Volumetric Meshes Based on Medial Representation for Medical Applications

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1.Introduction:

Unstructured volumetric meshes' generation for 3D objects has been used in many research areas such as Finite Element Analysis (FEA), Computer Graphics modelling, Biomechanics, etc. Numerous techniques have been developed[2], however, mainly three techniques have received much attention and have been often used: Delaunay-based methods, advancing front methods and octree methods. Generally the tetrahedral mesh generated by these techniques requires refinement of tetrahedral (tets) elements to improve the quality. However, generating high quality tetrahedral meshes remains a difficult task because tets do not tile space[1].

In the medical field, modelling organs and soft tissues characterised by complex geometries became possible with the use of MRI and CT. Different techniques are used to extract information and reconstruct accurate surface meshes[4]. However classical techniques fail to generate accurate tets meshes that fit exactly the initial surface. Increasing resolution improves the quality but it tremendously increases the number of tets which is not convenient for applications such as FEA[3].

The aim of this work is to overcome meshing drawbacks induced in thin parts. Thus, we propose a method that generates tet meshes in which resolution is distributed according to the thickness of the model. Objective surfaces are initially extracted from MRI data. This method is applied to model acetabular labrum and is compared to two reference methods.

2.Method:

A technique which allows to get and to manage models thickness is needed. Medial Axis (MA) technique consists of a medial surface defined by the centers and the radius of spheres. The advantage of this structure is that information about both topology and boundary locations of the object are well-defined. However, its drawback is the sensitivity to surface perturbations (excessive branching). We used the medial representation (M-Rep) which is an extension of the MA and responds to this problem[3].

The simplest M-rep is a single medial sheet composed by medial atoms with local information. Each atom describes a relationship between the sphere center and both the position and the normal at the two boundary points where the sphere touches the surface. A medial atom is defined as $M_i=\{x,F,r,\theta\}$, where x: the atom position, r: inscribed sphere radius, θ: half angle between the two boundary vectors and F: 3D frame (two vectors define the tangent plane at x and the third is its normal). Atoms lying on the border of the M-rep have an additional parameter defining the elongation which controls the curvature around the crest of the object.

By using MA information[4], we propose to construct a M-rep grid proportional to the radius r and whose implied boundaries will fit the objective surface that was previously extracted from

MRI data. The first step is the construction of a regular sampled rectangular grid whose nodes represent atoms positions. The number of nodes is set according to the desired number of tets. In the second step, the nodes of the sampling grid are displaced to fit the MA while taking into account the thickness. Then atoms parameters are evaluated and modified till the resulting external surface fits the initial one. In the third step, starting from the atoms, additional points are created between the medial surface and the boundaries. Moreover, for rim atoms, points that will lie on the surface crest are added. In both cases, additional points form hexahedral cells that finally are subdivided into five tets. We use an alternating manner to insure their adjacency.

3.Results:

We used this representation to generate tetrahedral mesh specific to medical application: we are interested in hip impingement which is directly related to the acetabular labrum and especially to its thickness. Furthermore, in order to simulate labrum deformation from hip joint motion, we need to use FEA and thus an accurate volumetric mesh is necessary.

Fig.1. shows the results achieved by three technics: our proposed approach: Volumetric Meshes Based on M-rep (VMBM-rep), Variational Tetrahedral Meshing (VTM)[1] and TetGen[5].

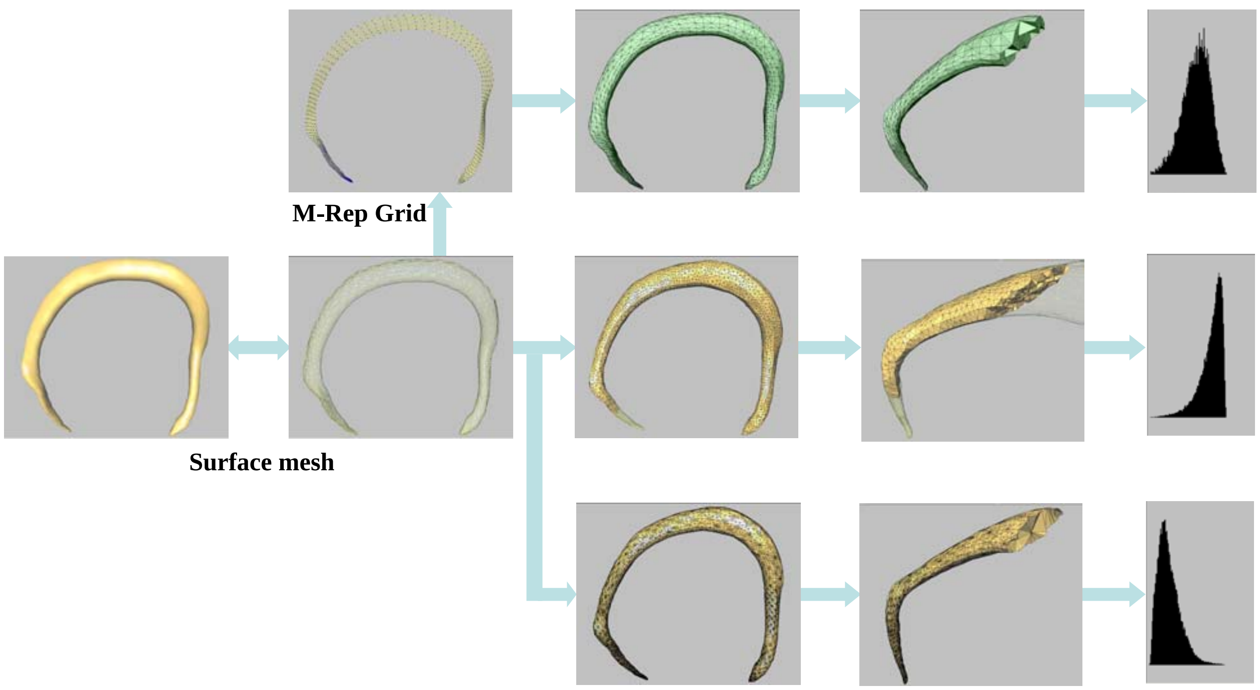

Fig.1. Comparison between tetrahedral meshes generated by the three techniques. From top to bottom: VMBM-rep, VTM and TetGen. From second to fourth column: Whole volumetric mesh, detail of a thin part, aspect ratio histogram.

Depending on the application's aim, requirements on the number and the quality of tets and the accuracy of the volumetric mesh envelop are requested.

-Optimal tets number (maximising the trade-off between accuracy and complexity): VMBM-rep generates the fewest tets (13456) compared to VTM (68638) and TetGen (48838).

-Tets quality: We use the dihedral angles and the three times ratio of inscribed and circumscribed spheres radius (ideally 70.52° and 1)[1]. For the dihedral angle, the achieved values are: VMBM-Rep min:1.06°,max:178.09°,average:71.77°; VTM:0.22°,179.50°,69.66°; TetGen:0.41°,177.16°, 70.76°. Likewise, the aspect ratio achieved values presented by histograms in fig.1 are respectively: 0.005,0.98,0.59; 0.004,0.99,0.79 and 0.009,0.99,0.26.

Concerning the accuracy of the envelop, it can be seen from fig.1. that the thin part of the volumetric model of VTM does not fill the thin part of the shape contrary to the VMBM-rep and TetGen models.

4.Discussion:

According to the achieved results, we have:

For number of tets on which the accuracy and the efficiency of FEA depend, our proposed approach presents better results.

For tets quality, VTM approach is better, however, it doesn't fill the shape. The TetGen tets quality isn't good as VTM and VMBM.rep. In both cases tets quality can only be improved with a higher resolution but VTM filling problem remains.

To conclude, Tetgen and VMBM-rep, both present the advantage to fill all shape, although tets quality is better in the later approach. The proposed approach is thus the better compromise between tets quality and the number of tets.

For future work we need to improve tets quality and to generalise the approach for multi-models by constructing and linking the M-reps of different models.

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