AUTOMATIC DESIGN OF FINITE ELEMENT MODELS: APPLICATIONS TO PATIENT SPECIFIC BIOMECHANICAL STRUCTURES

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Introduction

Finite Element (FE) analysis is a numerical method that permits to obtain an approximate solution to a wide variety of engineering problems, as continuum mechanics problems, which makes this method wildly-used in the field of biomechanics. This method is based on a volumetric discretization of the structure, with the definition of a 3D mesh.

Two methods are classically used to define a Finite Element mesh: manually or with automatic mesh generators. Manually building a mesh is the optimal method as one can easily use hexahedral elements and control their distribution over the mesh [1]. However, this method is usually limited to one specimen due to the prohibitive amount of manual labor required to build the mesh.

This paper introduces a new algorithm, called the *Mesh-Matching* algorithm, which aims at automatically building 3D meshes for Finite Element Analysis.

Principles of the Mesh-Matching algorithm

The Mesh Matching algorithm [2] tries to maintain the advantages of a manual mesh design, while introducing an automatic mesh conformation process. The global algorithm is based on the following strategy:

1. A Finite Element “generic” biomechanical model is manually built. This step is long, tedious, but is done once.
2. Patient data are collected (US, CT or MRI).
3. The generic FE mesh is automatically conformed to patient morphology, by the mean of a local elastic registration [3].
4. The new patient mesh is regularized so that it can be used for FE analysis. This patient mesh has a topology similar to the generic mesh (same number of elements and same element types).

Next parts of this paper present evaluations of the Mesh-Matching algorithm for two clinical applications, namely orthognatic surgery and exophtalmia reduction.

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Orthognatic Surgery

Orthognatic surgery attempts to establish normal aesthetic and functional anatomy for patients suffering from dentofacial disharmony.

For this, maxillary and mandibular skeletal segments are osteotomized and repositioned by the surgeon [4].

One of the issues raised by this surgery is the consequence of those bones repositioning onto the aesthetic of the patient face. Indeed, it is quite difficult for the surgeon to evaluate the post-operative deformations of the facial soft tissues that are due to the mobilisation of the bonny structures. To assist the surgeon in this issue, a 3D biomechanical model of the face was developed [5]. The strategy proposed by the Mesh-Matching algorithm was applied:

1. A “generic” 3D Finite Element model of the face was manually built.
2. CT data were collected for six different patients.
3. The generic model was conformed to each patient.
4. Each model was regularized to be used for Finite Element Analysis.

Figure 1 presents the generic 3D Finite Element model of the human face. This model is based on a 2 layers mesh, with elements connecting the external skin surface to the skull.

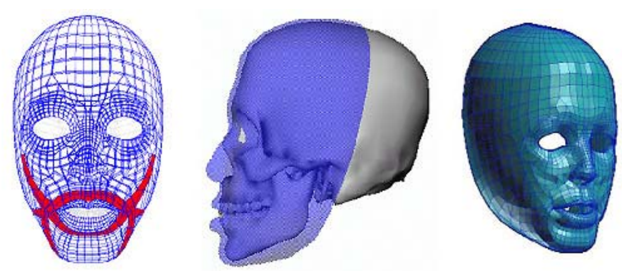

Figure 1: Generic Finite Element model of the face

This generic model is then conformed to patient data. Figure 2 shows the results provided by the Mesh Matching algorithm applied to a given patient.

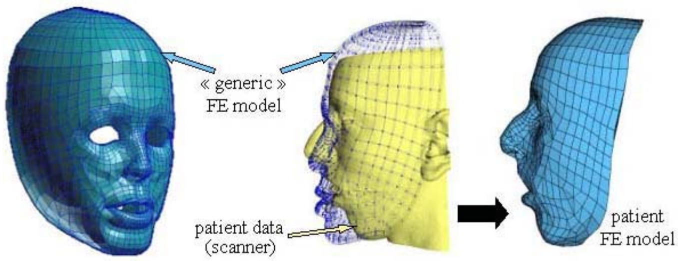

Figure 2: Mesh-Matching: conformation of the generic model to a patient morphology

The Mesh-Matching algorithm was successfully applied to six patient morphologies. For each patient, the 3D mesh was regularized to carry out Finite Element Analysis [5]. Figure 3 plots the Finite Element models that were automatically generated to match the six patient data.

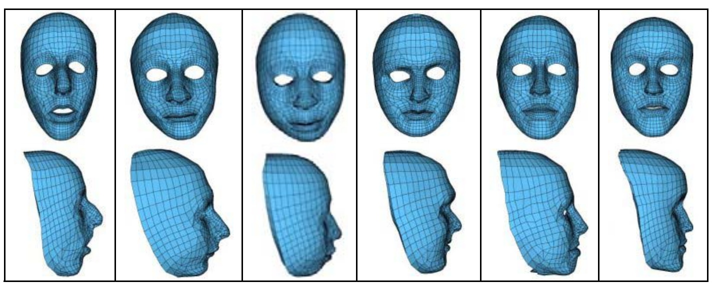

Figure 3: Finite Element models of six patients

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Exophtalmia Reduction

The exophtalmia is a pathology that is defined by an excessive forward protrusion of the ocular globe inside the orbit. Its consequences are functional as well as aesthetical. For disthyroidy exophthalmia, a surgery is usually needed, once the endocrinal situation has been stabilized. A classical surgical technique consists in decompressing the orbit by opening the walls, and by pushing the ocular globe in order to evacuate some of the fat tissues inside the sinuses [6]. This gesture is very delicate, especially in the choice of the size and the location of the hole that has to be made in order to obtain the suited globe backward displacement.

To assist the surgeon in the definition of this planning, a 3D biomechanical model of the orbital soft tissues and its interactions with the walls was designed. Following the Mesh-Matching strategy, a generic model is defined by a Finite Element poro-elastic meshing of the orbit (figure 4).

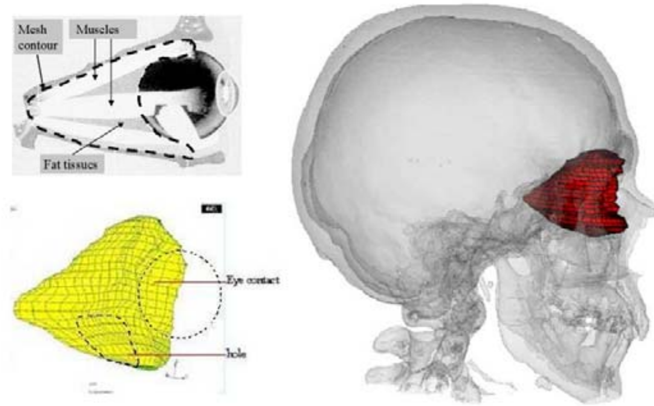

Figure 4: Generic Finite Element model of the orbital soft tissues

This generic model was automatically adapted to the morphologies of four patients, extracted from TDM exams. Four different FE models were then generated and used to simulate osteotomies in the maxillary or ethmoid sinuses regions (figure 4). Heterogeneous results are observed, with different backwards movements of the ocular globe according to the size and/or to the location of the simulated hole [7].

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