CAD RECONSTRUCTION AFTER TOPOLOGY OPTIMIZATION, AN APPROACH WITH SECTIONS

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Resume

The paper presents an approach for CAD reconstruction of 3D models which design space is defined in history based CAD software and changed by topology optimization. The approach is based on intersecting a plane with the geometry obtained by topology optimization. The plane follows a predefined path, intersecting the model at different locations, and moving along the path with a predefined step. For producing the guiding path intersections along three perpendicular axes are used. Three different models are used for testing and the results obtained from these tests are presented and discussed. Partial reconstructions of the models are produced.

Keywords

CAD reconstruction, history based CAD, sections along path, feature recognition, topology optimization

Introduction

Topology optimization is used in many different settings in the aerospace and automotive industry for design of different structures and mechanical elements [Bendsøe et al. 2004]. In these settings efficient use of materials is important, and topology optimization is providing a mathematical approach that optimizes material layout within a given design space. It takes into account given set of loads and boundary conditions, and finds a layout that meets a prescribed set of performance targets.

There are several software solutions that provide topology optimization capabilities [Pedersen et al. 2006], [Huang et al. 2010], [Sang et al. 2007]. The software used for producing the topology optimized geometry of the test models observed in the paper is Abaqus and Tosca.

A general workflow for topology optimization begins with the creation of the design space (essentially the initial material layout created as a CAD model), and continues with definition of mechanical properties of the materials, loads and supports, objective functions and constraints, generation of FEM mesh, optimization run, and finally verification of results. If the design space is a history based CAD model the information regarding different features and the history of their creation is lost during the actual optimization process. Therefore, the 3D model that is the end result of the topology optimization process is not suitable for direct work in history based CAD software, i.e. SolidWorks, Inventor, CATIA Part Design Workbench, Solid Edge, etc.

The geometry obtained through topology optimization is typically very complex. In order for a topology optimized model to be manufactured or further modified (changed), in the general case, it needs to be simplified and/or edited. But before importing back the obtained complex geometry in history based CAD software and edit it by common tools, one has to realize an additional workflow step - CAD reconstruction. This step involves redefining the geometry obtained after topology optimization in such a way, that it could be recognized and therefore enabled for changes in a history based CAD environment. In order for such a redefinition to be achieved the obtained geometry has to be recognized as separate features and reconstructed from these features. Currently this is done mostly manually, and for complex models that means a lot of time spent on geometry stitching and no time spent on design refinement.

CAD reconstruction is extensively used in obtaining meshes and/or surfaces from point cloud or image data [Lin et al. 2005], [Denker et al. 2013]. Very often it is related to reverse engineering.

In [Soni et al. 2009] a feature-based parameterization technique is used for reconstruction from point cloud data.

In [Yang et al. 2012] a method for parametric reverse modeling and redesign for prismatic shapes from point cloud is presented. The idea for using section curves for feature extraction and creation is introduced. Though the paper do not elaborate on how the "appropriate" section curves can be obtained. It proposes a workflow for reconstruction from data groups of sections. There is a mention about analyzing the data and searching for axes of symmetry but with complex shapes, in general, this is not a trivial task.

The significant difference between CAD reconstruction from a point cloud (3D scan data) or image data and CAD reconstruction from topology optimized geometry is that data is available not only for point coordinates but also connectivity of the points. Typically the resulting geometry data after topology optimization can be written in Wavefront obj or stereolithography (STL) file format. Both of these file formats include connectivity data between points, either in an implicit or explicit form.

The aim of the research presented in the paper is to answer the question "How to redefine 3D geometry obtained through topology optimization, so it could be imported back in history based CAD environment reconstructed as a feature based model and be editable with standard tools?" The ultimate goal is for a fully automated reconstruction process.

An approach with sections

The proposed approach for CAD reconstruction of a 3D model produced by topology optimization is summarized in Fig. 1. It is composed of seven steps:

- input of 3D model data including point coordinates and connectivity between points;
- calculation of sections;
- grouping of section contours;
- aggregation of extracted features;
- export to history based CAD software;
- import in history based CAD software;
- reconstruction of the recognized features inside the CAD software.

Step 1: Three dimensional model data. The expected input for the section approach is a description of the model's geometry in terms of point coordinates and connectivity between the points.

Step 2: Calculation of sections. The calculation of sections is along a chosen axis. The sections are produced by intersecting a plane, perpendicular to the chosen axis, with the model's geometry. The plane is moving along the axis with a predefined

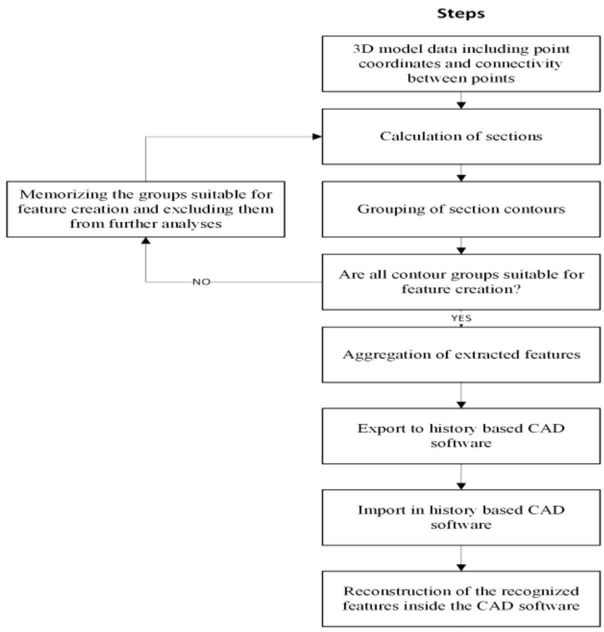

Fig. 1 Steps of the proposed approach for CAD reconstruction of a model which geometry is produced through topology optimization

increment – step. The produced sections are composed of point coordinates and connectivity data.

Step 3: Grouping of section contours: In order to obtain features, grouping of the produced contours has to be done. There are different criteria according to which contours can be grouped: length, area, centroid, etc. The software implementation presented in the next section uses the criterion "overlap". Contours that comply with the chosen criteria are grouped together in a contour group. Contour groups are the basis for feature creation in subsequent steps.

Typically for models with complex geometry, for the purpose of feature recognition (producing useful contour groups), it is not enough to calculate sections in only one direction, e.g. along the X axis. That can be observed in the case of test model C (Fig. 2c). In that case a step in which the obtained features are assessed is necessary. The purpose of this step is a decision whether or not sections in other directions are necessary for better feature extraction. If additional section calculations are needed, first exclusion of the so far correctly recognized features must be made, or if there is no need for additional information aggregation of features step 4 follows.

In order to preserve the so far established groups the latter have to be memorized and excluded from consecutive section calculations. Doing so "strips" the model from already extracted features and enables the recognition of other "hidden" features. Excluding the already established groups is followed by a return to step 3.

Essentially step 3 and its sub-steps are a search for features according to specified criteria.

Step 4: Aggregation of extracted features: This step is necessary if the contour groups defining different features were extracted through producing sections in more than one direction (axis). All contour groups that were obtained and preserved in step 3 are aggregated (combined) into one model.

Step 5: Export to history based CAD software: As the goal of the approach is obtaining a 3D CAD model native to history based CAD software, exporting the contour groups is an important step. The exported data has to be in an appropriate file format and in a form that is easy to use (edit, manipulate) in the corresponding CAD environment.

Step 6: Import in history based CAD software: Importing and generating the contour groups inside the history based CAD software is a necessary step in order for features to be built from these data.

Step 7: CAD reconstruction of the extracted features: Different features can be built from the established contour groups. The most straightforward of them are loft and extruded boss/base features.

Application of the approach

Three test models are used for verification of the proposed approach (Fig. 2).

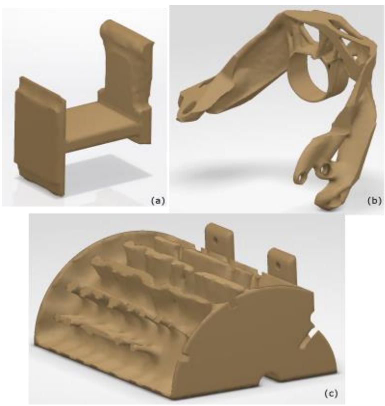

Fig. 2 (a) Model A, geometry after topology optimization; (b) Model B, geometry after topology optimization; (c) Model C, geometry after topology optimization

Model A is with relatively simple geometry and well defined features resembling rectangular shapes. Model B is with significantly more complex geometry than model A and with structures resembling tubular shapes. Model C has also very complex geometry combining tube shaped and prismatic protrusions with a more heavy (bulky) body. The geometry of all models shown in Fig. 2 is obtained through topology optimization of an initial design space. Topology optimization is conducted in Abaqus and Tosca. The models' geometry was additionally smoothed in Tosca.smooth.

For the purpose of verifying the approach a software application, PyReconstruct, is developed. The application automates the calculations necessary for the execution of steps 2 through 5 of the proposed approach. It is written in Python 2.7.10, uses Tkinter for GUI creation and pyqtgraph 0.9.10 for 2D/3D visualization. PyReconstruct can import model data (point coordinates and faces) from Wavefront obj files. In Fig. 3 model A is shown imported in the application.

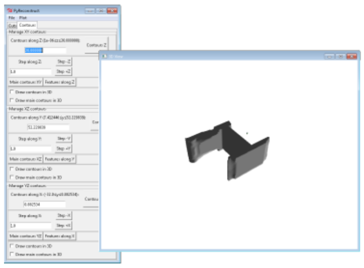

Fig. 3 Model A imported in PyReconstruct. GUI and 3D view of the application

Currently PyReconstruct supports creation of sections along the main X, Y, and Z axes of the model. The axes maximum and minimum values are determined by calculating the 3D bounding box of the model. Therefore the contours produced lay in planes parallel to one of XY, XZ, or YZ plane.

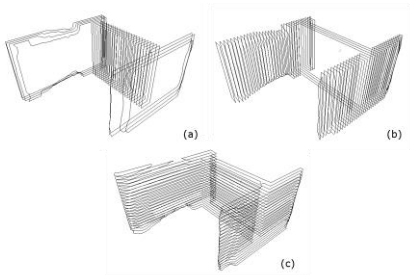

Fig. 4 Contours of model A (a) along X axis (parallel to YZ plane); (b) along Y axis (parallel to XZ plane); (c) along Z axis (parallel to XY plane)

In Fig. 4 are shown the contours produced from sections along X, Y, and Z main axes of Model A in PyReconstruct. The distance between the section planes (the step) is 1 mm. The contour groups calculated from the application are shown, color coded, in Fig. 5. For every group a color is assigned so that the contours in one group have the same color. It can be observed that for model A contour groups describing all its characteristic features can be extracted from the contour groups obtained along Y or Z axis.

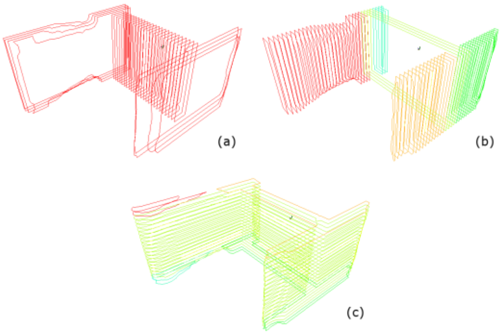

Fig. 5 Contour groups of model A, color coded (a) along X axis; (b) along Y axis; (c) along Z axis

In the current implementation of PyReconstruct the user decides which contour grouping is advantageous by visually browsing through the obtained groups by a group picker widget. In the case of model A the groups along the Y axis are assessed as good for reconstruction purposes.

The next step is to export the contours in a suitable file format. PyReconstruct exports the contour point and connectivity data in dxf file format where the contours are represented as splines. For the dxf export ezdxf 0.6.5 library for Python is used. The exported geometry is imported in SolidWorks (Fig. 6a) as 3D curves.

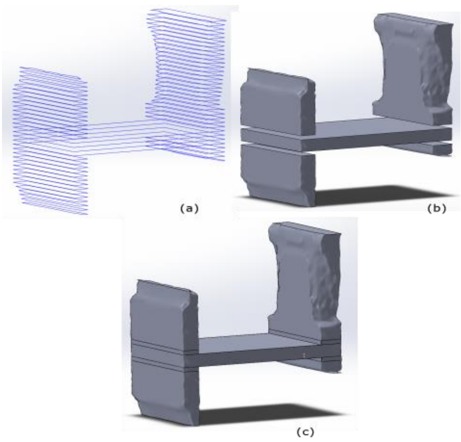

Fig. 6 (a) Contours of model A imported in SolidWorks as 3D curves (b) Partial reconstruction of model A in SolidWorks with loft features (c) Partial reconstruction of model A with manually constructed "fill" features

The curves are then made into loft features according to contour group data. The result is a partial reconstruction of model A (Fig. 6b). For obtaining a fully reconstructed model the different features must be connected so that they are able to update according to changes in geometry of the features to which they are connected. As of the time of writing the current paper the author is not aware of a history based CAD software that supports such operation or feature. A possible workaround is projecting sketches of the features to be joined in a common plane (where the joining is to be) and manually editing the sketch. The result for model A, after such manual work is shown in Fig. 6c. The model is still partially reconstructed due to the fact that the connected features are not propagating changes in geometry to one another. Nevertheless, the so partially reconstructed model can be edited with common tools, used for producing additional sketches, used in FEM analysis, etc.

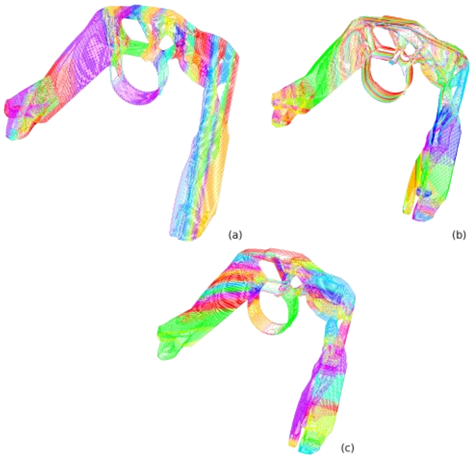

Fig. 7 Contour groups of model B, color coded (a) along X axis; (b) along Y axis; (c) along Z axis

Fig. 8 Partial reconstruction of model B in SolidWorks with loft features

Contour groups for model B are shown in Fig. 7, and a partial reconstruction in Fig. 8. The reconstruction is done on the basis of the contour groups along the Z axis (Fig. 7c). This model has much more complex geometry than model A, nevertheless a partial reconstruction is possible by choosing contour groups in one direction. However, the issue with joining the groups together in the CAD software is harder to overcome as there are more contour groups. For model B, there are contours that are single, i.e. they comprise a group, and therefore cannot be included in the reconstruction without additional manual work. In order for some loft features to be created additional division of some contour groups is necessary. This is because of the grouping criterion – “overlap”. Clearly additional grouping criteria are necessary if the reconstruction is made only with loft features.

Model C cannot be reconstructed only with contour groups in one direction. The loop in Fig. 1 (step 3) has to be performed in order for useful groupings to be obtained. This loop is not yet implemented in PyReconstruct and further investigation of possible realizations is needed.

Conclusions

An approach for CAD reconstruction after topology optimization is proposed. For verifying and automating some of the steps of the approach a software application is developed. Three models, with progressive increase in shape complexity, are used for testing and verification purposes. Applying the approach and the developed software application leads to partial reconstructions of the test models. The partially reconstructed models are composed of features supported by the history based CAD environment. These reconstructions can be used for further design development and in FEM analysis after additional joining of the different contour groups. Further development of the software application is needed in order to implement and verify fully the approach.

Acknowledgments

The scientific research the results from which are discussed in the present paper are financed from the Internal competition of TU-Sofia for year 2017.

The author would also like to thank Peter Clausen and the whole team of Dassault Systemes from the Karlsruhe office for sharing of knowledge and expertise, and also a big “Thank You!” to prof. Stoyan Maleshkov for the support and collaboration.

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