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Isogeometric collocation for large deformation elasticity and frictional contact problems

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Abstract

Isogeometric collocation methods have been recently proposed as an alternative to standard Galerkin approaches as they provide a significant reduction in computational cost for higher-order discretizations. In this work, we explore the application of isogeometric collocation to large deformation elasticity and frictional contact problems. We first derive the non-linear governing equations for the elasticity problem with finite deformation kinematics and provide details on their consistent linearization. Some numerical examples demonstrate the performance of collocation in its basic and enhanced versions, differing by the enforcement of Neumann boundary conditions. For problems with strong singularities, enhanced collocation is shown to outperform basic collocation and to lead to a spatial convergence behavior very similar to Galerkin, whereas for weaker or no singularities enhanced and basic collocation may give very similar results. A large deformation contact formulation is subsequently developed and tested in the frictional setting, where collocation confirms the excellent performance already obtained for the frictionless case. Finally, it is shown that the contact formulation in the collocation framework passes the contact patch test to machine precision in a three-dimensional setting with arbitrarily inclined non-matching discretizations, thus outperforming most of the available contact formulations and all those with pointwise enforcement of the contact constraints.

Keywords: Isogeometric analysis, Collocation method, Large deformation elasticity, Frictional contact

1. Introduction

Isogeometric analysis (IGA) was introduced in [1] with the original objective to tightly integrate computer aided design (CAD) and finite element analysis (FEA). To define geometric entities, CAD makes wide use of non-uniform rational B-splines (NURBS), due to their geometric precision and free-form modeling capability. Using the same functions as basis functions in the FEA setting greatly simplifies mesh generation and results in an exact reproduction of the initial CAD geometry within the realm of analysis. Apart from geometric exactness, IGA has proved in the past ten years to provide remarkable additional advantages compared to conventional (C^0 continuous) Lagrangian shape functions, mostly stemming from the higher and tailorable continuity of the basis functions. In addition to NURBS, other functions (either emanating from CAD or not) have been introduced to allow for local refinement, most notably T-Splines [2, 3, 4], polynomial splines over hierarchical T-meshes [5, 6, 7], and hierarchical B-splines/NURBS [8, 9].

A still open issue when using higher-order isogeometric basis functions is how to reduce the computational cost in the generation and assembly of the stiffness matrix for Galerkin methods [10]. Several quadrature strategies have been proposed to exploit the continuity of the basis functions for a reduction in the number of the integration points, see e.g. [11]. An extreme answer to the quest for efficient quadrature schemes recently led to the proposal of the so-called isogeometric collocation (IGA-C) method, where quadrature is eliminated completely [12]. In this method, the strong form of the governing differential equations of the problem at hand is enforced at a set of discrete collocation points, equal in number to the control points. IGA-C has been demonstrated to lead to substantial cost advantages at high orders of the discretization [10].

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