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Robust shape and topology optimization using CutFEM

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Abstract In this work we present a parametric level set method for shape and topology optimization based on a density type design representation and the CutFEM method (Hansbo & Hansbo, 2004). The CutFEM method introduce a crisp boundary representation and ensures a strict partitioning of solid and void regions on a fixed background mesh. However, the special integration scheme adopted here does have some drawbacks concerning artificially high stiffness in slender notches. This artifact can, and will, be exploited by the optimization procedure and hence must be remedied. In order to alleviate this problem we propose a robust formulation based on the, by now, classical robust formulation which is directly adopted from its density based methods counterpart. This is possible since the underlying parametric level-set field is treated exactly as done in density methods, using the same convolution and smoothed Heaviside filters. This allows us to introduce and ensure a certain length scale in the optimized design, which is achieved by imposing the volume constraint on the dilated design, whereas the compliance is computed only for the eroded design for minimum compliance problems. We remark that, in this case, no extra constraints are introduced as done in e.g. Jansen(2018), which additionally allows us to perform the simulation and optimization on much coarser meshes.

The combined shape and topology optimization procedure is implemented in Matlab/MEX using mathematical programming for the shape update and a heuristic scheme for the topology update. That is, we compute the design sensitivities for the shape optimization only for the cut elements using the semi-analytical adjoint method. The level-set is then updated using the Method of Moving Asymptotes. Although the shape optimization approach allows for holes to close, it cannot nucleate holes in the interior of structure. That is, new holes can only form by evolving from the design boundary, which is a situation very unlikely to occur for most topology optimization problems. It is also well-known that pure shape optimization is extremely sensitive to the choice of initial configuration. To alleviate this severe drawback, we introduce a hole-nucleation scheme that enables the optimizer to start from a full material design without holes. The heuristic hole-nucleation is, for the minimum compliance example in Fig. 1, based on the strain energy density computed in the solid elements, which for the simple case of static compliance is nothing more than a scaled topological derivative.

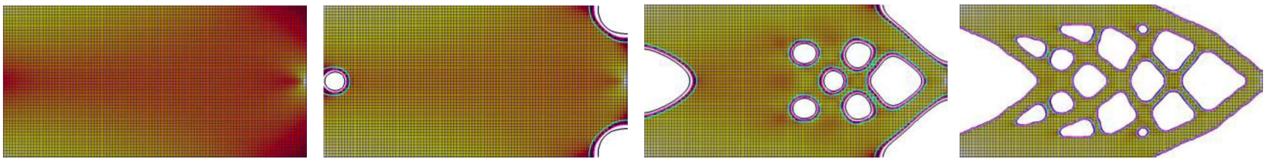

Figure 1: Example of a cantilever optimized for minimum compliance subject to a 50% volume constraint using the hole-nucleation scheme. The figures show design iteration 1, 14, 38, 200 and are colored by the strain energy density. The black, magenta and cyan lines correspond to the dilated, blueprint and eroded designs, respectively.

The designs seen in Fig. 1 shows four snapshots of the design evolution and demonstrates how the design evolves from a solid structure to an optimized structure meeting the volume constraint while maintaining the prescribed length scale on the solid. The proposed density based level-set optimization method has also been extended to compliant mechanism design problems.

References

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