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FEATURE EXTRACTION FROM DESIGN SPACE

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Optimization is a powerful computational tool. However, there is still a hesitation to introduce the optimization tool to daily routine for engineering design, because an optimal solution is still far from an actual design. This paper discusses the difference between optimization and design, and proposes how to put optimization to good use in engineering design.

Optimization is rigidly defined by mathematical variables and functions. To define an optimization problem, one has to know exactly what are design requirements, which are not obvious at all, because design often involves decisions based on tacit knowledge of a designer. A designer needs a flexible solution, rather a variety of solutions, so that he can modify and adapt the design for changes he has to face day by day. Therefore, a rigid optimal solution does not facilitate design activities.

This leads us to learn design theory to understand design itself and how to aid design activities by computational tools. There are many design researches, which reflect many facets of design activities. One of such researches pointed out the importance of abduction [1]. Peirce distinguished between three families of reasoning patterns: deduction, induction and abduction [2]. Deduction obtains theorems from axioms and facts, induction obtains axioms from facts and theorems, and abduction obtains facts from axioms and theorems [3]. Abduction can be considered as special patterns of inference to the best explanation, which includes not only the discovery but also a preliminary evaluation of explanatory hypotheses [4]. Yoshikawa has claimed that the design in a narrow sense is the abduction [1]. The heart of the design is to draw an inference to the best design based on a preliminary evaluation of design candidates.

A designer needs a map of how to draw an inference to the best design. If computational tools create a Bird's-eye view of the design space, the result literally provides the map that support design activities. Design space can be mathematically defined by design variables and design objectives. If multiple design objectives are specified, design space can be regarded as a multi-objective optimization problem. Among the multiple design objectives, conflicting objectives are essential and they will provide Pareto-optimal solutions [5], which form Pareto front, a key feature in the design space. The shape of the Pareto front tells various aspects of design tradeoffs and it is easily drawn on a sheet of paper for the two objectives. For higher dimensions, data mining techniques can be applied to feature extraction from design space.

For feature extraction from design space, Multi-Objective Design Exploration (MODE) has been developed [6,7]. MODE is not intended to provide an optimal solution but to reveal the structure of the design space from trade-off information and to visualize it as a panorama for a decision maker. The MODE system consists of a Kriging model, an adaptive range multi-objective genetic algorithm, an analysis of variance and a self-organizing map (SOM). SOM is one of data mining techniques and it divides the objective function space into several clusters. Each cluster represents a set of designs with specific design features. A designer may be interested in a cluster with good design features, which are composed of particular combination of design variables. Such combination of design variables may be extracted as a design rule. Data mining techniques are very useful for extracting design features.

In Japan, the New Energy and Industrial Technology Development Organization (NEDO) subsidized the development of an environmentally friendly high performance small jet aircraft. Mitsubishi Heavy Industries, Ltd. (MHI) was the prime contractor for the project. The purpose of this project was to build a prototype aircraft using advanced technologies, such as low-drag wing design, and lightweight composite structures, which were necessary for the reduction of environmental burdens. In March 2008, MHI decided to bring this conceptual aircraft into commercial use. This commercial jet aircraft, named the Mitsubishi Regional Jet (MRJ), has a capacity of about 70-90 passengers. This project focused on environmental issues, such as reduction of exhaust emissions and noise. Moreover, in order to bring the jet to market, lower-cost development methods using computer-aided design were also employed. In particular, the design of the Regional Jet was formulated as Multi-Disciplinary Optimization problem and approached with MODE. Through the applications of MODE, this paper illustrates the importance of understanding and extracting design features from the design space, instead of obtaining a single optimal solution.

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