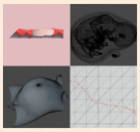

VR Obstetric Simulation

Junting Liu.[1,2], Benny Lo.[1,2]
[1]The Hamlyn Centre for Robotic Surgery, United Kingdom; [2]Department of Surgery and Cancer, United Kingdom;

HAMLYN SYMPOSIUM ON MEDICAL ROBOTICS 2021

Introduction

In the scenario of real-time clinical simulation, especially for obstetric C-section simulation, a fast, robust mesh-cutting system will be required for an interactable implementation. Furthermore, according to the C-section procedure, the cut tissues will be expanded for exposing the organs underneath, which requires the simulator to perform the expansion of a finite incision.

Currently, existing elastic object simulation methods like the Material Point Method could provide a highly realistic simulation of cutting and creating incisions on soft objects [1]. However, despite the high performance, the cost of time for rendering MPM results is usually counted in hours, making MPM not applicable for the objective of this project since an interactable simulator requires real-time rendering.

Previous research about mesh modifying methods in the clinical simulation was mainly about cutting through a complex volume[2] instead of performing a surface incision and expanding animation. While no whole chunk of tissue will be removed during the obstetric clinical process, an integrated method for fast incision creating and recursive expanding will be more appropriate for the novel implementation of this project.

Hence the two major objectives of this project could be concluded as:

- **To develop an interactable mesh-cutting method for fast incision creation**
- **To implement a structure that could perform the expanding deformation of the cut tissues with low time complexity for real-time implementation**

Core concept: Triangle splitting

For the current progress, which was mainly done in the Unity engine, the fundamental concept of implementing the objectives are based on a specifically designed single triangle cutting method:

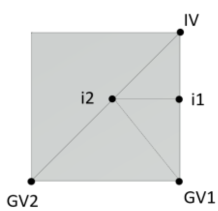

Figure 1. Example of the applied triangle splitting method

According to Figure 1, in each triangle being split, based on the mesh-related rule of the Unity engine, the vertices should be clock-wisely named and assigned during the runtime. The IV, which stands for the Isolated Vertex, along with i1 and i2, could form the new upper triangle for the resulting mesh. While the GV1 (Grouped Vertex) is the direct clock-wise successor of IV, and i1 is the intersection on this edge, IV-i1-i2 could inherit the clock-wise property from the original triangle. Similar rules could be applied to the rest two component-triangles. And i1 and i2 could be duplicated for further expanding operations.

The original way to identify the clock-wise successor of a vertex in space would involve variable-related calculations for each triangle, leading to a noticeable increase of the overall complexity. By this inheriting method, for each triangle, no extra calculation of vectors will be required.

Progress: Batch process of triangle splitting

By applying the triangle splitting technique in the previous section as batches of intersections and involved triangles, a real-time interaction could be initially implemented with the only required information

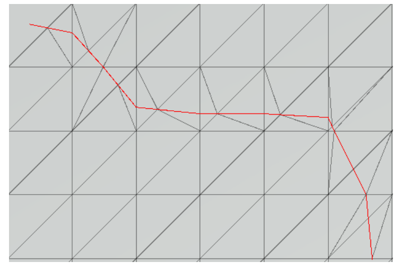

Figure 2. Implemented batch triangle process

As shown in Figure 2, by storing all the added vertices on specific positions in the mesh data, the incision could then be generated and ready to be further manipulated.

Progress: Vertical incision and material mapping

Based on the available batch triangle processing method, the incision could then be initially generated horizontally. As mentioned before, a volume-based deformation method could be costly in runtime. Two leaning vertical incision planes could be added to mimic the vertical tissues during the process to rebuild the clinical scenario.

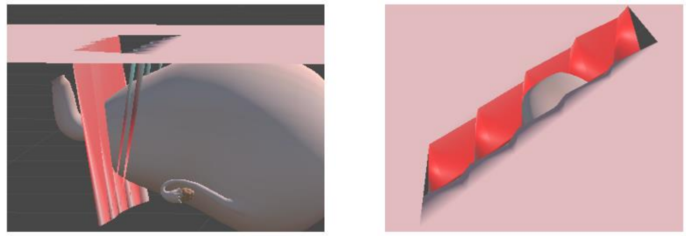

Figure 3. Current progress of vertical incision

According to Figure 3, the current progress may seem to be relatively primitive, but all the previous concept and implementations were proven to be applicable from this demo. Improvements are being developed, such as applying customized shader file to map much more complicated materials on the skin and tissue for realistic simulation.

Future development

A particle-like vertices managing system is being implemented for the expanding function. For each particle in the structure, the direct neighbours will be stored for recursive iteration. A pseudo-force based inter-particle interaction system is also being designed and implemented. For coping with a more complex model, the current mesh modifying script should be enhanced to be more suitable for a 3-D model.

Further refinement of the previous codes and VR oriented controlling system, and related optimisation is vital for the completion. Equipment like surgical knives will be added and being operational combined with the incision creating method.

The current expanding method is incomplete and will be implemented with arbitrary force applying for position support. Combined with the pseudo-force based particle system, ideally but not been proven yet, the process of removing the placenta and fetus could be performed with real-time rendered and deforming models.

References

[1] Yuanming Hu, Yu Fang, Ziheng Ge, Ziyin Qu, Yixin Zhu, Andre Pradhana,and Chenfanfu Jiang. A moving least squares material point method with displacement discontinuity and two-way rigid body coupling.ACM Trans-actions on Graphics (TOG), 37(4):150, 2018.
[2] Jia, SY., Pan, ZK., Wang, GD. et al. Stable Real-Time Surgical Cutting Simulation of Deformable Objects Embedded with Arbitrary Triangular Meshes. J. Comput. Sci. Technol. 32, 1198–1213 (2017). https://doi.org/10.1007/s11390-017-1794-z