. Shi is with Experimental Robotics Laboratory, School of Engineering Science, Simon Fraser University, Burnaby, BC V5A 1S6, CANADA `fuhans@cs.sfu.ca`

S. Payandeh is with Experimental Robotics Laboratory, School of Engineering Science, Simon Fraser University, Burnaby, BC V5A 1S6, CANADA `shahram@cs.sfu.ca`

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by restricting the integration time step dt to be inversely proportional to the square root of the stiffness.

Instability is still a problem for the model in [3], especially when the mesh has very small triangles. To solve this problem, we set a threshold for each spring and add a post-step process after each deformation computation. We choose a post-step constraint enforcement process after each time step computation to eliminate the large stretch as defined in [4].

We divide one complete suturing procedure into five steps: needle pierces the object, soft constraints slid on the needle, soft constraints slid on the suture, apply the suture tension to close the wound or incision, knotting. To prevent any two connected springs from bending easily to any undesirable angle, we have added torsional springs and dampers to each of these newly created springs. Because the torsional spring and damper should be configured on two connected springs as a pair, we have to deal with two connected springs at the same time.

To make the suturing simulation more realistic, we need to simulate not only normal situations, but also unwanted scenarios. Tissue ripping is one of these unwanted circumstances that always happens to novice surgeons or medical students. It is also one of the key metrics to evaluate the trainee's performance during the training.

Based on the assumption that the stitch goes through from the top surface to the bottom surface of the soft tissue, we define two types of tearing: *Tear-Into* and *Tear-Through*. Fig. 3 (a) shows that point C is a top start constraint in tear-into case, point D is a groove constraint. Fig. 3 (b) shows that point C is a top start constraint, point D is a bottom start constraint.

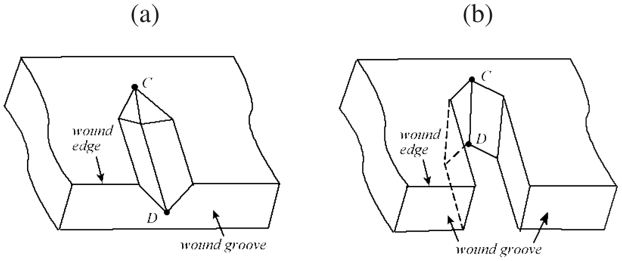

Fig. 3. (a) Tear-into the soft tissue. C is the top start constraint and D is a groove constraint (b) Tear-through the soft tissue. C is the top start constraint and D is the bottom start constraint.

III. VIDEO CONTENTS

The video submission accompanying this abstract showcases the whole suturing procedure and several special cases: Suturing simulation shows the normal suturing steps. Tear-through case 1 shows that tearing path crosses the wound. tear-through case 2 shows that tearing path does not cross the wound. Tear-into case 1 shows that two needle insertion are too close from each other and the tearing path does not cross the wound. Tear-into case 2 shows that the needle insertion points are too close to the edge of the wound, and the tearing path crosses the wound.

IV. CONCLUSION

We present a modeling and simulation approach for practical suturing for surgical training environments based on physics models. The experiment results show that our simulator could suture a pre-wound soft tissue together with smooth force feedback and also allow the user to tie a knot. However, there are still several issues need to be considered. First, as mentioned in above sections, implicit Euler's method has more advantages than simple explicit method, although it is more difficult to implement and requires more computational procedures due to the need to compute the inverse of the large sparse stiffness matrix. However, modern GPU computational environment may offer the required computational environment for tackling more computationally intensive algorithms. Secondly, the current subdivision method can cause many unwanted small triangles if the user put the needle back and forth through the soft tissue at the same area. To solve this, we may need to keep track of the topology of the movements of the needle. For example, if the user pull the needle back, the subdivided triangle should go back to its original unsubdivided configuration.

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