Mathematical programming methods for large-scale topology optimization problems

This thesis investigates new optimization methods for structural topology optimization problems. The aim of topology optimization is finding the optimal design of a structure. The physical problem is modelled as a nonlinear optimization problem. This powerful tool was initially developed for mechanical problems, but has rapidly extended to many other disciplines, such as fluid dynamics and biomechanical problems. However, the novelty and improvements of optimization methods has been very limited. It is, indeed, necessary to develop new optimization methods to improve the final designs, and at the same time, reduce the number of function evaluations. Nonlinear optimization methods, such as sequential quadratic programming and interior point solvers, have almost not been embraced by the topology optimization community. Thus, this work is focused on the introduction of this kind of second-order solvers to drive the field forward.

The first part of the thesis introduces, for the first time, an extensive benchmarking study of different optimization methods in structural topology optimization. This comparison uses a large test set of instance problems and three different structural topology optimization problems. The thesis additionally investigates, based on the continuation approach, an alternative formulation of the problem to reduce the chances of ending in local minima, and at the same time, decrease the number of iterations. The last part is focused on special purpose methods for the classical minimum compliance problem.

Two of the state-of-the-art optimization algorithms are investigated and implemented for this structural topology optimization problem. A Sequential Quadratic Programming (TopSQP) and an interior point method (TopIP) are developed exploiting the specific mathematical structure of the problem. In both solvers, information of the exact Hessian is considered. A robust iterative method is implemented to efficiently solve large-scale linear systems. Both TopSQP and TopIP have successful results in terms of convergence, number of iterations, and objective function values. Thanks to the use of the iterative method implemented, TopIP is able to solve large-scale problems with more than three millions degrees of freedom.

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