USE OF ADVANCED TECHNIQUES TO DIRECTLY CREATE FINITE ELEMENT MODELS OF BIOLOGICAL OBJECTS

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Introduction

The use of finite element modelling allows a parameter-selective investigation of real-world phenomena. For example in the field of bioimpedance research, finite element models are especially applied for optimising electrode configurations in order to approve the accuracy of non-invasive stroke-volume estimation as well as to solve the forward problem of impedance tomography. All these applications require very complex and specially tailored models, mostly based on NMR or CT scans of the human body part under investigation. The model creation is very time consuming and requires considerable experience in both geometry modelling techniques and mesh generation. Consequently an anatomically averaged human body is modelled. However, this strategy is always an abstraction of the interindividual anatomical variability and may result in large errors. Furthermore in some applications, for example in the field of EEG/EP source estimation, modelling which is not based on the real patient's anatomy is complerly meaningless.

Various efficient finite element modelling packages are available commercially. However, for applications in biomedical engineering which require the use very complex models the limits of most of these program packages will be reached quickly or they can only be applied with strong restrictions in terms of functionality.

Methods

An image acquisition-modelling-analysis system has been developed recently1, which considerably reduces the time consumed in the creation of finite element models of human body parts taking into account the real patient's anatomy. The system covers the following components:

1. image processing system for the direct creation of 3D geometric data of biological objects
2. software translating 3D geometric data into CAD-related geometric models
3. coupling of the created CAD-models with mesh generation and mesh refinement techniques for the creation of realistic finite element models

Image acquisition

The "3D object reconstruction problem" has been met with the development of a technique for the generation of normal images. The principal idea is to replace the images in two planes by images in one plane, by using the fact that any perspective projection is a projective projection. The differential matching method was used assuming that approximate values of the parameters are known and replacing the non linear problem by a linear one. The values of the desired parameters result from the minimization of energy of the observation noises with respect to the parameters of the problem. Apart from the image acquisition system for the reconstruction of the 3D geometric data of the object using a camera system, another way for reconstructing the 3D geometry of a real object, of interest to bioengineering applications, is the modelling based on the analysis of NMR or CT scans. In either case, the output of the image acquisition stage is a cloud of 3D points on the surface of the object of interest (both methods) and also inside the object (NMR and CT scans data).

Geometric modelling

These points are converted to a mathematically expressed geometric model based on a curve and surface description using Non-Uniform Rational B-Splines (NURBS). Currently, there are two techniques implemented for the construction of NURBS surfaces. The first builds a surface taking into account all the data points which can be approximated within a given tolerance or interpolated if there are sufficient degrees of freedom available. Because of the usually large amount of data available this technique is somewhat slow but sufficiently accurate. Using the second technique, the data points are organised in cross sections which will be interpolated or approximated within a given tolerance, thus creating cross section curves. These cross section curves are "skinned" to produce a surface model [1]. To couple the image acquisition - geometric modelling system with the finite element mesh generator IGES-file format is used.

Mesh generation

The system developed uses commercially available finite element mesh generation software (e.g. I-DEAS, ANSYS) to generate finite element models. Alternatively, 2D and 3D unstructured mesh generation techniques have been developed using the advancing front method [2]. The corresponding finite element mesh generation software requires a boundary definition by spline curves or surface patches. Image processing techniques are used to generate the bounding spline curves. The 3D mesh generator creates tetrahedral and hexahedral elements. This ensures that the most complex of geometries are meshed adequately.

Results

Based on CT scans a finite element model of a human heart has been created. Fig. 1 shows the geometry of the CAD-related model, including myocardium, atria and ventricles, aorta and arteria pulmonalis. Creating the NURBS surfaces based on "skinned" cross section curves is faster because of the reduced amount of data points that are fitted, but sometimes this leads to models of lower accuracy. However, this geometric modelling technique is well suited for cross sectional data, for example tomography data.

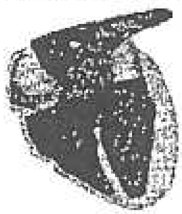

Figure 1: geometric CAD-related model of the human heart

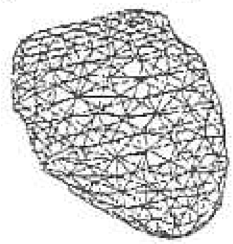

Figure 2: finite element mesh of the myocardium

A high quality of the FE-mesh can be reached by special adaptive meshing procedures. Adaptive mesh generation can be directly coupled with the developed image acquisition-geometric modeller system. To mesh very small geometrical structures like pericardium, shell elements are preferred. A strategy has been developed for the automatic generation of FE meshes in case of models consisting of coupled solid and shell elements (e.g. heart with pericardium).

The "image acquisition-geometric modelling-mesh generation system" has been tested in different applications concerning biological objects. One of the major advantages of the system is, that a limit of input data points will not be reached.

References

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