

Advances in NDE and Image-Based Modelling for Automotive and Defense

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Abstract

There have been many recent advances in image-based modelling as a method for converting 3D image data (such as CT and micro-CT) into robust models for Computer-aided Design (CAD), Computer-aided Engineering (CAE) and 3D Printing. New solutions can be used to obtain models for use in automotive and defense applications, with this paper providing an overview of key techniques.

Reconstruction of 3D image data allows for capture of internal structures for inspection and quantification of manufactured automotive parts throughout. Models can also be exported as image-based meshes suitable for analysing mechanical properties in FEA and CFD software. Analysis of original scan data enables exploration of defects at an early stage in the manufacturing process, and internal structures to be captured without destruction of components.

Novel techniques can similarly be used to replace the internal volume of CAD and image-based parts with lattice structures, which can reduce the weight of a built part without compromising performance. Defense industries can also use these image-based modelling techniques for a variety of tasks, including the design of soldier-specific helmets and simulation of different types of head impact.

Introduction

Image-based modelling offers many advantages for researchers working with 3D image data (MRI, CT, micro-CT, FIB-SEM...) that want to create robust virtual models for analysis and simulation. Advances in these techniques mean that models that faithfully reproduce complex topologies can be created and used for a variety of applications, including image-based finite element analysis (FEA) and computational fluid dynamics (CFD). Within the fields of automotive and defense, these techniques can be used for comprehensive analysis of components without the need for destructive testing, as well as for investigating the relationship between equipment and the human body.

Challenges and Solutions in Automotive NDE

Non-destructive evaluation (NDE) in automotive workflows can be cost effective for analysing parts and components during different manufacturing and testing stages. It can often be a challenge, however, to create accurate 3D models, with CAD models typically representing

idealised geometries that do not reflect the original part. Original equipment manufacturers wanting to rapidly and accurately reverse engineer parts therefore require solutions that preserve complex features.

With image-based workflows, it is possible to visualise, segment, quantify and export models based on automotive scans for simulation and other processes such as Additive Manufacturing. Software techniques have been developed at Simpleware Ltd. (Exeter, UK) that reduce the complexity typically associated with generating these models, from visualisation and exploration through to metrological analyses and production of multi-part numerical models, or meshes.

Typical workflows involve obtaining volume data from a scanning modality such as CT – images are converted from 2D pixels into 3D pixels (voxels) using image processing software. At this stage, image data can be processed to segment out regions of interest, including pore networks and any cracks or defects on the part; this approach is valuable for gaining a rapid 3D view of part defects for inspection. Image data can reveal errors produced during manufacturing phases, and create potential for more comprehensive analysis and quantification of material characteristics.

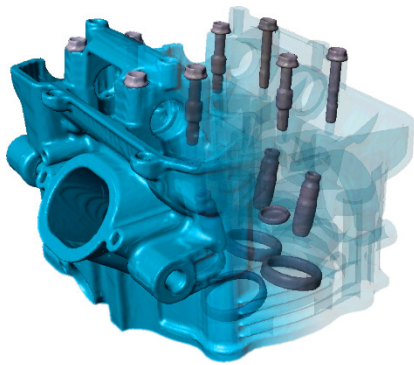


Fig. 1 Visualisation and virtual inspection of an engine block

In terms of this analysis, it is possible to quantify porosity, tortuosity and other characteristics by applying software techniques for calculating statistics and taking measurements. Information on crack sizes, lengths and distribution statistics can be compiled in order to better understand the structure of scanned parts and to understand how and why they might display quality problems during later design and manufacturing stages. Once relevant information has been segmented and image data quantified, models can be exported, for example, as NURBS (Non-Rational-B-Splines) for CAD, or as multi-part meshes for FEA/CFD, to analyse performance under different conditions.

The meshing techniques developed at Simpleware are particularly robust for handling complex multi-part geometries, and use an ‘Enhanced Volumetric Marching Cubes’ (EVOMaCs) algorithm; this adapts the marching cubes algorithm [1] to support the meshing of multiple segmentation domains, and can be combined with a multi-part surface remeshing approach that allows voxel-based meshes to be effectively decimated according to the size and complexity of local features. Remeshing is useful, for instance, if the size of a mesh has to be reduced in order to meet specific computational simulation requirements [2].

When analysing automotive parts, image-based approaches can be extended to calculating effective material properties using homogenisation methods. Homogenisation aims to approximate a complex heterogeneous material, such as a metallic alloy, with a homogeneous material whose response to external loading resembles as closely as possible that of the original material. With this approach, materials image data can be analysed by working with ‘effective’ material properties that link micro and macro-scale modelling. A built-in finite element solver

calculates the response of a cuboidal sample of a material to a sequence of boundary conditions, enabling effective properties such as stiffness, elasticity, absolute permeability and electrical conductivity to be obtained [3].

Lattices and Lightweighting

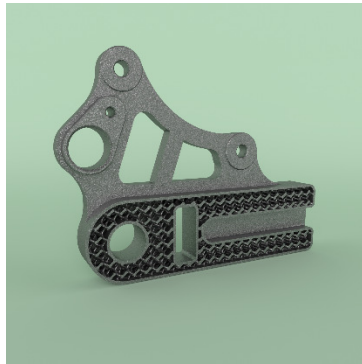


Fig. 2 Example of a bike calliper with lattice

Image-based methods also have advantages when working to reduce the weight of manufactured parts through lattice generation and Additive Manufacturing. Replacing the internal volume of a part with a lattice allows the weight of a part to be reduced without compromising mechanical strength; adjustments can be made to lattice types by working within image space, allowing for design optimisation prior to productions. Research and development into new parts and components within the automotive industries can particularly benefit from this ability to test out new designs. Applications have recently exploring lightweight engine valve designs, while industrial research has also been carried out through UK projects such as SAVING, LIGHT and GOSSAM; these have investigated and found success with projects such as reducing the weight of racing bikes [4].

Defense Applications

These techniques have applications to more specialized defense projects, including the characterisation of alloys and other parts used for equipment. In addition, image-based modelling enables the creation of very high-quality human body models for analysing the interaction between anatomical structures and objects such as helmets. Research carried out by Simpleware with the US Naval Research Laboratory has particularly shown the benefits of non-destructive analysis of head impact as part of research into better understanding and reducing traumatic brain injuries.

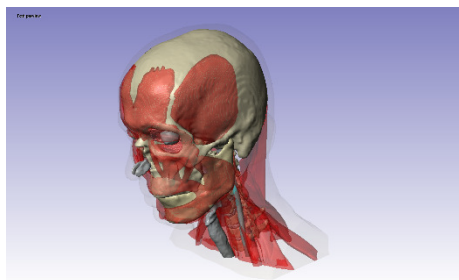


Fig. 3 Human head model generated from MRI data

In this project, a head model was created from high-resolution Magnetic Resonance Imaging (MRI). Image segmentation tools were used in SimplewareScanIP to identify and label regions of interest (ROIs) within the greyscale data such as the brain, skull and muscles. Extensive image processing was used to ensure an accurate and detailed reconstruction of the original scan geometry. Parts of the head and neck not available from the original scan were imported as CAD files and integrated into the overall segmented image dataset. With this approach to combining CAD and image data, it is straightforward to

modify a geometry to include helmets and other headgear.

Following segmentation, robust image-based meshes were generated using Simpleware's proprietary software algorithms. The Simpleware-NRL head model was specifically meshed for

studying traumatic brain injury as an unstructured, all-tetrahedral mesh consisting of 3.72 million volumetric elements. The pre-segmented image data enables new meshes with different parameters to be set up. The NRL used the mesh for simulating head injury for Abaqus/Explicit, and specifically blunt impact loading using experimental data for validation. Blast overpressure loading simulations were also carried out. Simulations showed good agreement with experimental data in the literature [5].

The study demonstrated the feasibility of image-based modelling for defense applications, for example studying head impact using different helmet designs and under varying types of impact. The methods used to create the human head model from pre-segmented image data is particularly novel in terms of specifying finite element meshes for a specific application. Moreover, the head model has been used towards studies into head impact and helmet design in sports such as rugby and cricket, and shows good promise for better understanding concussion and other head injuries.

Conclusions

Non-destructive evaluation of complex material samples and of the relationship between the human body and other structures provides a method for generating significant, accurate results from imaging data. Being able to virtually evaluate material samples and experiment with different designs allows for the diversification of manufacturing research and development, while ongoing research into, for example, helmet designs has widespread applications beyond defence in areas like sports sciences. The image-based techniques developed by Simpleware and implemented through its software demonstrate the value of rapid and accurate processing of scans and their use for design and simulation across multiple fields.

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