Abstract

Exploration of Pareto Front for Multi-objective Topology Optimization Problem Using Adaptive Weight and Configuration-based Clustering Scheme

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A topology optimization method is one of effective approaches to find initial configuration of engineering product in the early stage of the design process in that the method has large degree of freedom to find optimum shapes in the design domain compared to other approaches such as size or shape optimization method. Therefore, topology optimization method has been widely used in engineering problem to find innovative design that an engineer cannot easily think about. With the development of computer-aided engineering and design method, multi-physics based analysis and optimization have been increasingly researched. In addition, interest for multi-objective optimization also increases to enhance conflicting performances in a single product at once.

Unlike single objective optimization, a number of so-called Pareto optimum designs, i.e. non-dominated solutions, are found on a Pareto front in case of multi-objective optimization. Therefore, there is an advantage that a designer can understand the range of the optimum performances that can be achieved by optimization. However, time cost for optimization process is too expensive as a lot of solutions are obtained. Moreover, depending on the

multi-objective optimization method, final shape of the Pareto front would be different, and the performance of the optimized designs would be even worse than those obtained by other method. To overcome these limitations, researches have been performed to develop the method to find Pareto front efficiently by reducing the time cost for optimization and to deliver the Pareto optimum solutions to designers effectively so that a lot of solutions can be easily understood.

Multi-objective optimization methods have been developed in three different approaches, and they are weighted-sum method, epsilon-constraint method, and heuristic method. Among these, weighted-sum method has been widely used in engineering problem since it guarantees to find the solutions on the Pareto front unlike other two approaches, and also it is easy to employ. However, there are some limitations on the use of weighted-sum method to find all Pareto optimum solutions according to the shape of the Pareto front. Solutions on the non-convex region of the Pareto front are theoretically unobtainable, and it is not guaranteed for designer to find different optimum solutions on the discontinuous/multi-modal/linear Pareto front. Moreover, since uniform weights do not correspond to the evenly-distributed solutions on the Pareto front, an engineer needs to adjust the values of weights to find different Pareto optimum designs.

Therefore, to overcome the aforementioned limitations of the weighted-sum method, a new multi-objective optimization method is developed by using adaptive weight determination scheme in this work to explore all Pareto optimum solutions regardless of the shape of Pareto front. By considering the geometrical meaning of the weighted-sum method in the objective space, the values of the weights are adaptively updated. To find the evenly-distributed solutions on the Pareto front gradually, proposed approach uses the information of other optimum solutions to determine the values of next weights systematically. The developed algorithm helps decrease the time cost to find solutions on the Pareto front while the engineer does not have to decide any parameters during the optimization process. To find the solutions on the non-convex or linear region of the Pareto front, reference point based compromise programming method is employed to make the objective function nonlinear, and the algorithm to adaptively update the weight for compromise programming method is also developed. Finally, to obtain designs on the discontinuous/multi-modal Pareto front, design space is systematically reduced in the objective space so that all different designs can be explored. To verify the effectiveness of the proposed multi-objective optimization method, it is applied to mathematical benchmark problems and engineering problems considering design of structure and magnetic device, and it is confirmed that the Pareto optimum solutions could be efficiently found compared to other traditional methods in terms of the time cost of the optimization process and performance of the product.

To deliver the Pareto optimum solutions to the designer effectively, it is required to classify many solutions and decide the representative designs to briefly summarize the Pareto front. In this work, configuration-based clustering scheme is developed to distinguish the different optimum designs that are obtained from multi-objective optimization. When a density method is used for topology optimization, a configuration of design is represented by design variables that show the existence and nonexistence of the material. Therefore, to evaluate the similarity of the different designs, distance needs to be measured not only in the objective space but also in the design variable space where the information about configuration is involved. To discern the similarity of the designs, in this work, characteristics of designs are summarized considering the physical meaning such as length of structure, number of closed space and joints, center of mass, and moment of inertia. By using these entities, distance between other designs are measured. If the distance between two designs is small enough, they can be considered as similar designs and classified in same cluster even though the distance in the objective is large. By using the clustering scheme, it would be easy to distinguish the representative designs of the Pareto front by clustering the obtained solutions.

Finally, aforementioned two methods, i.e. multi-objective optimization method with adaptive weight and configuration-based clustering scheme, are combined to explore Pareto front and clustering simultaneously during the optimization process. Final goal of multi-objective topology optimization is to obtain the Pareto front and deliver the representative designs to the designer. Therefore, it would be better to find representative designs during multi-objective optimization rather than obtaining all solutions on the Pareto front at first and summarizing the solutions after finishing the optimization. By performing clustering just after new solutions are obtained, representative designs can be found in early stage of the optimization process, and time cost for total optimization would be reduced.