Smooth topology optimization results using continuous density functions

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Abstract

Topology optimization involves computing the optimal distribution of material for optimizing an objective function. Over the years many different approaches have been developed that differ in methods for shape and topology representation, material characterization, and sensitivity computation or optimization methodology. Traditional approaches like homogenization method and SIMP assume the porosity or density of the material to be constant within each element. This eliminates the possibility of extracting smooth continuous contours of the density as the boundary. Similarly other methods such as genetic algorithms and evolutionary approaches assume that elements are either on or off which only permits stair-stepping boundaries. The desire to define smooth boundaries is met when the density is interpolated or approximated using nodal values, as has been done in several recent works. This permits continuous contours to be extracted and defined as the boundary. These boundaries pass through the background mesh generated on the feasible region. Accurate analysis is possible using mesh independent analysis techniques developed in the recent past. However, piece wise linear interpolations do not necessarily lead to smooth and well-connected regions. It still suffers from the many problems faced by other methods such as islanding and wavy boundaries. We are studying two different approaches to overcome this issue. Firstly, the use of higher order elements permits the density to be defined as a tangent and curvature continuous function. B-spline based approximations have a larger support that extends over several neighboring elements than traditional Lagrange interpolation. This has a natural smoothing effect that suppresses islanding and provides limited control over the length scales of the resultant geometry. Another fundamentally different approach for ensuring smooth optimal shapes is to add a penalty for non-smooth shapes into the objective function. The advantage of this approach is that one can get smooth shapes without using higher order elements and incurring the associated costs. However, the weighting needed for the penalty is difficult to estimate and often requires multiple attempts to fine tune. The paper will present a comparison between these two approaches for obtaining smooth shapes as optimal results. Techniques for automatically estimating smoothing penalty factors will be presented. In addition, reasons for non-convexity, mesh dependence and non-uniqueness of solution in traditional approaches will be explored and the benefits of smooth density function requirement in overcoming these issues will be discussed. The applicability of these techniques to many traditional objective functions will be studied including compliance minimization, mass minimization with stress constraints and the design of mechanisms.