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On Solving Large-Scale Free Material Optimization

Alemseged Gebrehiwot Weldeyesus[1], Mathias Stope[1]

[1]Technical University of Denmark, Denmark

Abstract

Free Material Optimization (FMO) deals with determining the optimal material distribution and the optimal local material properties of load carrying structures. The design variable is the entire elastic material tensor with the only requirement that it has to be symmetric and positive semidefinite, otherwise only mildly restricted, at each point of the design domain. FMO thus obtains ultimately best conceptual optimal designs that can be used as benchmarks for other models or to propose new design concepts. The use of fine finite element discretization is crucial in solving FMO problems to get a useful solution defining precisely the optimal local properties of the material. Moreover, the variables in the optimization problems are the independent entries of the material tensor at each finite element. This combination leads FMO problems to be in general large-scale problems that are modeled as nonlinear semidefinite programming, a class of optimization problems involving matrix inequalities. For their size and nature these problem formulations are usually efficiently solved by special purpose optimization methods that can utilize the sparsity resulting from the many matrix inequalities where each matrix inequality involves a small sized matrix. Unlike most first-order based methods that have been used so far we use a second-order primal-dual interior point method developed by combining solution techniques to the standard nonlinear optimization problems and linear semidefinite programming. The method robustly obtains solution of high accuracy to large-scale FMO problems within modest number of iterations that almost does not grow with an increase in the size of the problems. The method and its efficiency are demonstrated by solving set of large-scale FMO problems of simultaneous analysis and design, nested and dual formulations. We report solutions to the largest standard FMO problems to date.