8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

AN EFFICIENT APPROACH FOR AUTOMATED MESHING OF 3D IMAGE DATA

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Key Words: *Image-based meshing, Biomedical Modelling, Biomechanics, Computing Methods, Pre-operative planning, Post-operative performance.*

ABSTRACT

Computational simulation technology has become an indispensable tool for researchers across the biomechanics discipline. Crucial to the effectiveness of such a tool is its ability to efficiently simulate patient-specific problems. This paper will present a unique and exceptionally efficient approach that converts 3D digital images (provided typically by CT, Ultrasound or MRI scanners) directly into highly accurate computational models. Meshing from image data presents a number of challenges but also unique opportunities so that a conceptually different approach can provide, in many instances, better results than traditional approaches. Image-based mesh generation raises a number of issues which are different from CAD-based model generation.

A. CAD-based versus Image-based Meshing

CAD-based approaches use the scan data to define the surface of the domain and then create elements within this defined boundary [1]. The element creation process was initially quite simplistic, but automatic meshing has been an area of great interest in the FEA/CFD community, with applications well beyond the biomedical field, and so reasonably robust algorithms are now available [2]. These techniques do not easily allow for more than one domain to be meshed as multiple surfaces generated are often non-conforming with gaps or overlaps at interfaces where one or more structures meet.

A more direct approach would be to combine the geometric detection and mesh creation stages in one process. This approach involves identifying volumes of interest (segmentation of 3D image) and then directly generating the volumetric mesh based on an orthotropic grid intersected by interfaces defining the boundaries. In this paper a methodology is used that generates 3D hexahedral or tetrahedral elements throughout the volume of the domain, thus creating the mesh directly. This technique was originally developed for FE analysis of bones, for both stress and vibration analysis [3], and has been implemented as a set of computer codes (ScanIP, $^{+}$ScanFE and $^{+}$ScanCAD).

B. Robustness and Accuracy

In the case of modeling complex topologies with possibly hundreds of disconnected domains (e.g. inclusions in a matrix), approaching the problem via a CAD-based approach is virtually intractable. By contrast treating the problem using an image-based meshing approach is remarkably straightforward, robust, accurate and efficient. Indeed meshes can be generated automatically which is of image-based accuracy with domain boundaries of the finite element model lying exactly on the iso-surfaces thereby taking into account partial volume effects and providing sub-voxel accuracy.

C. Anti-aliasing and Smoothing

Where anti-aliasing and smoothing is applied to the segmented volumes, the presented technique is both topology and volume preserving. If appropriate algorithms are not used, the process of smoothing and anti-aliasing the data can introduce significant errors in the reconstructed geometry and topology. Most implemented smoothing algorithms are not volume preserving and lead to shrinkage of convex hulls and in many cases topological changes. Whilst this is not particularly problematic when the purpose is merely enhanced visualization, the influence can be dramatic when the resultant models are used for metrology or simulation purposes.

A comprehensive solution will be illustrated including: an extensive set of tools for image processing and segmentation, a unique in-house developed multi-part marching cubes algorithm with specifically designed multi-part smoothing algorithm, a set of mapping functions that automatically maps signal strength in the original images to pre-defined material properties (e.g. mapping Hounsfield Number to the Elasticity Modulus), a semi-automated method for extracting inter-domain boundaries (e.g. identifying contact surfaces between adjacent parts), and a fully compatible interface with the majority of commercial FEA and CFD packages. An extra functionality that allows the introduction, positioning and integration of implants (represented by standard CAD format such as IGES, STEP or STL) into an already existing scan/ model will also be presented. Utilizing such functionality in typical parametric studies (e.g. effects of variation in implant positioning on stresses distribution) as well as in pre-surgical planning has proved to be very beneficial.

Several FEA examples will be presented in this paper, including the virtual positioning of patient-specific CAD implants within a pre-operative scan. Post-operative performance will be simulated using the combined models, and multiple scenarios can be tested straightforwardly.

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