Extraction of Design Characteristics of Multiobjective Optimization – Its Application to Design of Artificial Satellite Heat Pipe

Min Joong Jeong[1], Takashi Kobayashi[2], and Shinobu Yoshimura[3]

[1] Computational Biology Research Center, National Institute of Advanced Industrial Science and Technology, 2-43 Aomi, Koto-ku, Tokyo, 135-0064 Japan
jeong@cbrc.jp, http://www.cbrc.jp

[2] Design Systems Engineering Center, Mitsubishi Electric Corp., 5-1-1 Ofuna, Kamakura, Kanagawa, 247-8501 Japan

[3] Institute of Environmental Studies, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656 Japan

Abstract. An artificial satellite design requires severe design objectives such as performance, reliability, weight, robustness, cost, and so on. To solve the conflicted requirements at the same time, multiobjective optimization is getting more popular in the design. Using the optimization, it becomes ordinary to get many solutions, such as Pareto solutions, quasi-Pareto solutions, and feasible solutions. The alternative solutions, however, are very difficult to be adopted to practical engineering decision directly. Therefore, to make the decision, proper information about the solutions in a function, parameter and real design space should be provided. In this paper, a new approach for the interpretation of Pareto solutions is proposed based on multidimensional visualization and clustering. The proposed method is applied to a thermal robustness and mass optimization problem of heat pipe shape design for an artificial satellite. The information gleaned from the propose approach can support the engineering decision for the design of artificial satellite heat pipe.

1 Introduction

A multiobjective optimization yields ideally innumerable alternative solutions known as Pareto solutions. There is no any superior one in the solutions because of their definition. However it is a very difficult task to judge Decision-Making (DM) from Pareto solutions. Two kinds of methods are well known to overcome the difficulty. First, preference methods give fixed preferences to objectives before multiobjective optimization, and then find one solution for DM. Second, trade-off methods are used to make DM from Pareto solutions after optimization. However, attempts to support DM with the preference or trade-off may result in poor design characters [1, 2]. That is because the DM using one solution may be inadequate when we include all factors that influence the choice of a particular design, such as durability and manufacturability. Therefore, if the whole set of

C. A. Coello Coello et al. (Eds.): EMO 2005, LNCS 3410, pp. 561–575, 2005.

Pareto solutions are provided to engineers with proper information, they can use this information to choose the best overall design.

Visualization has been one of the most useful tools to guide information of correlations and characters between parameters, functions, and actual design shapes [3]. However, Pareto solutions are normally in a multidimensional space, and deter from extracting the information. To overcome this difficulty, the authors propose a synchronous 3D visualization. In the visualization, a multidimensional parameter and function space is divided into several 2D or 3D subspaces, and visualized in parallel. Each datum corresponds to a line segment between the subspaces and its shape in the real design space at the same time. Therefore, engineers can understand the correlation and effect of each datum in optimized solutions.

Furthermore, it is introduced that a clustering approach which considers a set of Pareto solutions as a group of several distinct clusters. This approach is based on the concept that the solutions consist of obvious characters in their function and parameter space. To measure the similarity and dissimilarity of solutions more essentially, the Euclidean distance and a point symmetry distance[4, 5] are hybrided.

As a practical engineering application, the proposed approach for interpretation of multiobjective solutions is applied to a thermal robustness and mass optimization problem of heat pipe shape for an artificial satellite [6]. Two functions and five parameters are considered in the design optimization. Using the proposed approach, we search for the information that can support engineering decision for the design of artificial satellite heat pipe.

2 Multiobjective Optimization of Artificial Satellite Heat Pipe

For a cooling system of artificial satellite, heat pipes based isothermal radiator panels are generally employed. Fin efficiency is dramatically improved using orthogonal interconnected (matrix layout) heat pipes as shown in Fig. 1. To maximize the fin efficiency of isothermal panels, the minimization of the temperature gradient between the lateral and header heat pipes becomes a very important design object [7]. On the other hand, saving the total mass (weight) of a thermal control subsystem is highly important to reduce load (pay load cost) on a booster-rocket. The satellite panels contain many embedded aluminum heat pipes, which generally occupy over 50% of the total mass of the fundamental radiator panels. Thus the thermal design of artificial satellite requires both the fin efficiency and mass saving of the heat pipes at the same time. Additionally, the operating temperature of the heat pipes is very widely ranging from $-20.0°C$ to $60.0°C$ in orbit. The thermal performance of the heat pipes must be stable in the temperature change. Therefore, the temperature dependency must be also taken into account for the heat pipe design. In this study, a combination of Response Surface Methodology (RSM) and Monte Carlo simulation is applied at first to formulate functions of the mass and thermal performance of the pipe