EnhanceR BonePro Evaluation Report

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1. Introduction

Bone biomechanics research are gaining understanding in bone mechanical properties, static and dynamic impact on bone, and bone implant stabilities. To tackle these problems, numerical approaches have been applied as the same bone sample can undergo several tests including tests that are not possible in experiment. The finite element (FE) method is a numerical method that is employed to solve complex bone geometry and structure which range from trabecular microstructure level to the whole bone level.

For each study, a computational workflow is customised. Bone images are specifically processed and converted to an FE-solver-ready input file. Subsequently, FE analyses are performed and results are post-processed. However, standardisation of these workflow and knowledge transfer become challenging.

In the framework of EnhanceR project, the BonePro project was therefore initiated to investigate the technical approaches in this field by collaboration of bone biomechanics research groups at the University of Bern, ETH Zurich, AO Research Institute Davos, EPF Lausanne and Vienna University of Technology.

The specific goals of this project were to gain an overview knowledge of related software and libraries, create a conceptual design of a bone biomechanical analysis pipeline, and provide a prototype of computing pipeline container for demonstration purposes, to be used as a verification of the feasibility of such a software platform in future project proposals

This report is to summarise the shared knowledge of project partners. The report includes common computational pipeline and requirements, image-processing tools, visualisation tools and FE solvers that used in the calculations.

2. The common computational pipeline and requirements in bone biomechanics research

In each study, a computational pipeline was developed to tackle problems and contained a general following workflow:

- Input image data
- Process image, e.g., cropping, rotating, coarsening, segmentation, registration, cortical thickness evaluation and fabric anisotropy quantification
- Add an implant (if any)
- Calibrate the image intensity
- Map material from original images, a template or a statistical model
- Assign boundary conditions to the model
- Write a solver-ready input file
- Perform a finite element analysis
- Extract information from results files
- Visualise result files

In the process of generating a pipeline, researchers needed a user interface tool to visualise processed bone models.

In basic research, the mechanical properties of bone in micro and macro level were modelled and computed. Bone samples were processed and converted to simple geometry such as a cube or flat top and bottom. A pipeline could be prepared by using a Python script to call image-processing functions, FE solvers and post-processing functions. Then, the computation could run in batch mode without user interfaces.

In applied research, the geometry of bone samples were not modified to simpler geometry and an implant might be added to a bone image. Therefore, researchers had to manually create the FE model. This required an intensive interaction with GUI software and the whole pipeline could not run in batch mode.

Based on the discussions with project partners, the ideal software for computational bone biomechanics should have an interactive GUI, be able to perform the above mentioned workflow and provide macro functions to work on large dataset.

As such a software was not available, to achieve their goals, researchers were using various software as listed in the next section.

3. Review of tools

The tools are categorised into four groups.

- Image processing and visualization tools
- CT-based FEA tools are
- CAE/CAD tools
- Finite element solvers

3.1 Image processing and visualization tools

- AimIO is a free open-source C++ class for reading and writing Scanco AIM image files. (https://github.com/Numerics88/AimIO)

- Amira is a platform to visualize and process 3D medical images including CT, MRI, 3D Microscopy and others modalities. (License provider: Thermo Fisher Scientific, https://www.fei.com/software/amira-for-life-sciences/)

- Elastix is a free open-source toolbox for rigid and nonrigid registration of images based on ITK library. SimpleElastix is an extension of SimpleITK that includes the elastix C++ library and can be integrated into other C++, Python, Java, R, Ruby, Lua, Tcl and C\# programming tools. This software was initially developed at the Image Sciences Institute, The Netherlands. (http://elastix.isi.uu.nl/, http://simpleelastix.github.io/)

- Fiji or ImageJ is a free open-source image processing package. It can include the BoneJ plugin for bone image analysis. (https://fiji.sc/, http://bonej.org/)

- ITK is a free open-source software library for image analysis employing algorithms for image registration and segmentation. SimpleITK is a simplified layer of ITK facilitating rapid prototyping. (https://itk.org/, http://www.simpleitk.org/)

- ITKIOScanco is a free open-source software module based on ITK to read and write Scanco ISQ file. (https://github.com/KitwareMedical/ITKIOScanco)

- MIPAV (Medical Image Processing, Analysis, and Visualization) application enables visualization and analyzation of numerous medical images modalities including PET, MRI, CT, or microscopy. MIPAV is a free open-source software. (https://mipav.cit.nih.gov/)

- MITK-GEM is a free open-source software application providing software pipeline to interactively create FE models from image data. It was built based on MITK Workbench software framework and includes GUI and image processing plugins, such as fase image segmentation using graph cut, volume meshing using tetgen and density to modulus conversion for bone material property assignment. The software was developed by Dr. Benedikt Helgason (ETH Zurich), Dr. Yves Pauchard (University of Calgary), Thomas Fitze and Diego Browarnik (ZHAW). (http://araex.github.io/mitk-gem-site/)

- SimpleWare is a software to visualize and analyze 3D image data, and generate model for FE/CFD simulations. (License provider: Synopsys, https://www.synopsys.com/simpleware.html)

- Slicer is a free open-source software for medical image processing and 3D visualization. (https://www.slicer.org/)

- Paraview is a free open-source application to visualize and analyze image data. (https://www.paraview.org/)

3.2 CT-based FEA tools and services

- CT2S service calculate an estimate of the strength of human bone provided by INSIGNEO Institute for in silico Medicine. (https://ct2s.insigneo.org/)

- Medtool is a script manager that facilitates the generation and evaluation of simulation models based on 3D images. It includes functionalities such as material homogenization, interfaces to VTK/ITK and FE solvers, trabecular orientation measurement and plug-in possibilities. (License provider: Prof. Dieter Pahr (TU Vienna), Dr. Pahr Ingenieur e.U. ,http://www.dr-pahr.at/software_en.php)

- VirtuOST provides measurements of bone mineral density and prediction of bone strength based on CT scans. (License provider: O.N. Diagnostics, https://ondiagnostics.com/patients/virtuost-vs-standard-bmd-test/)

3.3 CAE/CAD tools

- Abaqus CAE is CAE tool for Abaqus finite element modeling and visualization. (License provider: Dassault Systemes, https://www.3ds.com/products-services/simulia/products/abaqus/abaquscae/)

- ANSA is a CAE pre-processing tool which converts CAD data into input file for various FE solvers. (License provider: BETA CAE Systems, http://www.beta-cae.com/ansa.htm)

- Geomagic for SolidWorks is a software toolset that plugs directly into SolidWorks environment. It helps reducing time required to build complex 3D models by directly scanning data. (License: 3D SYSTEMS, https://www.3dsystems.com/software)

- HyperWorks offers CAE simulation platform for product design. (License provider: Altair, https://altairhyperworks.com)

- LS-PrePost is a pre- and post-processor that delivered with LS-Dyna. (License provider: Livermore Software Technology Corporation, http://www.lstc.com/products/ls-prepost)

- SolidWorks is a solid modeling CAD software. (License provider: Dassault Systemes, https//www.solidworks.com/)

- Salome-Meca is the integration of the code_aster solver in the SALOME platform including the AsterStudy module for Computer Aided Engineering (CAE). (https://code-aster.org)

3.4 Finite element solvers

FE solver	Licence provider	Free	Material nonlinearity	Geometrical nonlinearity
Abaqus FEA	Dassault Systemes		x	x
Ansys	Ansys, Inc.		x	x
Calculix		x	x	x
COMSOL	COMSOL Multiphysics		x	x
FAIM	Numerics88 Solutions Ltd.		x	
FEAP	University of California, Berkeley		x	x
FEBio	University of Utah	x	x	
LS-Dyna	Livermore Software Technology Corporation		x	x
ParaFEM	University of Manchester	x	x	
ParFE	ETH Zurich	x	x	x
ParOsol	ETH Zurich	x		

4. Conclusions

Various free open-source and commercial tools were used in computational bone biomechanics. In the pipeline generation, researchers interacted with GUI-based tools with UI or other visualisation possibilities to help verify the process. For large data set, researchers ran computational pipeline in an automated fashion. When bone sample geometry was simplified and interaction to GUI was not needed, computational pipeline could run in batch mode. When bone sample geometry was unique and implants needed to be added, a pipeline could be partly automated with macro functions provided by the software.