Chapter 9

Techniques for the Generation of 3D Finite Element Meshes of Human Organs

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ABSTRACT

The Finite Element Method (FEM) is probably the most used technique to model the mechanic properties of a body. The method needs a subdivision of the body (or domain) to be simulated in simpler geometrical structures. This subdivision is known as a mesh. This chapter gives a short introduction to the FEM, then continues with the most important aspects to consider for choosing a mesh like, element type, quality and node density. Finally this chapter reviews several meshing techniques currently used in the medical-field simulations. The techniques are classified and compared.

INTRODUCTION

Continuum mechanics (CM) is a branch of mechanics that deals with the analysis of the kinematic and mechanical behavior of materials modeled as a continuum, e.g., solids and fluids (i.e., liquids and gases). In a nutshell, CM assumes that matter is continuous (ignoring the fact that matter is actually made of atoms). This assumption allows the approximation of physical quantities over the materials, such as energy and momentum, at the infinitesimal limit. Differential equations can thus be employed in solving problems in CM.

Let $\Omega$ be a volumetric domain defined in 3D and $P$ a point inside $\Omega$. A deformation occurs in $\Omega$ as external (surface or volumetric) forces $f$ are applied to some $P$ in $\Omega$. If $\Omega$ is considered as an elastic body, the deformation is characterized by:

- A displacement vector field $u$ caused by $f$ applied over one or more $P$. 

DOI: 10.4018/978-1-60566-733-1.ch009
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Figure 1. Displacement vs deformation. Top, initial system. Bottom left, displacement (a difference regarding the x and y axis). Bottom right, deformation (a difference regarding the r and s axis).

- An internal state of deformation, mathematically defined by a “strain tensor” for each \( P \) in \( \Omega \).
- The “force reaction” of the body to the external forces; this is mathematically defined by a “stress tensor” for each \( P \) in \( \Omega \).

The Local Equilibrium of the Medium (LEM) is an expression defined for each \( P \) in \( \Omega \) that links the displacement, the strain and the stress tensor through Partial Differential Equations (PDE). In order to do so, an analytical relationship is assumed between the strain and the stress tensors, known as the constitutive law of the material.

The difference between displacement and deformation is made in function of the Reference System (RS) used to measure each one of them. The first one is made regarding the overall RS. The second one, uses a relative RS associated to the domain. Figure 1 illustrates the initial state of the system at the top; at the bottom left panel a displacement is produced as the coordinates of point \( P \) change to \( P' \) regarding the x and y axis, however no deformation is presented in the r and s axis. At the bottom right panel the inverse situation is produced as no displacement of \( P \) is presented in the x and y axis. In the other hand, point \( P \) has a severe deformation regarding the r and s axis.

The strain level measures the domain deformation regarding the relative position of \( P \) in \( \Omega \). Let vector \( a \) be the initial position of \( P \) and vector \( b \) be the position of \( P \) after the deformation in the relative axis: \( r, s \). The strain level is then defined as:

\[
\frac{\|b\| - \|a\|}{\|a\|}
\]

The importance of measuring the strain level is that when it is inferior to 10% the “small strain” hypothesis can be made, which assumes a linear geometrical resolution of the PDEs. Otherwise, a “large strain” framework is necessary, which means a much more complex resolution of the system.
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