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Towards an adaptive volume mesh derived from Computed Tomography data.

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Abstract — This paper presents a single process to create an adaptive volume mesh composed of elements integrated with CT information for finite element modelling of lumbar vertebrae. From the CT images of the lumbar spine, a semi-automatic segmentation using Canny method was implemented to extract the boundaries of the bone which were then used as an input to create the surface mesh of the vertebrae by applying Matching cubes algorithm. Subsequently, the volumetric mesh was automatically generated and CT information was mapped on to the relevant elements.

Key words — segmentation, modelling, mesh generation, lumbar spine, CT images

1. Introduction

Low back pain, a common chronic musculoskeletal disorders, is adversely affected by problems in the lumbar spine. Numerical models like patient specific finite element models derived from medical imaging have been commonly developed to provide quantitative and objective indicators for the better diagnosis and treatment prescription of the spinal disease. Some commercial software are specialized in generation of 3D geometrical and meshed models derived from medical images, however, it is inflexible to control the mesh element type with triangle-based surface model. Numerous studies individually focused on developing of specific segmentation methodologies, meshing technique or material properties assignment, statistical models and morphing techniques have been developed.

Some techniques [1,2,3] for the direct automatic generation of voxel-based patient-specific FE models from the CT data based on matching cubes algorithm [4] have been studied. However, being a voxel-based method, the resultant number of finite elements is significant. Recently, a robust modeling protocol was developed to perform the meshing using bicubic Hermite patches with the contour-based geometries [5], [6]. Although these above approaches provide flexible geometrical models for meshing purpose and overcome the geometrical complexity (bifurcation) of the biological tissue, there is no consideration into material properties assignment to element. Moreover, material assignment using commercial software usually used literature-based laws leading to the requirement of a serious validation process. Many material properties assignment methods have been developed to improve the patient-specificity as well as the level of automation [7, 8, 9, 10]. However, in order to perform FEM simulation for complex bio-structure like lumbar spine, material properties assignment step created by aforementioned methods needs to be associated with the commercial software packages related to geometry modelling and mesh generation.

In the framework of finite element modeling of the lumbar spine, there is no fully integrated process for geometric modeling, adaptive meshing and material assignment of the spinal structures. In fact, the purpose of this study is to provide solutions for this modeling challenge.

2. Materials and methods

A modeling workflow was developed to take the geometric modeling, meshing and CT information assignment into a whole modeling process (Figure 1). The input of this process comprised 343 CT slices of the lumbar spine with 0.625 mm slice distance, 1.25 mm slice thickness and a resolution of 0.607/pixel.

For the first step, from these medical images, the semi-automatic segmentation using Canny method [11] was implemented to extract boundaries of the vertebrae. In this step, the Canny method finds edges by looking for local maxima of the gradient of image associated with a Gaussian filter. The method uses two thresholds: a high threshold related to the highest value of the gradient magnitude of the image for selecting strong edges, and a $0.4 \times \text{high threshold}$, named low threshold, for selecting weak edges which are connected to strong edges. It is important to note that the threshold is based on strong material properties knowledge of our team [7]. Then, the post-processing has been automatically performed to remove from binary image small objects with minimal number pixels criteria.

In the second step, based on the masks created by the labeled contours, the triangulated surface mesh of each vertebra was constructed by applying Matching cubes algorithm [4]. At the beginning of the last step, the surface mesh was cleaned up to get the high quality surface mesh by eliminating duplicate and overlapping or redundant faces, edges. After that, from this cleaned surface mesh, the tetrahedral mesh was automatically generated [12]. Finally, intensity values in grey level which were mapped could be integrated into relevant elements of this volume mesh.

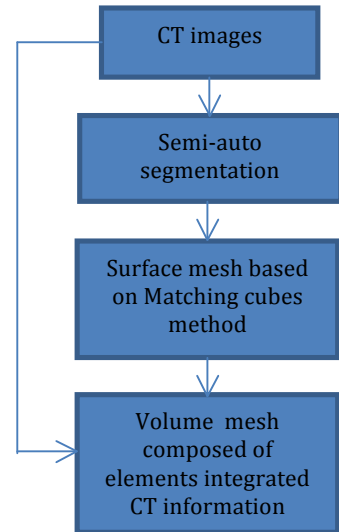


Figure 1 – Modelling workflow

3. Results and discussion

The segmentation process was done on a sequence of CT slices of lumbar vertebrae (provided by European project MySpine). (A)

Figure 2 shows an example of a CT mapping input in gray level and Hounsfield unit (2A), extracted boundaries with a manual correction (2B) and the output labeled masks in binary or Hounsfield unit (2C).

A time required to perform segmentation for each vertebra was several seconds and less than 2 minutes in case of manual intervention. This is a reasonable time compared to that of manual segmentation. (B)

Based on the Matching cubes method, the surface meshes of lumbar vertebrae from L1 to L5 were generated (Figure 3). (C)

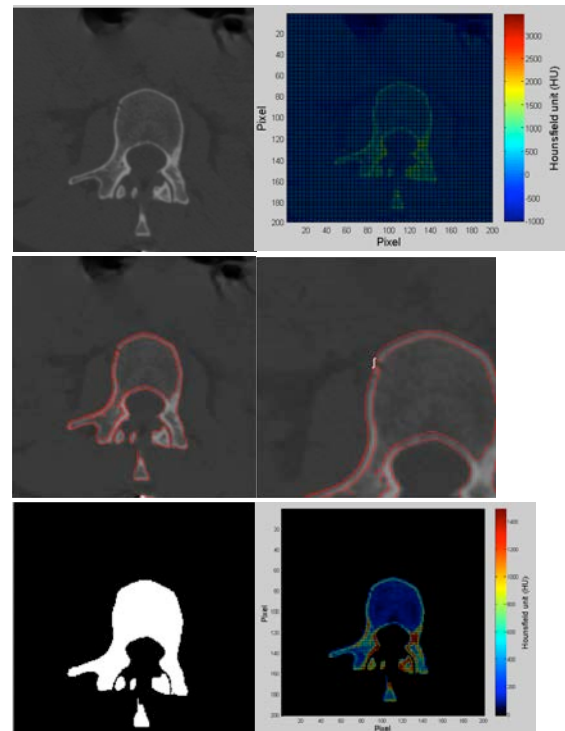


Figure 2 – Semi-automatic segmentation process

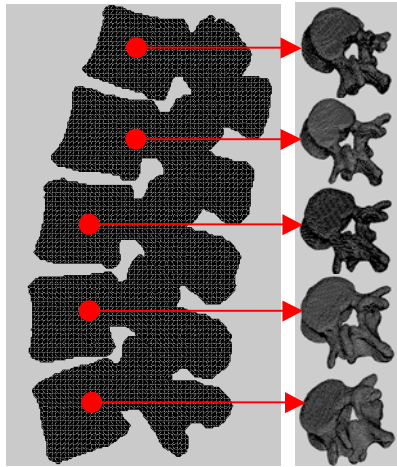


Figure 3 – Surface mesh of lumbar vertebrae from L1 to L5

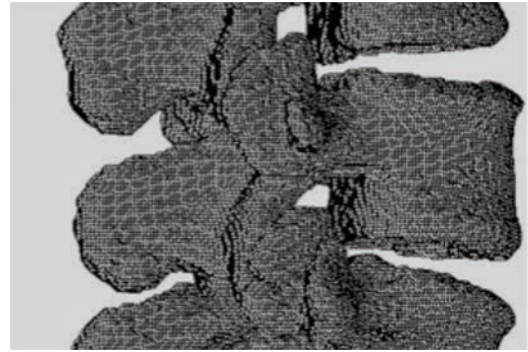


Figure 4 – Tetrahedral mesh of lumbar vertebrae from L1 to L5

The final process was tested on vertebra L2. By eliminating duplicate and overlapping or redundant faces, edges, the number of triangular faces is reduced from of 91560 faces. And from this finer surface mesh, the tetrahedral mesh was automatically generated (Figure 4).

4. Conclusions and Perspectives

A preliminary fully integrated process of geometric modeling, meshing and CT information assignment for lumbar vertebrae has been presented. As perspectives, the strategies improving the automatic segmentation and adaptive meshing and material assignment will be implemented and studied for both vertebrae and intervertebral discs.

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