Generation of Lofted NURBS Curves for 3D Model Generation with COMSOL Multiphysics®

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Abstract

Introduction
A key challenge to finding quantitative solutions to biological problems is to model the complex 3D geometry of naturally occurring structures. Model generation often starts from serial sections from CT or MRI scans, confocal microscopy, or physical sectioning. Third party CAD packages can be used to assemble stacks of serial sections to generate 3D models to import into COMSOL Multiphysics®. In addition, prior to V4 of COMSOL, there was a "loft" command to allow construction of 3D models from serial sections within COMSOL. However, the loft feature is not currently available in COMSOL, presenting a hurdle for problems that depend on geometry construction within COMSOL (as opposed to a third party package). In particular, we have worked on evolutionary and growth processes that depend on repeatedly updating model geometry, based on intermediate analysis results, that require repeated model constructions during analysis [Roberts, Santner, Hart, 2009], and we are looking to solve these problems using COMSOL.

Use of COMSOL Multiphysics:
A solution for building 3D structures from serial sections has been developed based on the use of the COMSOL LiveLink™ for MATLAB® module to construct lofted 3D NURBS (Non-uniform Rational B-Spline) geometries. The method, which could be generalized for other cases, was developed for generating the 3D geometry for a rat tibia as part of ongoing bone adaptation studies.

In brief, the process depends upon:
1. a. COMSOL Multiphysics® (commercial software)
b. COMSOL LiveLink™ for MATLAB® module (commercial software)
2. a. MATLAB® (commercial software)
b. MATLAB® Curve Fitting Toolbox (commercial software)
3. The nurbs_toolbox for MATLAB®
Toolbox available for download for free from Mathworks site, File Exchange.
Also, the external web page for the toolbox is: http://www.aria.uklinux.net/nurbs.php3
4. igesout function for MATLAB®
Function written by Daniel Claxton available for free from Mathworks File Exchange site
5. Data files with points on the periphery of serial sections (this will depend on the structures of interest). The example data are files with x,y,z-coordinates representing points on the periphery

of bone (rat tibia) sections taken from MicroCT scans. There are distinct files for each slice, on the periosteal surface and the endosteal (endocortical) surface that were output from the NIH Image package. Users will want to change this portion of the code to meet their own needs.

Results:
The method to generate complex 3D models was developed using serial sections representing a portion of a rat tibia. Figures show points on serial sections, spline fits, lofted NURBS surfaces, the COMSOL solid model, and the COMSOL FE mesh to demonstrate the implementation of the method.

Conclusion:
The process described here for generating 3D geometry for naturally occurring, irregular geometries, can be adapted for a wide variety of problems including 3D blood vessels, neural tissues, bone, etc. It is a fast, robust method for generating biofidelic 3D models. Data and MATLAB scripts will be uploaded to the COMSOL Model Exchange page following the conference.

Reference

Roberts, M.D., Santner, T.J., and Hart, R.T., "Local Bone Formation Due to Combined Mechanical Loading and Intermittent hPTH-(1-34) Treatment and its Correlation to Mechanical Signal Distributions," Journal of Biomechanics, 42:2431-2438, 2009.

Figures used in the abstract

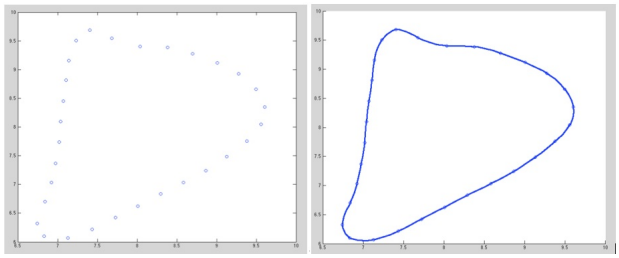

Figure 1: a. Points on one slice of the bone periosteal (outer) surface. b. Points with the corresponding spline curve

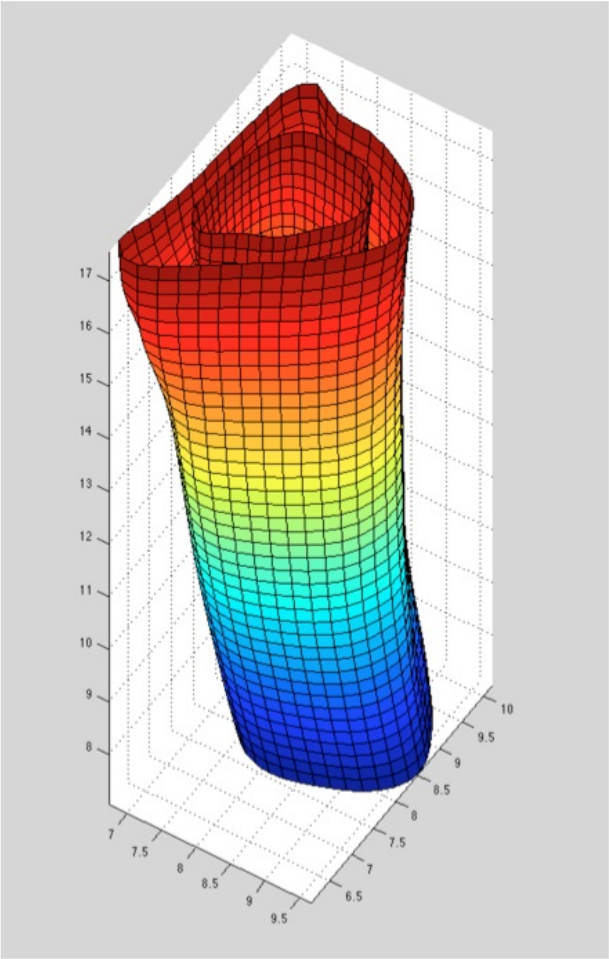

Figure 2: Lofted NURBS surfaces, including periosteal (outer) and endocortical (inner) surfaces of a portion of the rat tibia

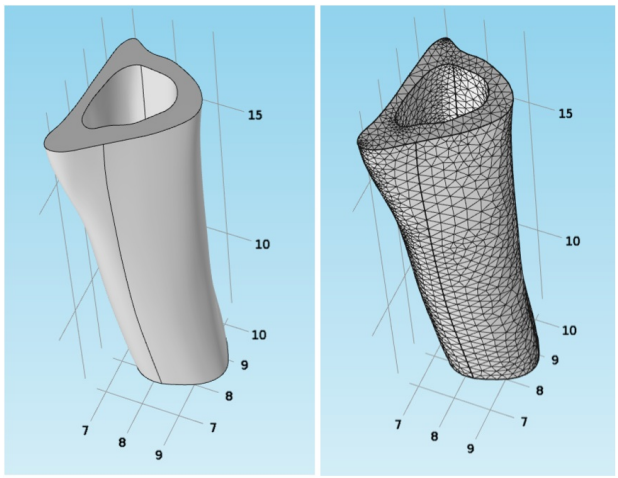

Figure 3: a. NURBS-based 3D geometry of the bone segment in COMSOL. b. Finite element mesh generated in COMSOL.