Simpleware: From 3D image to mesh in minutes

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In the past, converting 3D images into meshes for use in Finite Element (FE) analysis often necessitated time consuming processes and a gross simplification of the model geometry. UK-based, imaging specialist Simpleware Ltd. currently offers two new software products, *ScanIP* and *+ScanFE*, as an advanced solution to this problem, enabling users to quickly and accurately convert any 3D dataset, such as a magnetic resonance imaging (MRI) scan, into high-quality meshes in minutes.

Simpleware Ltd. has established itself as the world leader in the provision of software and services for the conversion of 3D imaging data into numerical models. *ScanIP* provides image visualisation and processing and allows files to be exported to other manufacturing software programs. *+ScanFE* is a mesh-generation module that creates volumetric meshes which can be exported directly to leading FE (and CFD) commercial solvers.

Simpleware's flagship software product *ScanIP* provides an extensive range of image processing and meshing tools to generate highly accurate subject specific models based on data from 3D imaging modalities such as MRI, Ultrasound and Computed Tomography (CT). Features of particular interest include a metal artifact removal filter (for artifacts in CT scans), improved topology and volume preserving smoothing algorithms and a broader range of visualisation modalities.

Novel proprietary algorithms and techniques developed by Simpleware, also permit fully automated, robust generation of FE models based on 3D imaging data and these have been implemented into a commercial code, *+ScanFE*. Mesh generation based on imaging data is an area of great interest in the FE community but the majority of approaches to date have involved generating a surface model from the scan data which is then exported to a commercial mesher – a process which is time consuming, not very robust and virtually intractable for the complex topologies typical of actual composites. A more direct approach is to combine the geometric detection and mesh creation stages in one process. The process incorporates an adaptive meshing scheme, which is fully automated and robust, creating smooth meshes with low element distortions regardless of the complexity of the segmented data.

A sophisticated assignment of material properties is based on signal strength allowing a general mapping function between greyscale and density or Young's Modulus to be defined (several different functions can be assigned to each part). These are all in addition to the proprietary technology which ensures high quality multi-part meshes which conform perfectly at part interfaces (both STL and volume meshes).

In addition to simplifying the meshing process dramatically, the mesh generation from scan data has several important advantages:

a) accuracy of meshed topology is only contingent on image quality. The geometry of the structure is reproduced in the finite element mesh at sub-voxel accuracy.
b) structures consisting of several different materials can be meshed automatically.
c) interfacial contacts can be modelled.

As well as performing convergence studies of field parameters of interest by increasing mesh density, convergence of models to morphology with increased image resolutions can be carried out. Where the properties vary in a continuous fashion throughout the structure, the approach can be used to derive a relationship or mapping function between the signal strength and the material properties which can be extremely useful for studying a wide range of problems including open celled foams, soil samples, and bone.

Case Study

A case study was carried out to explore the feasibility of using clinical data for post-clinical structural evaluation of implant performance. An *in vivo* clinical scan of a patient fitted with a total hip replacement (THR) system was used to explore the influence of mesh density on the predicted response as well as the influence of the assumed contact model at the cup–implant interface.

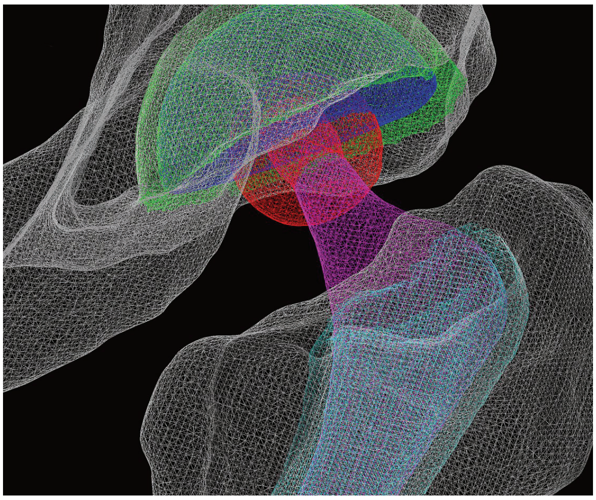

Figure 1: Hip, Femur and Implant in +*ScanFE*.

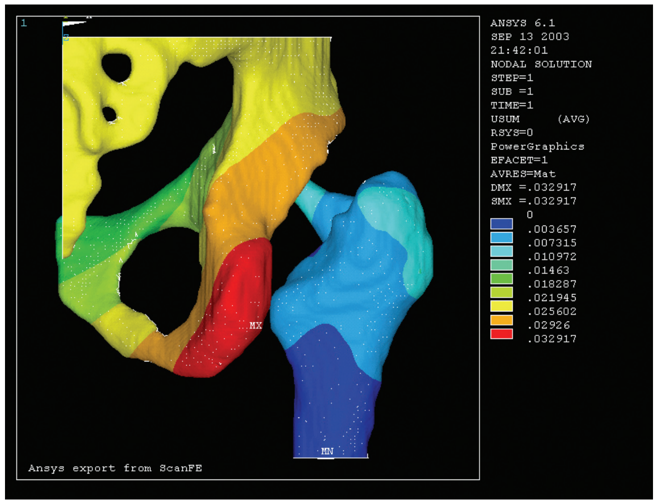

Figure 2: FEA Analysis Results.

Methodology

A CT scan of in-plane resolution, 0.77 mm and slice-to-slice separation, 1 mm was re-sampled and a Metal Artefact Removal (MAR) filter applied. Six masks were created using ScanIP: (1) Pelvis, (2) Cement, (3) Cup, (4) Stem, (5) Cement mantle, (6) Proximal Femur. Based on the six segmented structures, two smooth models of different mesh densities were generated using +*ScanFE* taking less than 3 minutes each. Additionally, a rapid prototyped model replica with the exact geometry as the FE mesh topology, was generated. Using commercially available FEA software, material properties, boundary conditions and loads – including muscle forces – were applied. All materials were assumed to be homogenous, isotropic and to behave linear elastically. Nodes at the top of the pelvis and distal part of femur were defined in +*ScanFE*. The response of the system was analysed under static loading conditions with a sliding interface at cup-implant interface. The total solution time (on an Intel 2.8 GHz) for the low density mesh was a little over 2 hours and 6 hours for the high density model.

Results

The study demonstrated the potential of the proposed approach for the generation of patient specific FE models based on *in vivo* clinical scans. In spite of their complexity and sophistication, full FE simulations can be carried out on an inexpensive and commonly available hardware platform.

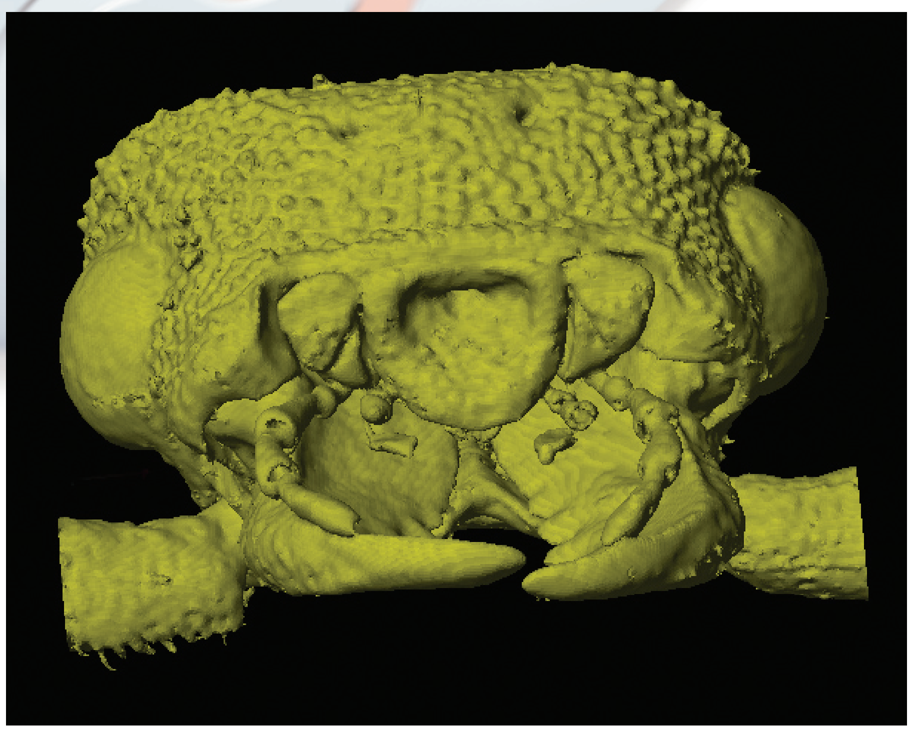

Figure 3: Beetle Mandible.

Natural Sciences

As a joint venture between the University of Exeter and Exeter Advanced Technologies (X-AT), Simpleware was asked to contribute to a set of exhibits on a theme of Biomimicry for the Eden Project's new Education Centre which opened recently. Biomimicry is the imitation of nature to develop scientific and engineering processes and classic examples include Velcro®, inspired by burdock seeds; parachutes inspired by dandelion seeds and in particular relation to the Eden Project, the structure of a dragonfly's eye as the inspiration behind the design of the Biomes. Rapid prototyped models and computer simulations have been developed from CT scan images of plant and insect specimens. The resultant models form elements of visual displays from which children and adults of all ages can learn about how scientists and engineers use nature as an invaluable source of inspiration.

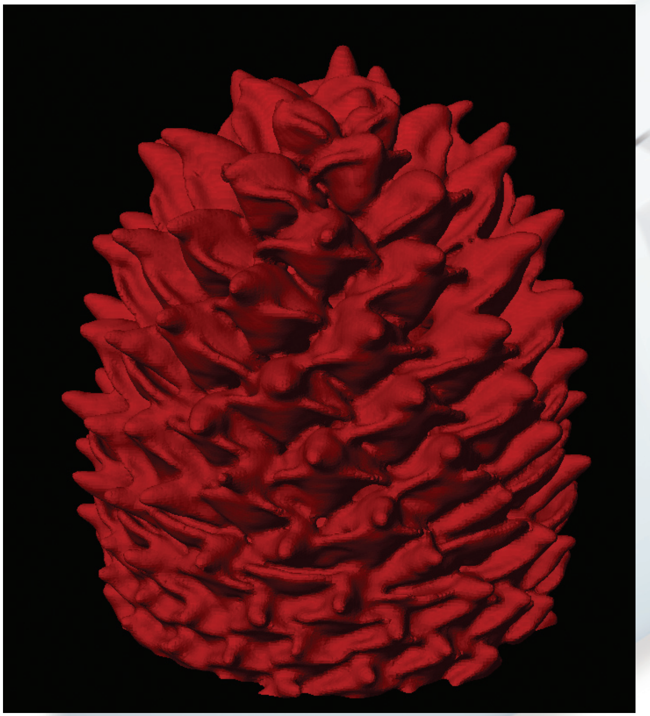

Figure 4: Pine Cone.

Simpleware is also currently involved in a range of natural science projects in collaboration with the Research Support Services (RSS) group at the University of Manchester. Using the high quality mesh generation techniques provided by Simpleware, FEA techniques will be used to study the structure and behaviour of a range of natural organisms. Once funding is secured, Simpleware and its co-investigators will explore the strength and functionality of a *Baryonyx* dinosaur skull (Natural History Museum) and the stress distributions within a beetle mandible (University of Gottingen) to identify the feeding habits of each creature. CFD analysis will also be used to study the hydrodynamics of graptolite locomotion to ascertain its marine environment (University of Edinburgh) and the wind driven pollination mechanisms of pine cones to determine their efficacy at pollen capture (University of Exeter).

The ease and accuracy with which models can be generated have opened up a wide range of previously difficult or intractable problems to numerical analysis, including blood flow, material characterisation of nanostructural composites and patient specific implant design. If the system is coupled with rapid prototyping hardware, it is also possible to produce a solid polymer or metal facsimile of the object in question - the process can then be effectively conceived as a 3D photocopier.

Simpleware has developed a new module, +*ScanCAD*, which allows the import and interactive positioning of CAD models within the image masks. This can be used to bring in reaming tools, implants etc. and integrate them into the image. STL or FE models can then straightforwardly be generated. The new release will also include level set methods which are very powerful techniques for segmenting images.

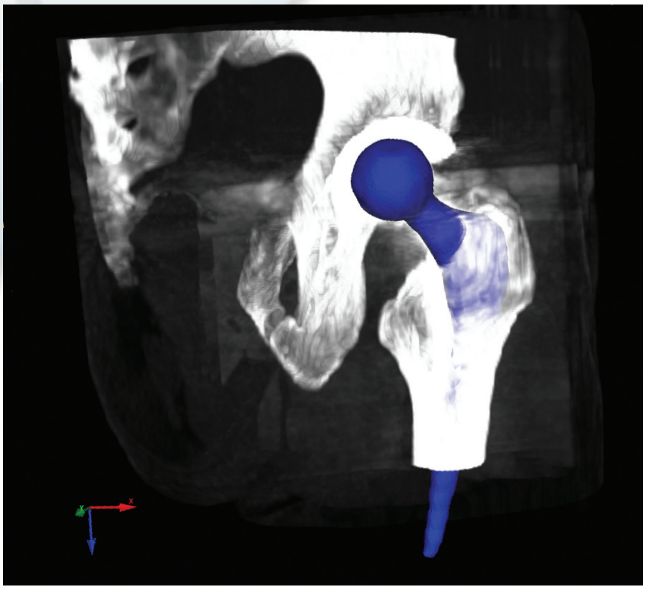

Figure 5: Hip with positioned CAD implant (Stryker).