

LEVEL SET TOPOLOGY OPTIMIZATION OF HYPERELASTIC STRUCTURES VIA THE CUT ELEMENT METHOD

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Abstract

Most topology optimization problems focus on linearly elastic materials subjected to small deformations, which is appropriate for conventional engineering materials such as steel or concrete. In contrast, many emerging applications, including soft robotics and compliant mechanisms, rely on materials that experience large deformations. In these cases, both geometric and material nonlinearities play a fundamental role in the structural response. This work presents a topology optimization approach for compliance minimization in structures composed of hyperelastic materials undergoing finite strains. The mechanical behavior is described using a Neo-Hookean constitutive model, which captures the nonlinear stress-strain response typical of elastomeric materials. The structural topology is represented using a level set method, enabling a continuous and sharp description of the evolving material boundary during the optimization process. To accurately capture the geometry of the structural boundary while maintaining a fixed background mesh, the formulation employs the cut element method. In this immersed boundary technique, elements intersected by the zero-level set interface are locally triangulated and numerically integrated only over the portion occupied by material. This procedure enables an accurate representation of sharp interfaces between solid and void regions without requiring remeshing, while preserving the advantages of structured meshes. In this framework, the level set-cut element approach naturally eliminates the need for artificial material interpolation laws. In addition, regularization techniques are employed to accommodate large compressive deformation in void regions. The nodal values of the level set function are explicitly parameterized by the design variables, and a consistent sensitivity analysis is performed with respect to these variables. The resulting nonlinear optimization problem is solved using the standard gradient-based Method of Moving Asymptotes (MMA). The main novelty of this work is the extension of the level set-cut element topology optimization framework, originally developed for linear elasticity, to compliance minimization problems involving hyperelastic materials and finite strain nonlinearities. The proposed method is demonstrated through two-

dimensional benchmark problems under finite strain, showing that the approach can generate optimized topologies while accurately capturing both geometric and material nonlinearities.