CAD-BASED SHAPE OPTIMISATION USING ADJOINT SENSITIVITIES

G. Yu and J.-D. Müller

School of Engineering and Materials Science, Queen Mary, University of London
e-mail: g.yu@qmul.ac.uk

ABSTRACT

Existing approaches to CAD-based design using adjoint sensitivities are reviewed and their shortcomings are recalled. An alternative approach is presented which uses the control points of the boundary spline representation as control variables. 2-D examples of this approach will be presented.

Introduction

The development of adjoint solvers has seen a significant increase in research interest over the last decade since they can provide inexpensive sensitivities for design optimisation. A number of industrial implementations have been demonstrated and there is strong industrial interest to integrate adjoint design optimisation into the design chains. These chains use CAD systems to manipulate the geometry and there is a desire to include in the derivative computation the design parameters defined in the CAD system.

However, the CAD systems in general are proprietary software codes which do not provide derivatives of the geometry surface X_s with respect to the design parameters α, $\partial X_s/\partial\alpha$. Current approaches to include CAD parametrisation in the chain of derivatives hence need to use finite-differences, [1, 2]. Robinson et al. [3] evaluate the surface displacement over a faceted coarse surface mesh and then interpolated on the boundary of the fine computational mesh. The interior mesh displacement is then obtained through smoothing extending this displacement into the volume mesh.

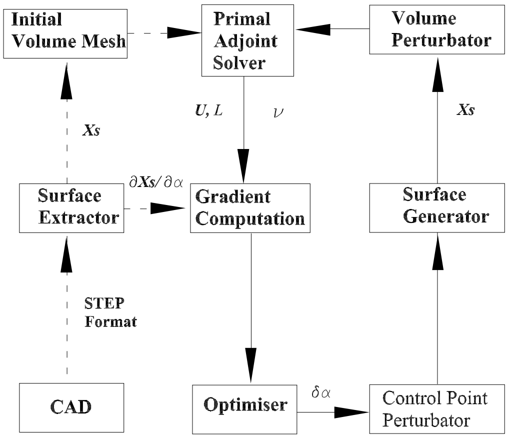

Figure 1: An optimisation loop using CAD-based sensitivities

This finite-difference approach is firstly inexact and secondly its computational cost scales linearly with the design variables. In particular the latter is a serious performance handicap when used with the recent node-based parametrisations (avoiding time-consuming hand parametrisations) and simultaneous timestepping methods for the KKT-system ('one-shot') where gradient evaluations occur very frequently.

Differentiation of the boundary representation

As an alternative, we propose to use the boundary representation (BRep) based on NURBS. Although this form cannot represent the CAD parametrisation, this is the form in which the CAD systems exports the geometry to post-processing tools such as mesh generators or tooling. We can reverse differentiate this representation with respect to design variables such as Euclidean control points and weights, and knot vectors. The optimisation chain is shown in Fig. . The surface extractor reads a surface description file in STEP format and recovers the NURBS surfaces using

$$\mathbf{X_s}(u,v) = \sum_{i=0}^{n}\sum_{j=0}^{m} R_{i,j}(u,v)\mathbf{P_{i,j}} \tag{1}$$

As a first implementation will present results on using the coordinates of the control points as design variables. The derivatives of the surface with respect to the design variables in any given location on the surface will be obtained by applying automatic differentiation (AD) in reverse mode to a generic NURBS implementation. These derivatives will be used to complete the chain rule of derivatives for the cost function J w.r.t. the design variables α,

$$\frac{\partial J}{\partial \alpha} = \left(\frac{\partial J}{\partial X_s} + \frac{\partial J}{\partial U}\frac{\partial U}{\partial X_s}\right)\frac{\partial X_s}{\partial \alpha},$$

where the PDE-constrained sensitivity $\frac{\partial J}{\partial U}\frac{\partial U}{\partial X_s}$ is evaluated with an adjoint method.

The results will be compared to a node-based parametrisation [4] which requires additional smoothing to prevent high-frequency oscillations in the shape.

References

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