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An improved adaptive constraint aggregation for integrated layout and topology optimization

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Highlights

- We present an improved adaptive constraint aggregation approach based on the KS function.
- Steffensen iteration is used to obtain better aggregation parameters.
- The improved approach is applied with the finite circle method to avoid the components' overlap in integrated layout and topology optimization design.
- Multi-point constraints (MPC) are applied to establish the interconnections between movable components and supporting structures.
- The improved approach can handle the constraint aggregation and the integrated optimization well.

Abstract

The purpose of this paper is to present a Kreisselmeier–Steinhauser (KS) function based adaptive constraint aggregation approach. It is implemented within the integrated layout and topology optimization of multi-component structure systems to avoid using large numbers of non-overlapping constraints defined by means of the previously proposed finite circle method (FCM). An improved adaptive approach is then put forward to obtain proper aggregation parameters for the KS function based constraint aggregation, contributing to less numerical difficulties while meeting the same aggregation precision compared with the existing adaptive approach. Furthermore, the complex step derivative approximation is utilized to yield better sensitivities for the aggregated constraint functions with high nonlinearity. Moreover, during the integrated layout and topology optimization, multi-point constraints (MPC) are applied to establish the interconnections between movable components and supporting structures, which can use fixed finite element meshes and analytical sensitivities. Finally, some numerical examples are tested to demonstrate the validity and effectiveness of the proposed formulation.

Keywords: Multi-component systems; Topology optimization; Constraint aggregation; KS function; Multi-point constraints; Complex step derivative approximation

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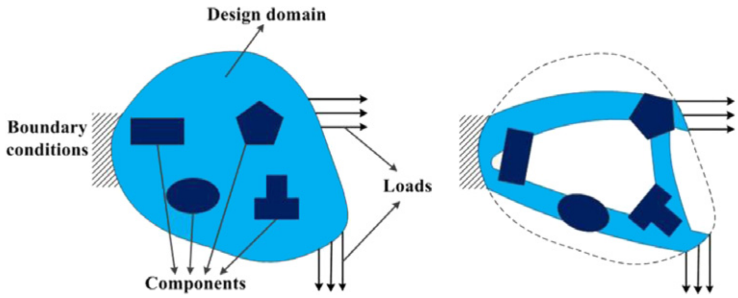

(a) Problem definition. (b) Optimized design.

Fig. 1. Illustration of integrated layout and topology optimization of multi-component systems.

1. Introduction

Topology optimization has been recognized as an effective approach to figure out the structure layout during the conceptual design phase since the homogenization based method was firstly proposed [1]. Different schemes including pseudo-density based methods, evolutionary methods and level-set methods were successively established [2–5]. Up until now, the idea of topology optimization has received much success in both theoretical study and practical applications [6–11], where optimization designs of multi-component structure systems were among the most challenging efforts. For example, in the early works [12], separated structural parts were considered as numbers of components designated as different design domains. A simultaneous design approach was developed to optimize the structural patterns of several components and locations of interconnections using density based topology optimization method. Similar implementations were also noted in some other previous works [13,14].

Another case of multi-component structure system commonly exists in the design of aeronautics and astronautics systems, where many functional components are assembled in some finite domains with supporting structures. Take a multi-satellite structure system design for example. The satellites' locations and the corresponding supporting structures are the critical determinants of structural mechanical performances. The idea was to carry out the topology optimization with movable solid or void components to obtain proper layout of components and structures simultaneously, which was mentioned as the integrated layout and topology optimization [15,16] as illustrated in Fig. 1.

During the optimization procedure, it is essentially important to avoid the geometry overlapping of different components, or components and design domain boundaries. Varieties of component shapes and design domain boundaries will lead to high nonlinearity and even discontinuity of the non-overlapping constraint functions. To solve this problem, different CAD modeling techniques such as octrees [17,18], sphere trees [19] and S-bounds based trees [20] have been proposed to detect the object collisions. These techniques approximated the components with various levels of small cubes or spheres and refined the model partition iteratively. However, they were confined to detect rather than evaluate the overlap. As a result, more necessary information could not be provided to find the searching directions and verify the attainment of optimum.

Later, the finite circle method (FCM) [21,22] and level-set based non-overlapping constraints [23,24] were therefore proposed to obtain the sensitivities of the collision. In FCM, contours of the components were approximately described using enormous numbers of circles. Feasible designs could be attained by controlling the distances between the circles. This method could provide effective sensitivity information to avoid the overlap in any case and had a rather simple analytical expression. In the level-set based method, the overlapping area of two components was calculated by the integral operation and constrained to zero, guaranteeing the two components would not overlap.

FCM proved effective in integrated layout and topology optimization but suffered from the tremendous numbers of constraints and considerable computing time due to the circles used for geometry approximation. As a result, it was necessary to use different constraint aggregation strategies, e.g. P-norm function and KS function, which have been popularly used for stress constraint problems [25–28] to improve the optimization efficiency. An essential issue of applying these functions was how to choose proper aggregation parameters. Constant aggregation parameters may not meet the demand for good aggregation performance in different iterations. Therefore, an adaptive approach was made to obtain proper aggregation parameters [29,30]. In these works, the first derivative of KS function w.r.t. the aggregation parameter was used as the aggregation performance index. By setting a lesser threshold for the first derivative, the