The IST Programme
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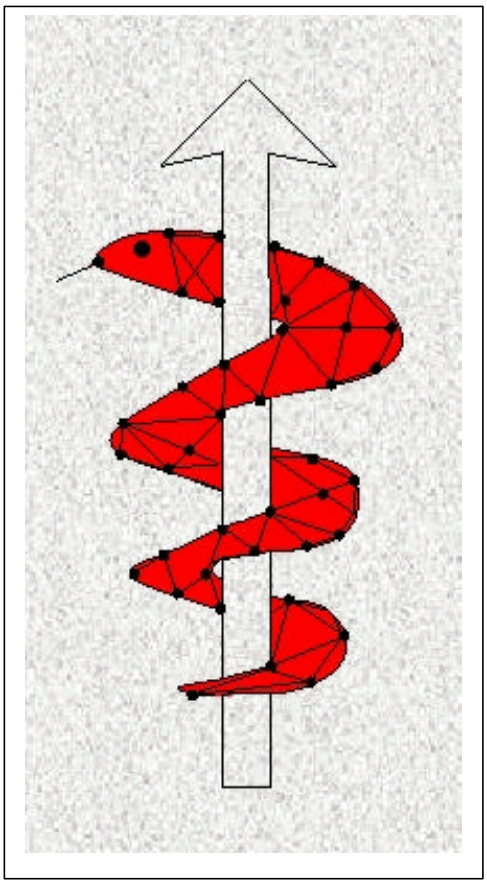
SimBio

SimBio - A Generic Environment for Bio-numerical Simulation

http://www.simbio.de



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Design Report for Test Application 7.2: Bio-mechanical Head Model

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The SimBio Consortium :
NEC Europe Ltd. – UK
A.N.T. Software – The Netherlands
K.U. Leuven R&D – Belgium
ESI Group – France
Smith & Nephew - UK
MPI of Cognitive Neuroscience – Germany
Biomagnetisches Zentrum Jena – Germany
CNRS-DR18 – France
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Validation: Biomechanical Head Model

Introduction

Workpackage 7 deals with the evaluation and validation of the results obtained with simulations using the SimBio environment. Simulations for each of the application problems will be performed using the SimBio environment, implying an implicit software developer and end-user evaluation of the component integration approach. These simulations will be validated against physical data and the impact of the SimBio approach evaluated in the context of the final target use of such simulations.

In this subtask, the clinical usefulness of bio-mechanical head modelling using the SimBio environment will be demonstrated. The application addresses the delineation of changes of lesions with time and the detection of mechanical forces induced by pathological and surgical processes. Such studies offer a new approach for differential diagnosis and outcome prediction. In addition, simulations will reveal information about the static and dynamic properties of the brain.

Two different simulation strategies will be pursued:

- Forward models: The real locations and strengths of forces (or corresponding hypotheses) are known a priorily. The consequences of these forces acting on the whole system are computed, visualised and evaluated. Computed deformation fields may be compared with scan data in order to check the validity of simulation results.
- Inverse models: No prior information about forces is available. In this case, time series examinations are employed and analysed by a non-linear transformation. The resulting deformation field is used to derive a force field, based on incorporated realistic material parameters. Force fields need to be analysed for their singularities ("force sources" and "sinks") in order to provide a comprehensible 3D visualisation. Since a validation based on physical models is not possible here, force fields will be compared in a group of similar clinical cases for their plausibility and checked against prior neuro-anatomical knowledge.

The applications accompany the set-up of the SimBio environment during the total project duration thus allowing repeated feedback cycles in order to investigate the impact and correctness of the SimBio innovations.

2 Work Planned

Three different patient groups will be studied using the SimBio toolbox for bio-mechanical simulations of the head:

- The Clinic for Facial Surgery at the University Clinic of Leipzig (responsible: Dr. Dr. Th. Hierl) is treating patients with in-born deformations of the skull. A stereotactic frame (a so-called *halo*) is mounted to the head by three fixation screws on each side of the head. During surgery, sub-parts of the skull are mobilised and attached to the frame by wires. Pulling wires in a certain direction at a certain distance per day will bring skull parts slowly to a desired position, thus correcting the skull deformation. Typically, 1mm shifts per day are achieved, and after 4-5 weeks, are clinically sufficient results is obtained. Because skull parts are now in their "natural" position (and under natural load conditions), a self-contained healing process is induced.
  The application of this rather new therapy still contains many unknowns:
  1. The allowable force range for halo fixation is unknown. If screws are pulled too tight, the skull may brake.
  2. The choice of the direction and speed applied to the wires attached to the skull parts is currently driven by clinical experience only. The outcome of the procedure may be optimised by simulations in terms of restoration precision and treatment time.

  From a group of 10 patients with in-born deformations of the skull, spiral CT images will be obtained in a native state (TP1), after halo fixation (TP2), and at treatment end (after halo removal, TP3). Datasets will be subjected to the following procedure:

1. Transferral of CT data from the clinical scanner to the MPI on WORM media.
2. Conversion of DICOM files to Vista format.
3. Registration of the time-series examinations, taking the first dataset as reference.
4. Segmentation of the CT datasets into materials bone, halo and soft tissue (brain, CSF, meninges, muscles, fat, skin etc.).
5. Conversion of the TP1 image data into volumetric meshes.
6. Addressing material parameters to elements of the mesh.
7. Addressing direction and strength of known forces (halo screws, surgical wires) manually using the visualisation module of WP5.
8. Performing a forward simulation using solvers for the bio-mechanical problem as developed in WP3.
9. Computed deformations are applied to TP1 data and compared with TP2 data (for halo fixation) and with TP3 data (for wire forces).

In case predictions do not meet the measurements, the model needs refinement. Either more realistic material parameters (or non-linear behaviour), or a more detailed skull model (using attached ligaments, angular points) needs to be taken into account.
Results of this first validation phase are expected to be available at month 18.

- During the course of the Leipziger Langzeit-Studie (LEILA, responsible: Prof. Dr. H.J. Gertz), patients with mild cognitive disturbances are examined behaviourally, clinically and by various neurophysiological and neuropsychological scales. The study currently comprises of 150 patients, in which the first examination time point (TP1) was completed, and follow-up examinations (TP2) are planned during the next 12 months.
  Examinations of TP1 and TP2 will be evaluated by inverse bio-mechanical models in order to derive the deforming forces induced by the atrophing process. 20 suitable cases with a significant atrophy rate (from volumetric measurements) will be selected as a subset.. Datasets will be subjected to the following procedure:
  1. Transferral of MR data from the clinical scanner to the MPI on WORM media.
  2. Conversion of DICOM files to Vista format.
  3. Registration of the time-series examinations, taking the first dataset as reference.
  4. Segmentation of the MR datasets into materials white matter, grey matter, cerebro-spinal fluid (CSF) and meninges.
  5. Computation of a non-linear deformation, which maps TP1 onto TP2 (see WP4.2).
  6. Conversion of the deformation field into a force field.
  7. Characterisation of the force field by its singularities.
  8. Comparison of the results in the group and against clinical experience.

  In a first stage, the non-linear transformation will be computed on the underlying voxel grid of the scanner. In a refinement step, a finite element mesh using realistic material parameters will be introduced in algorithms developed in WP4.2, allowing for a more realistic model behaviour.
- The Day-Care Clinic of Neuropsychology at the University of Leipzig (responsible: Prof. Dr. D.Y. von Cramon) is treating patients with focal brain damage (after cerebral infarction, hemorrhage or severe head trauma). Patients are scanned routinely by MRI at the time of admission and discharge (approx. 3 resp. 12 months after onset).
  Examinations of TP1 and TP2 will be evaluated by inverse bio-mechanical models in order to derive the deforming forces induced by restorative processes after focal brain damage. 20 suitable cases with well-defined lesions will be selected. Datasets will be subjected to the following procedure:
  1. Conversion of Bruker files to Vista format.
  2. Registration of the time-series examinations, taking the first dataset as reference.
  3. Segmentation of the MR datasets into materials white matter, grey matter, cerebro-spinal fluid (CSF) and meninges.
  4. Computation of a non-linear deformation, which maps TP1 onto TP2 (see WP4.2).
  5. Conversion of the deformation field into a force field.
  6. Characterisation of the force field by its singularities.
  7. Comparison of the results in the group and against clinical experience.

In total, 50 patients in three different problem groups will be studied in this validation task. The underlying clinical and modelling questions allow a comprehensive testing of the SimBio tools and the approaches taken for bio-numerical simulation.

MPI will co-operate with UTC to study the influence of material parameter ranges on the simulation results, as well as the influence of the anisotropy in the mesh. Based on available material, limits of linear elasticity theory will be evaluated for this application. From results of these simulations, we will either re-cycle through the modelling process to improve the environment or move on to more complex bio-mechanical simulation.

3 Work completed

At the current date (September 20, 2000), the following steps have been accomplished:

Group A (Forward models):
8 datasets have been recorded at 3 time points. Five datasets have been transferred to MPI and were treated by steps 1-4 as described above and forwarded to NEC for implementing and testing the forward solvers.

Group B (Neurodegenerative Diseases):
5 datasets have been selected at 2 time points, which have been transferred to MPI and were treated by steps 1-4 as described above. Whenever SW from ST4.2 is available, these data will undergo further evaluation.

Group C (Focal Brain Diseases):
10 datasets have been selected at 2 time points, which were treated by steps 1-4 as described above. Whenever SW from ST4.2 is available, these data will undergo further evaluation.