On Regularized Node-Based Shape Optimization

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One reason why node-based structural shape optimization problems cannot be solved numerically is that the shape change from the initial shape to the optimized shape may be very large and not realizable with the given finite element mesh. This led to the idea to restrict the shape change. To accomplish this task, a special inequality constraint based on a fictitious elastic strain energy has been developed.

In a node-based structural shape optimization problem, the finite element mesh has two functions:

1. the mesh is the basis for the finite element analysis of the state problem and the basis for the computation of all discretized functionals defining the shape optimization problem (the objective functional and the functionals of the constraints),
2. the mesh is a geometry model that provides the node coordinates as design variables, which allow to modify the shape of the (discretized) structure.

The structural shape optimization problems considered in this work are based on linear elastostatic state problems; the objective function is either the (discretized) compliance or the (discretized) volume of a structure. Without an adequate regularization, solving the considered node-based structural shape optimization problems with gradient-based optimization algorithms fails; that is, an optimized structure that fulfills the first-order necessary conditions cannot be determined. To make node-based shape optimization problems solvable, we had the idea to restrict the shape change using a so called energy constraint.

The energy constraint is an inequality constraint that limits a discretized fictitious strain energy. The fictitious strain energy is a functional that is defined in analogy to mechanical strain energy. The size of the feasible set defined by the energy constraint is controlled by the upper energy limit; the larger the energy limit is chosen the larger is the feasible set and the admissible shape change. Apart from the energy constraint, no further regularization techniques are applied; node-based shape optimization problems subject to the energy constraint can be solved with gradient-based optimization algorithms for problems with inequality constraints. The obtained optimized structures have smooth boundaries. Since the energy constraint is based on a functional, a regularized node-based shape optimization problem is the discretized version of a corresponding continuous problem. Numerical examples show that the solutions of a regularized shape optimization problem converge upon mesh refinement.

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