Image-based simulation of the human thorax for cardio-pulmonary applications

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Presentation overview

- Company
- Software solution
- Case Study
- Conclusion
Company
Simpleware

Developers of world-leading image processing environment for the conversion of 3D images into numerical models

- Image-based meshing software and services for your research in:
  - Biomechanics
  - Materials
  - Natural Sciences

- Global customer base

- World-wide reseller network
Simpleware Software

Automatic conversion of 3D images into high quality CAD models and meshes, which can be directly used for:

- Computer Aided Design (CAD)
- Rapid Prototyping (RP)
- Finite Element Analysis (FEA)
- Computational Fluid Dynamics (CFD)
Direct approach - from scan to model

ScanIP
Image processing

+ScanCAD
CAD import & positioning

+ScanFE
Volume mesh generation

COMSOL
(CAD & FE/CFD)

simpleware

Scanning
ScanIP software
Image Processing/Segmentation
+ScanCAD module
Import and positioning of CAD data
ScanFE module
FE/CFD mesh generation
Simpleware - Software Integration

CT, MRI, Micro-CT → ScanIP → IGES, STL
- image processing tools
  - Filtering, Smoothing, Segmenting

ScanIP

CAD, STL → "ScanCAD" → FE, CFD
- integrating CAD into image
  - Implant positioning & integration
  - Meshes with and without implant

"ScanCAD"

CAD, STL → "ScanFE" → FE, CFD
- volumetric meshing
  - Surface, Volume, Contact Surfaces
  - Material properties, Boundary Cond.
Case Study
Human thorax for cardio-pulmonary applications
Introduction

- For medical diagnostic purposes there is an increasing need for non invasive techniques to measure all kinds of parameters that can provide insight in the functioning of cells, organs or organ systems
  - Amount of blood that is ejected by each cardiac contraction (stroke volume)
  - Functioning of the lungs during normal breathing or artificial ventilation.

- This study focuses on calculating the current distributions for ICG and EIT in models of the human thorax.
  - Impedance Cardiography (ICG)
  - Electric Impedance Tomography (EIT)
Methods

- **Impedance Cardiography (ICG).**
  - Small, harmless alternating current is injected into a patient.
  - The current distributes through the thorax, and resulting voltages are measured with additional electrodes on the thorax.
  - If the heart contracts the diameter of the aorta increases. Its electrical impedance changes as well and changes in voltages at the skin occur.

- **Electric Impedance Tomography (EIT)**
  - To measure the filling of the lungs with air, a ring of electrodes is attached to the patient’s thoracic skin.
  - Two neighbouring electrodes inject a small alternating current; resulting voltages are measured at all other 13 adjacent electrode pairs.
  - From these measurements one tries to reconstruct the impedance distribution in the electrode plane. As lungs, muscles, blood etc. have different impedances the reconstructions provide information about tissue distribution in the cross-section of the patient.
Method

Create a FE model to determine which part of total electrical current flows Heart, lungs and Aorta.

- In ICG and EIT.
- Effect of geometry changes due to
  - Breathing and cardiac contraction
  - Bone Structure

How ICG Works:

- An alternating current is transmitted through the chest.
- The current seeks the path of least resistance: the blood filled aorta.
- Baseline impedance to current is measured.
- Blood volume and velocity in aorta change with each heartbeat.
- Corresponding changes in impedance are used with ECG to provide hemodynamic parameters.
Method: Simpleware generated Finite Element Model

- Import image data from CT or MRI
- Use ScanIP to segment the regions of interest
  - Lungs
  - Aorta
  - Heart
- ScanFE mesh after smoothing, consisting of 173,986 elements with electrodes
- Segmented regions form sub-domains within COMSOL
Exported FE Mesh in COMSOL

- Current flow through each organ
- Integrated the total current density over volume of each individual organ
- The current flowing through each organ is calculated as a percentage of the total current flowing through the plane.

Subdomain settings: electrical resistivities
Results

- FEM solution of the four current electrode setup

- The streamlines are magnitude controlled:
- Distance between adjacent streamlines is related to the local current density.
- The colour of streamlines is logarithmically related to the local current density
Results

- FEM solution of the two current electrode setup

- Electrical current streamlines are quite widely distributed through the thorax
Results

Percentage of current flowing through lungs, expiratory and inspiratory state, with different lung tissue conductivities, (VUmc MRI dataset)
FE for Electrical Impedance Tomography (EIT)
Simpleware generated Finite Element Model for EIT

- ScanIP: the 16 electrodes are drawn around the thorax in the segmentation process.
- +ScanFE: generates the volume mesh
- Import the mesh in COMSOL (*.mphtxt)
- The electrode subdomain is disactivated; only the points from the electrode subdomain remain.
- These points are used to inject electrical currents of 5 mA.
Results

- Influence of Breathing and Cardiac Cycle
Results

Electrical current distribution through the lungs as part of the total current as a function of lung tissue conductivity in an FEM modelled EIT experiment
Conclusions
Conclusion

Developed FEM models deliver interesting insight in the current Distribution throughout the upper thorax.

FE based modelling showed that greater part of electrical current Density is not concentrated in the aorta as stated by commercial ICG device producers but widely distributed throughout the thorax.

Although 2D experiments showed that influence of ribs did not Alter the current distribution through the organs significantly the Model would be more realistic when bone structure could be taken Into account to explore 3D situation.
Using image based meshing you can…

- ...generate **straightforwardly** and **rapidly accurate models** for simulation/analysis - allows image processing to move beyond descriptive/statistical analysis of data

- ...mesh **any number of structures** simultaneously (handles multi-part junctions) and **define contact surfaces** between them - interfaces are without gaps or overlaps.

- ...generate coupled finite element and finite volume meshes for **multi-physics** applications

- …**incorporate designs** in the image data – predict and compare the performance of different designs
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