Many-Objective Optimization: An Engineering Design Perspective

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Abstract. Evolutionary multicriteria optimization has traditionally concentrated on problems comprising 2 or 3 objectives. While engineering design problems can often be conveniently formulated as multiobjective optimization problems, these often comprise a relatively large number of objectives. Such problems pose new challenges for algorithm design, visualisation and implementation. Each of these three topics is addressed. Progressive articulation of design preferences is demonstrated to assist in reducing the region of interest for the search and, thereby, simplified the problem. Parallel coordinates have proved a useful tool for visualising many objectives in a two-dimensional graph and the computational grid and wireless Personal Digital Assistants offer technological solutions to implementation difficulties arising in complex system design.

1 Introduction

Real-world engineering design problems often involve the satisfaction of multiple performance measures, or objectives, which should be solved simultaneously. Automotive and aerospace examples provide illustrations of some typical design challenges and demonstrate that these problems often involve a large number of objectives. It is demonstrated how a typical set of engineering design specifications might be mapped onto a familiar formulation of an EMO problem. EMO research has, for the most part, focused on problems having 2 or 3 objectives; however, in recent years there has been growing interest in the area of *many-objective* optimization where the problem might consist of 4 – 20 objectives, for example.

Of the three key requirements for EMO solution set quality - proximity, diversity and pertinency - a case is made that pertinency, focussing on solutions in the designer's region of interest, has a special prominence in *many-objective* optimization studies. A method whereby the MOEA is operated in an interactive manner through progressive articulation of preferences is described and an example worked through to explore the potential of this approach.

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The means of using the method of parallel coordinates to reduce the study of a *many-dimensional* Pareto front to a 2-D representation reveals a number of strengths and limitations. *Many-objective* optimization in an engineering design context is inevitably very compute-intensive and there is an expectation that a design procedure will often be time-consuming. Two schemes are introduced to deal with these demands. In one scheme, the MOEA is parallelised to execute effectively in a computational grid environment in reduced time. For the second scheme, it is shown that wireless PDAs can be effective tools for designers in the interactive computational steering of the design process.

2 Design Approaches

In this section we provide examples of conflicting objectives in two areas of engineering design and then provide some background to solution approaches used in the past.

2.1 Typical Engineering Design Optimization Problems

Automotive Engineering Examples

Historically, in automotive engineering, the process of establishing trade-offs has been to conduct parametric studies. That is, evaluating the conflicting objective functions at different values of the decision variables (parameters), comparing the results in objective space and then finally selecting a single trade-off solution. An example of such a parametric study is shown in an enumeration plot (see Fig. 1), where two conflicting objective functions (empirical models of NOx and Brake Torque) are plotted against each other, evaluated as a function of their input (decision) variables.

Brake Torque is a surrogate variable for fuel economy and is easily measurable on an engine dynamometer test rig; maximising brake torque is equivalent to optimizing fuel economy. NOx or Oxides of Nitrogen are one of the three legislated exhaust emission pollutants and in this case is measured pre-catalytic converter. Minimising NOx minimises the precious metal (e.g. Platinum or Rhodium) coating in the catalytic converter and thus cost.

In Fig. 1 the decision variable is EGR (Exhaust Gas Recirculation) rate, which gives a benefit in brake torque and NOx. Brake Torque maximises at moderate EGR rate, but NOx minimises at maximum EGR rate. Thus, the objectives conflict.

Since the optimization problem is to maximise Brake Torque and minimise NOx, trade-off solutions in the lower RH corner of Fig. 1 are preferred. Using a parametric approach, many objective function evaluations are required, which may be expensive, particularly if there are a large number of objective functions. (In automotive engineering it is not uncommon to have problems with 4-10 objectives.) Also, it is possible that suitable Pareto-optimal solutions will not be discovered and that a suboptimal trade-off solution will be selected.

Fig. 1 is obtained from empirical models of Brake Torque and NOx. The models are based on automated test data arising from a designed experiment on an engine on an engine dynamometer test rig. The resulting models are then validated against independent test data and against known physical trends.