Response surface models for design optimisation

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Introduction

Developing Computational Fluid Dynamic (CFD) solvers are finding increasing use in the design process of aerospace components. In addition, rapid production of computational grids for components with complex geometries is becoming possible through the use of robust, generic parametric geometry definition in combination with rapid meshing tools. This emerging technology provides greater freedom in the design of components for a given set of design parameters, allowing for a variety of increased design space. Composed of thousands of design variables, this larger design space enables wider ranges of possible component geometries to be assessed. An example of this capability is shown in Fig. 1, where a parametric rotor blade geometry is deformed via a control parameter.

Large Design Spaces

The aim of this research project is to enable large design spaces defined by parametralised geometry to be searched efficiently and effectively. This will involve the development of improved surrogate-based optimisation methods using design space reduction, parallel multi-objective, multi-fidelity and hybrid response surface models (RSM). Computer design optimisation requires repeated calling of expensive CFD solvers during the design search. In addition, each function call requires the execution of pre-processing software for geometry creation and meshing, setting boundary conditions and multi-grid levels, and post-processing software for extracting and visualising flow field information. The overall workflow for each function call is complex, and involves a number of data management and storage issues.

Workflow

A recent collaboration between Microsoft, Rolls Royce and University of Southampton involved a Proof of Concept (PoC) exercise for high productivity computing for engineering design optimisation. The basis of the PoC was to demonstrate an end-to-end Rolls Royce design scenario, utilising aspects of Microsoft technology which prove of value individually, but also as an integration point for the existing workflow solution. The example design scenario chosen was a high-fidelity CFD flow field solution for a compressor rotor blade defined by a parametric geometry, as shown in Fig. 4. The complete workflow included an optimisation of package, several pre-processing stages, high-fidelity CFD solution cells involving parallel CFD solver running on the Windows CC multi-core processor, and several post-processing steps, as shown in Fig. 5.

The workflow solution involved several specific technologies: Windows Forms for presentation technology, Windows Workflow Foundation and Visual Studio, Microsoft SQL Server, and Windows CC including interoperability with Linux computer resource. The solution was able to demonstrate reasonable run time on a standard desktop, making it possible to run the PoC as a robust, yet flexible framework for design optimisation using mixed fidelity solver methods contained within complex workflows. The system will assist in the current project in the research and development of improved surrogate-based optimisation methods.

Ongoing Work

Work is currently focused on building and validating appropriate data structures for storing CFD results for use in future research. The generation of CFD results is currently managed by scripting, but the PoC technology is being assessed for this purpose. Design of Experiment (DoE) methods such as optimised Latin hypercube, are used to build a series of data sets of multi-fidelity, adaptive, or finite fidelity solutions. The results can then be used in research for mixed fidelity, multi-fidelity and other result schemes. A scheme currently being investigated is the use of adaptive, (interpolating) and simple (regression) Kriging models, examples of solutions which are shown in Fig. 4. Simple Kriging requires fewer matrix-vector multiplications than ordinary Kriging. Kriging prediction for large data sets for design problems with very large degrees of freedom rapidly becomes intractable due to matrix inversion and difficulties in hyperparameter tuning. Methods to address these problems are being investigated such as pre-conditioned conjugate gradient methods for inverse matrix-vector multiplications, parallel matrix inversion, N-body approach, and hyperparameter tuning using gradient information.

Fig. 1: Parametric geometry definition for NASA compressor rotor geometry.

Fig. 2: Arbitrary parametric geometry definition.

Fig. 3: Compresses geometric data for NASA compressor rotor geometry.

Fig. 4: Example workflow for obtaining high-fidelity CFD flow solution for the NASA compressor rotor geometry.

Fig. 5: Kriging predictions of the third design function using a simple process.

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