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Multi-material continuum topology optimization with arbitrary volume and mass constraints

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Abstract

A framework is presented for multi-material compliance minimization in the context of continuum based topology optimization. We adopt the common approach of finding an optimal shape by solving a series of explicit convex (linear) approximations to the volume constrained compliance minimization problem. The dual objective associated with the linearized subproblems is a separable function of the Lagrange multipliers and thus, the update of each design variable is dependent only on the Lagrange multiplier of its associated volume constraint. By tailoring the ZPR design variable update scheme to the continuum setting, each volume constraint is updated independently, in series or in parallel. This formulation leads to a setting in which sufficiently general volume/mass constraints can be specified, i.e., each volume/mass constraint can control either all or a subset of the candidate materials and can control either the entire domain (global constraints) or a sub-region of the domain (local constraints). Material interpolation schemes are investigated and coupled with the presented approach. The key ideas presented herein are demonstrated through representative examples in 2D and 3D.

Keywords: topology optimization; multi-material; volume constraints; mass constraints; ZPR update; additive manufacturing

1 Introduction

The multi-material, volume-constrained, compliance minimization problem considered here is stated (in discretized form) as:

$$\begin{aligned}
\min_{\mathbf{x}_1,\ldots,\mathbf{x}_m} \quad & J = \mathbf{f}^T \mathbf{u}\left(\mathbf{x}_1,\ldots,\mathbf{x}_m\right) \\
\text{s.t.} \quad & g_j = \sum_{i\in\mathcal{G}_j} \sum_{e\in\mathcal{E}_j} z_i^e(x_i^k) V^e \leq V_j^{max}, \qquad j = 1,\ldots,N_c \\
& 0 \leq x_i^k \leq 1, \qquad i = 1,\ldots,m; \;\; k = 1,\ldots,M_i \\
\text{with} \quad & \mathbf{K}\left(\mathbf{x}_1,\ldots,\mathbf{x}_m\right)\mathbf{u}\left(\mathbf{x}_1,\ldots,\mathbf{x}_m\right) = \mathbf{f}
\end{aligned} \tag{1}$$

where $\mathbf{x}_1,\ldots,\mathbf{x}_m$ represent m density fields defined at M_i control points in the problem domain for each of the m candidate materials, J is the structural compliance, g_j are the volume constraints, $\mathcal{G}_j$ is the set of material indices associated with constraint j, $\mathcal{E}_j$ is the set of finite element indices associated with constraint j, z_i^e is the density of material i in finite element e, V^e is the volume of finite element e, V_j^{max} is the material volume limit corresponding to constraint j, N_c is the total number of volume constraints, and $\mathbf{K}$, $\mathbf{u}$, and $\mathbf{f}$ are the stiffness matrix, displacement vector, and force vector, respectively, of the associated elastostatics problem that has been discretized into finite elements.