Isogeometric shape optimization of nonlinear, curved 3D beams and beam structures

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ABSTRACT

Straight beams, rods and trusses are common elements in structural and mechanical engineering, but recent advances in additive manufacturing now also enable efficient freeform fabrication of curved, deformable beams and beam structures, such as microstructures, metamaterials and conformal lattices. To exploit this new design freedom for applications with nonlinear mechanical behavior, we introduce an isogeometric method for shape optimization of curved 3D beams and beam structures [1]. The geometrically exact 3D beam theory is used to model nonlinear 3D beams subject to large deformations and rotations. The initial and current geometry are parameterized in terms of NURBS curves describing the beam centerline and an isogeometric collocation approach is used to discretize the strong form of the balance equations [2]. Then, a nonlinear optimization problem is formulated in order to optimize the positions of the control points of the NURBS curve that describes the beam centerline, i.e., the geometry or shape of the beam. To solve the design problem using gradient-based algorithms, we introduce semi-analytical, inconsistent analytical and fully analytical approaches for calculation of design sensitivities. The methods are numerically validated and their performance is investigated, before the applicability and versatility of our 3D beam shape optimization method is illustrated in various numerical applications, including optimization of an auxetic 3D metamaterial.

REFERENCES

[1] O. Weeger, B. Narayanan, M. L. Dunn, "Isogeometric shape optimization of nonlinear, curved 3D beams and beam structures", *Comput. Methods Appl. Mech. Eng.,* Vol. **345**, pp. 26–51 (2019)

[2] O. Weeger, S.-K. Yeung, M. L. Dunn, "Isogeometric collocation methods for Cosserat rods and rod structures", *Comput. Methods Appl. Mech. Eng.*, Vol. **316**, pp. 100–122 (2017)