A brief review of meshing techniques in medical images for biomedical computing and visualization

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***Abstract**: A visual representation of the interior of a body is important for biomedical analysis and medical intervention. The technique, process and art of creating this visual representation are called medical imaging. Two most commonly used medical imaging techniques are CT(Computer Tomography) and MRI (Magnetic Resonance Imaging). The image formed using CT and MRI needs to be analyzed. There are many algorithms developed recently for analyzing the images. In this paper we will be doing a review and analysis of different mesh generation algorithms like Finite Element Method (FEM), tetrahedral mesh generation algorithm and quality tetrahedral Delaunay meshing which is very useful in generating surface meshes on the 3D models.*

***Keywords**: Computer Tomography, Magnetic Resonance Imaging, Finite Element Method, Tetrahedral Delunay, Mesh Medical Imaging*

1. Introduction

A mesh is a discretization of a geometric domain into small simple shapes, such as triangle or quadrilaterals in 2D and tetrahedral or hexahedra in 3D. Meshes are useful in many fields. In geography and cartography, meshes give compact representations of terrain data. In computer graphics, most objects are ultimately reduced to meshes before rendering [1]. Meshing has played a very huge role in rendering images in medical imaging. The devices like MRI, CT scan, X ray and many more are used in medical fields to determine what or where the source of illness is in the human body. It is hard to study in-vivo of biological structures [2]. Mainly there are two types of meshes: structured mesh and unstructured mesh. Structured mesh is one which all interior vertices are topologically alike. An unstructured mesh is one in which vertices may have arbitrarily varying local neighborhoods. A hybrid mesh is formed by a number of small structured meshes combined in an overall unstructured pattern [1]. Structured mesh generates uniform shapes and the common 2D shape is quadrilateral and hexahedral in 3D. The common shapes for unstructured mesh are triangular in 2D and tetrahedral in 3D [2].

The purpose of this review paper is to introduce the readers to the existing techniques in meshing especially in biomedical field. We will be discussing about the different mesh techniques that are existing mainly related to the biomedical terms and how they are helpful to us. There are many mesh techniques but in this paper we will be mainly focusing in three topics: Tetrahedral mesh generation, Finite Element Analysis and Guaranteed Quality Tetrahedral Delaunay Meshing.

Diagnostic imaging devices like computer tomography and magnetic resonance imaging are able to produce anatomical description of various features such as tissues and organs. But these systems are not affordable by many doctors and also the medical students. Hence we need a proper algorithm as well as software which can view exact geometric information of objects. The actual physical model is generated by developed computer aided model by stacking the CT scan images which is analyzed by finite element method. Recently FEM has widely been used to simulate the mechanical deformation of tissues and organs during examinations or interventions [5].

Tools for an automated and efficient mesh generation, including the discretization of 3D surfaces, are important prerequisites for the complete integration of FEM. Therefore stereo lithography (STL) file format is used. This format approximates 3D surfaces of a solid model with oriented triangle of different size and shape in order to achieve smooth representation suitable for industrial processing of 3D parts using stereo lithography machines [6].

Delaunay meshing is a popular technique for generating tetrahedral meshes, since it is amenable to rigorous mathematical analysis. Delaunay volume meshing algorithms offers quality and fidelity guarantees objects that have smooth surface or doesn't form input angles less than 90̊ [3]. A tetrahedral meshing algorithm is proposed to create tetrahedral meshes from medical images in two steps, first is surface triangulation and second is volume triangulation. This mesh is used to create Finite Element Meshes [4].

2. Methods/ Review Of Literature

2.1 Finite Element Analysis

The paper [5] mainly deals with finite element analysis and also Rapid Prototyping. In finite element analysis .stl file of required model is needed to continue the process. The CT scan data is produced in computer by converting analog to digital using analog to digital convertor. It stores the digital image during scan and then reconstructs the image. This image is then stored in DICOM form which is then decoded to develop computer aided 3D model. CT and MRI represent the finest resolution capability in achieving volumetric resolution. These images are then converted into 3D using the developed programs and generate the .stl file using Delaunay triangulation algorithms for the same. To build up FEM mesh for segmented region its contour information is extracted from a volume of data. Then it is meshed into nodes and elements and material properties are endowed to each element in accordance with the given data. The developed software packages such as ANSYS are used to calculate mechanical stress and strains and predicts deformation. The .stl file of vertical model can be imported in proe, maya or solid work where the segmentation is carried out so that the unwanted peripheral structure is edited and removed. The obtained geometry is stored in .iges which is then transformed to ANSYS software. Then it is re-meshed using solid tetrahedral element in ANSYS software. The resulted information helps the medical practitioner to find the critical portion having the maximum stress intensity and the nodal displacement. It helps in suggesting proper prevention and precautions to the patient. These technologies are important in medical as it reduces cost and risk of patient. But at the same time it also has drawbacks. The drawback can be overcome by using the developed dicom image viewer software. This paper also describes about another technique that is Rapid prototyping where the CT scan data (dicom form file) is processed with dicom image viewer software then to .stl file crating software. This file is then is processed by catalyst software which is associated with RP machine to build actual physical model using additive technique. This technique is very useful as the physical model enables correct identification of the abnormalities, accurate understanding of the anatomical structure.

2.2 Guaranteed Quality Tetrahedral Delaunay Meshing

In the paper [3] an algorithm is introduced that guarantees that the elements of the resulting mesh have radius-edge ratio less than 2, boundary facets have angles larger than 30̊ , the mesh boundary is proved to be a good topological and geometrical approximation of the object surface, it meshes the volume and samples the object surface at the same time, starting from an initial set of 8 points. This paper provides necessary definitions, algorithms, proves the quality and fidelity. In the algorithm first a box is created which contains object Ω and is made sure that no points are closer than $2\sqrt{2}\partial$ units to object surface $\partial\Omega$. Then Delaunay triangulation of this box is computed and refinement starts here. During this refinement, some vertices are inserted exactly on the box; these vertices are called box vertices. It is further categorized into box-edge vertices and non-box-edge vertices. It explains two types of tetrahedral: intersecting tetrahedral (circumsphere intersects $\partial\Omega$) and skinny tetrahedral (circumsphere lies inside Ω and radius-edge ratio is larger than or equal to user-specified parameter). The algorithm then inserts new vertices to guarantees that the mesh boundary is close to the object surface and to remove tetrahedral or facets with large radius-edge ratio. To confirm it four rules are being checked. This paper also proves that if the quality parameter is not less than 1 then the algorithm terminates outputting tetrahedral with radius-edge ratio less than $\bar{p}$ and boundary facets with planar angles larger than 30̊. To prove this Lemma's (Lemma 2, Lemma 3) statements are referred. It also proves that the mesh boundary is equal (fidelity guarantees) using Lemma 4 and Lemma 5. Experiments are being conducted to check the algorithm. First they tested it on synthetic data and the refinement process lasted for 4 seconds. Then they tested it on real human brain image and the refinement lasted for 53 seconds. The algorithm really works and shows the results quite fast. The only drawback it deals with is elimination of silvers.

2.3 Tetrahedral Mesh Generation

In the paper [4] tetrahedral mesh is presented which is used to create Finite Element Meshing. For each pair of adjacent section two steps are conducted. First step reconstructs the triangular surface and the second step discretizes the object inside the triangular surface by an advancing front method. Firstly contours of the required objects are extracted from medical image. From the sectional contours, the surface consisting of two adjacent sections and one side surface will be constructed. Planar meshes are triangulated and then constrained Delaunay triangulation is performed. During reconstruction correspondence, tiling and branching are performed. In correspondence the coefficient Ʈ of given two contours is computed using a formula. The tiling process manages to form quality triangles by matching nodes on a pair of corresponding contours. If the numbers of corresponding contours on two sections are unequal, branching structures occur in 3D object which is reconstructed by the medial axis interpolation method. The polyhedron inside a triangular surface will by tetrahedralized inward from the surface with two group operators, either forming several tetrahedral at a time. By projecting branching node the surface triangles are classified into 5 categories. Then G1 and G11 operators are applied to B1 or B11 triangles. G1 operator forms a group of tetrahedral by cutting a B1 triangle and G11 operator is designed to wedge a B1 triangle. Then advancing front algorithm is being applied which generates tetrahedral iteratively using G1 or G11 operators. But the drawback here is that it may still end up untetrahedralizable kernels. The kernel is post processed by inserting a Steiner point visible to all vertices and connecting the point with each triangle of the kernel.

3. Analysis Of Result

TECHNIQUES	ADVANTAGE	DISADVANTAGE
Finite Element Method	Simple, compact and result oriented. Modeling of complex geometries and irregular shapes are easier. Cost is less comparatively.	Large amount of data is required. It requires longer execution time.
Delaunay Meshing	Fast generation of elements. Cost is less comparatively. Quality and fidelity is proved.	Only elements with radius-edge ratio less than 2 and boundary facets angles larger than 30° can be applicable. Elimination of silvers is difficult.
Tetrahedral Mesh Generation	Easily automated. Unique interpolation. Greater flexibility in fitting complicated domains.	Ends up untetrahedralizable kernels. Expensive.

4. Conclusion

There are many techniques to generate meshes. We have discussed some of the techniques that are used to generate surface meshes. These are widely used methods in the field of medical. The methods that we have discussed have both advantages and disadvantages. Few methods have already overcome those drawbacks using alternate methods and few are still under research to find flawless techniques. But the main drawback faced by all the techniques is cost, quality of element and time consumption. Hence more research is required to find a most efficient technique which can overcome all these drawbacks.

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