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Applications of Evolutionary Algorithms for Solving Real-life Design Optimisation Problems

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Abstract. The aim of this paper is to present an application and a framework using evolutionary algorithms like Genetic algorithms (GA) for solving real-life design optimisation problems. The application is centred around an engineering optimisation toolbox applied to the design optimisation of gas turbine combustor. This toolbox can handle high-dimensional problems and ease the computational cost of simulation through a distributed evaluation of the solutions. The framework involves the development of a flexible optimisation toolbox for providing an integrated optimisation capability within the CAD/CAM environment.

1. Introduction

The competition in today's global markets is putting increasing pressure on industry to optimise its activities. Optimisation techniques including both classical and evolutionary could provide industry with powerful tools capable of tackling engineering design problems. However, the use of these techniques is currently very limited as the complexity of real-life optimisation problems has prevented the industry from exploiting the potential of optimisation algorithms. The industry has, therefore, continued to rely on either trial-and-error or over-simplification for its optimisation problems. This has led to a loss of opportunity for obtaining better designs with reduced costs and design cycle times. The growth of research in the field of real-life optimisation has been encouraged by a desire to harness this opportunity.

Research undertaken at Cranfield University aims to provide solutions for optimisation in industry through the use of evolutionary algorithms such as GA. In this paper, we propose to implement the optimisation capability through a toolbox, which is made modular and user-friendly by using object oriented programming languages such as Java and C++. This modularity allows tools to be added thereby increasing the versatility and performance. This is the basis of the development of an applications and a framework. The application has been designed to handle high dimensional problems while tackling the computational expense of simulation, it is applied to gas turbine combustor preliminary design. The proposed framework

involves capturing designers' requirements for flexible optimisation and integrating evolutionary computing tools within CAD/CAM systems to address the requirements.

2. Gas Turbine Combustor Preliminary Design

A graphically based engineering optimisation toolbox has been developed, to ease the preliminary design of gas turbine combustors. It is based on evolutionary algorithms supported by a set of modular tools that helps the application of these techniques to engineering design. The proof of concept for the application of this method to combustor design comes from research undertaken by Despiere et al. (1997)

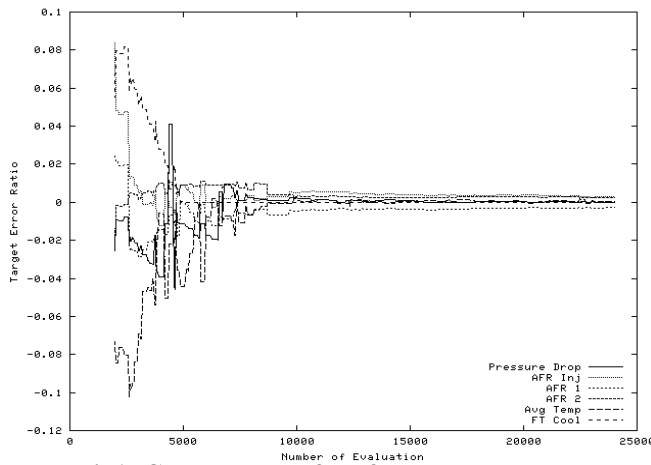


Fig1: Convergence of performance parameters toward the design targets

Combustor design requires the use of external simulation software to assess the quality of the solution. In order to allow communication between the optimiser and the simulation code an interfacing module has been developed, linking the toolbox with any simulation package that can communicate

through text files for input/output. High dimensional engineering problems requires the evaluation of many independent solutions, which is costly in terms of CPU time. For this reason the evaluation process was parallelised by using a module capable of evaluating the chromosomes in parallel over a distributed network of heterogeneous workstations. In order to further adapt the toolbox to engineering problems, Real Coded GA (Janikow et al., 1991 & Goldberg, 1990) has been implemented using steady state reproduction (Davis, 1991): that limits the number of calls to the evaluation function and to the simulation code.

This optimisation toolbox has been applied to the preliminary design of a gas turbine combustor. The optimisation procedure allows geometric characteristics of a combustor to vary by encoding them into twenty five real-numbered chromosomes. These define the properties of all the cooling and dilution ports of the combustor. The solutions generated by the optimiser are evaluated using a network simulation code (Stuttaford et al., 1996). The results are then used to calculate six performance targets, namely: pressure drop, wall temperatures, cooling air mass flow, and air fuel ratio in three different zones. The combination of these targets define the fitness.

Perf. Param.	Opt.1	Opt.2
Evaluations	24000	24000
ΔP	-0.045%	-4.944%
AFRinj	0.005%	4.675%
AFR1	-0.272%	4.914%
AFR2	0.277%	3.676%
AvgTemp	-0.257%	-0.808%
Coolingflow	0.034%	---

Table 1: Optimisations Results

amount of cooling flow required to control the flame-tube walls temperature, while constraining the problem to within a $\pm 5\%$ range of the previous design targets. The optimiser gave very promising results for this problem by reducing the ratio of cooling flow by 23% see Table1 for the achievement of the design targets. Finally to demonstrate the performance of the distributed optimisation module, an optimisation case consisting of 5000 evaluation has been run on 1 to 16 clients comparing the computational efficiency of clients to a serial run fig.2. More details on this application to be presented at the second International Conference on Engineering Computational Technology.

To demonstrate the capabilities of the optimiser it has been set to achieve the same performances targets as a 'manually' optimised combustor (Opt1). The demonstration application was successful, achieving the design targets see Table1 & Fig.1. The next step (Opt2) consisted in showing the capability of the optimiser to go beyond the 'manual design' targets, by minimising the

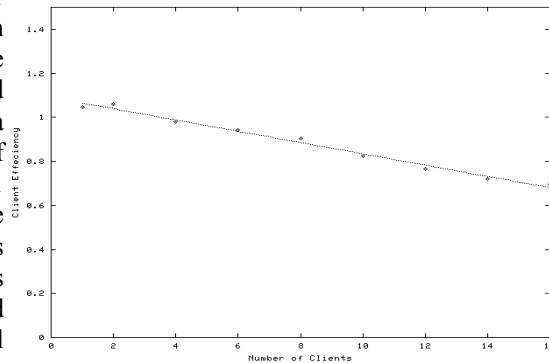


Fig2: Client Performance

3. Flexible Optimisation within CAD/CAM Environment

The research aims to develop a framework for flexible optimisation within CAD/CAM environment using evolutionary-based computing techniques. The framework enables a CAD/CAM environment to select appropriate techniques and parameters for an optimisation task. The flexible optimisation wheel shown in Fig.3 depicts the different combinations possible within the flexible optimisation framework. This framework provides a platform for dealing with various settings of evaluation tools and techniques, geometric modellers and optimisation algorithms.

In the recent past, some work has been carried out in the field of flexible optimisation. Jared et. al. (1998), Mussa et. al. (1998) and Roy et. al. (1998) specifically addressed the issue of enhancing the optimisation capabilities of existing CAD/CAM systems. Roy (1997), and Bentley and Wakefield (1998) also demonstrated the feasibility of developing a generic evolutionary design system. Keane (1996), Parmee (1996) and Greene (1998) have also attempted to develop a compact toolbox of robust optimisation techniques. However, in contrast to this

research the previous work has adopted a tactical rather than a strategic view of the concept of flexible optimisation.

The framework, in this research, is developed based on the industrial requirements for flexible optimisation. The industrial requirements have been captured through interviews with designers in various industry sectors. This revealed a number of issues concerning design optimisation that are addressed by the framework. Designers expressed their willingness for an optimisation framework that can incorporate their skills and experience in an interactive environment. They also

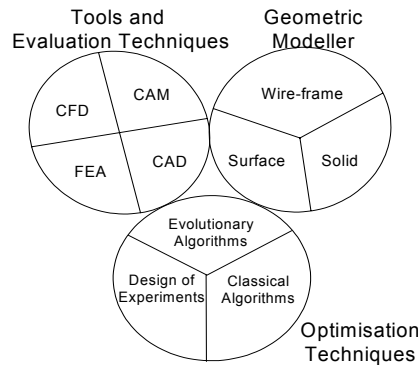


Fig3 : The Flexible Optimisation Wheel

mentioned the immense difficulties they face due the currently available optimisation packages being independent of the CAD/CAM system. It is felt in industry that most optimisation algorithms are problem specific and can not deal with the features of real life optimisation problems. It was observed that along with the presence of multiple objectives, the real-life optimisation problems also exhibit a lack of prior knowledge about the search space and the presence of qualitative issues like manufacturability and designers special preferences. The complexity of these problems is further increased by the presence of constraints and multiple interacting variables.

The research involves the development of a toolbox containing engineered multi-objective optimisation algorithms (Deb, 1999) capable of solving a variety of real-life design problems. In order to provide the optimisation capability online, it is essential for the flexible optimisation toolbox to be integrated within the CAD/CAM environment. The research develops a generic Application Programming Interface (API) and wrapper software for integrating the API with CAD system I-DEAS. Finally, the findings of this research would be implemented through a prototype decision support system using an industrial case study on surface development. The case study, which is the ongoing research activity, would provide surface designers with an interactive tool for the attainment of aesthetic geometry.

4. Conclusion

This paper presents the a practical application and a framework of evolutionary algorithms for design optimisation of complex engineering problems. The research is expected to aid in shortening design lead times and the associated costs coupled with an improvement of existing designs. It would make the optimisation jobs easier thereby making them less dependent on the designers' skills and experience. The approach developed in this work is aimed at making the optimisation algorithms more

popular in industry enabling the industry to optimise its activities for achieving better efficiency.

5. Acknowledgements

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