CREATING A 3D MODEL OF THE STOMACH FOR USE WITH HAPTIC INTERFACES

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Abstract

A 3D stomach-and-spleen model was created to support surgery simulation. The model needed to be visually accurate for the surgeon and digitally accurate for computations.

The model uses only quadrilaterals, defining a smooth B-spline surface first in the modeling package Blender and later in the simulation program, Simulation Open Framework Architecture (SOFA). SOFA allows a prospective surgeon to interact with the stomach model using haptic interfaces.

Currently, SOFA cannot compute the energy and force of curved surfaces. In one variable, the necessary formulas were found by differentiating the parametric equations of a curve with three control points. The final equation is seen in Figure 1.

Introduction

Stomach-and-Spleen Model

The University of Florida does not have a viable model of the stomach to train UF medical students in Laparoscopic Nissen Fundoplication. Such a model must be designed so the force-feedback device program, SOFA, and the program that transforms the model into a volumetric object, Computational Geometry Algorithms Library (CGAL) Tetrahedralize, can successfully interpret the model.

Calculating the energy of a Bézier Curve with three Control Points

Currently, SOFA approximates curves using line segments; SOFA cannot display curved lines because it cannot calculate the energy and force of curved lines as is necessary to model applied forces. This is undesirable because curved objects are not made up of straight lines, and it inherently limits the accuracy of 3D models.

Curves are represented within SOFA as Bézier curves, so the formula for calculating the energy of Bézier curves in particular must be written, and then converted into code and implemented into SOFA. This would significantly enhance the appearance of curved lines, such as veins and arteries, in procedures like the adrenalectomy.

The purpose of this study is to create a 3D model of the stomach in Blender that is both visually and digitally accurate. The next purpose is to write the formula for the energy of a curved object, so that the stomach is as visually accurate as possible.

Methods

Stomach-and-Spleen Model

A model of a stomach and a spleen was created in Blender by adding a mesh circle and extruding the vertices repeatedly. The vertices were moved, scaled, and rotated after each extrusion to fit the outline of the stomach. The spleen model was made by deforming a mesh circle into a 2D shape of the spleen, and extruding, moving, scaling, and rotating the vertices along the outline of the spleen.

Calculating the energy of a Bézier Curve with three Control Points

The formula was found by differentiating the parametric equations of a Bézier curve with three control points, substituting them into the arc length equation, differentiating, substituting it into the equation for the energy of a spring, and integrating

Figure 1

$$E = \frac{YA}{2}\int \frac{\left(\sqrt{A'u^2 + 2B'u + C'} - \sqrt{Au^2 + 2Bu + C}\right)^2}{\sqrt{Au^2 + 2Bu + C}}\,du$$

$$A = 4(c_0^2) + 16(c_1^2) + 4(c_2^2) - 16(c_0c_1) + 8(c_0c_2) - 16(c_1c_2)$$

$$B = -2(c_0^2) + 6(c_0c_1) - 4(c_1^2) - 2(c_0c_2) + 2(c_1c_2)$$

$$C = 4(c_0^2) - 8(c_0c_1) + 4(c_1^2)$$

$$A' = 4(c'^2_0) + 16(c'^2_1) + 4(c'^2_2) - 16(c'_0c'_1) + 8(c'_0c'_2) - 16(c'_1c'_2)$$

$$B' = -2(c'^2_0) + 6(c'_0c'_1) - 4(c'^2_1) - 2(c'_0c'_2) + 2(c'_1c'_2)$$

$$C' = 4(c'^2_0) - 8(c'_0c'_1) + 4(c'^2_1)$$

Figure 2

Results

Stomach-and-Spleen Model

The model visually depicts a stomach and a spleen well: it has the correct shape, proportions, thickness, color, and position (Figure 2).

It is anticipated that since both the stomach and the spleen are comprised solely of quadrilaterals, B-spline surface evaluation can be successfully performed and the subdivision operator will yield a smooth surface. This will be tested in future studies.

Calculating the energy of a Bézier Curve with three Control Points

The formula that was found is anticipated to correctly calculate the energy of a deformed Bézier Curve with three control points. This will be converted to code, implemented into SOFA, and then tested.

The result when the indefinite integral was entered into Wolfram Mathematica was too long and complex to deal with. It was concluded that Gaussian quadrature needed to be used to calculate the energy.

Discussion

The formula can enhance the appearance of univariate curves such as veins and arteries in procedures such as the adrenalectomy. This can be done by integrating it with respect to the control points, calculating the force. Then, once converted to code using Gaussian quadrature and implemented into SOFA, SOFA would be able to model applied forces during surgery simulations and represent those blood vessels using curved lines.

The formula needs to be extended to three variables before it can used to compute the energy of the stomach-and-spleen model. For the stomach to be represented in SOFA as a 3D Bézier object, another model must be created using a NURBS cylinder on Blender, the NURBS object must be converted to Bézier object, and the formula for calculating the energy of a trivariate Bézier object must be found.

The model that was made can and will be used for simulations of Laparoscopic Nissen Fundoplication, however the only drawback is that it will be made of line segments instead of the curves the actual stomach contains.

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Acknowledgements

I would first like to thank Dr. Peters, for without him accepting me into his lab and guiding me in my research, none of this would have happened. Next, thanks to the countless questions Mr. Saleh Dindar answered for me, I was able to find the information I needed for this project. Mr. DJ Meyers played a vital role as my counselor, both academically and socially, during my time at the University of Florida. Ms. Garima Singh was a large influence on the completion of this paper, for her assistance in the use of Blender allowed me to create a very accurate model of stomach. I would also like to thank Mr. Eduardo Manoel, because his help in the initial stages of my learning of Blender was essential for the creation of the stomach.

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