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An isogeometric collocation method for frictionless contact of Cosserat rods

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Abstract

A frictionless contact formulation for spatial rods is developed within the framework of isogeometric collocation. The structural mechanics is described by the Cosserat theory of geometrically nonlinear spatial rods. The numerical discretization is based on an isogeometric collocation method, where the geometry and solution fields are represented as NURBS curves and the strong forms of the equilibrium equations are collocated at Greville points. In this framework, a frictionless rod-to-rod contact formulation is proposed. Contact points are detected by a coarse-level and a refined search for close centerline points and reaction forces are computed by the actual penetration of rod surface points, so that the enforcement of the contact constraints is performed with the penalty method. An important aspect is the application of contact penalty forces as point loads within the collocation scheme, and methods for this purpose are proposed and evaluated. The overall contact algorithm is validated by and applied to several numerical examples.

Keywords: Isogeometric analysis, Collocation method, Contact formulation, Nonlinear rods

1. Introduction

Mechanical simulation of 3D beams, rods and structures undergoing large deformations has a wide range of applications in modern product development and design processes. For complex applications, such as the simulation of yarns [1], woven and knitted textiles [2], fibrous materials [3], hair, cables [4], pipings or additively manufactured structures [5], the capability to simulate rod-to-rod contact is essential. In this paper, we present an isogeometric collocation method for contact simulation of geometrically nonlinear spatial rods, which exploits the advantages of isogeometric collocation methods, i.e. numerical accuracy and efficiency, as well as integration into computer-aided design, for these applications.

Isogeometric analysis (IGA), first proposed in [6], has gained significant popularity in practically all fields of computational mechanics, in particular in structural mechanics where many new formulations for beam, plate, and shell analysis have been proposed. IGA for beams was first explored in [7] with the study of Bernoulli-Euler beam vibrations. Later, IGA of nonlinear Bernoulli-Euler beam vibrations was presented in [8]. The first isogeometric implementation for fully 3D Kirchhoff rods was reported in [9], and [10] developed a geometrically nonlinear formulation. All of the above works were based on the so-called thin beam theories, where shear deformation is neglected. Locking-free isogeometric formulations for curved thick beams were presented in [11], whereas in [12] a formulation for shear-deformable beams with only one unknown variable was proposed. Recently, object-oriented C++ libraries for the implementation of isogeometric methods have been introduced with *igatools* [13] and *G+SMo* [14], the latter being also the foundation of the implementation in this paper.

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