Application of Isogeometric Analysis for Interval Analysis

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Abstract

Geometrical uncertainty poses a significant challenge in manufacturing processes, often attributed to the underlying manufacturing technology and operating conditions. When combined with geometric complexity, this phenomenon can result in substantial disparities between numerical predictions and the actual behavior of mechanical systems. The underlying cause lies in the initial design phase, where insufficient information impedes the development of robust numerical models due to epistemic uncertainty in system dimensions. In such cases, set-based methods, like intervals, prove useful for characterizing these uncertainties by employing lower and upper bounds to define uncertain input parameters. Nevertheless, employing interval methods for treating geometric uncertainties can become computationally demanding, especially when traditional methods like finite element (FE) are utilized to represent the system and propagate uncertainty. This is due to the necessity of performing iterative analyses for different realizations of geometry within the bounds of uncertain parameters, requiring the repeated execution of the meshing process and thereby escalating the numerical effort. In this work, the potential of Isogeometric Analysis (IGA) for quantifying geometric uncertainties characterized by intervals is explored. IGA utilizes the same basis functions, Non-Uniform Rational B-Splines (NURBS), employed in Computer-Aided Design (CAD) to approximate solution fields in numerical analysis. This integration enhances the accurate description of complex shapes and interfaces while maintaining geometric fidelity throughout the simulation process. The primary advantage of employing IGA for uncertainty quantification lies in its ability to control the system's geometry through the position of control points, which define the shape of NURBS. Consequently, alterations in the model's geometry can be achieved by varying the position of these control points, thereby bypassing the numerical costs associated with uncertainty quantification using intervals. To propagate geometric uncertainties, a gradient-based optimization algorithm is applied to determine the lower and upper bounds of the system response. The corresponding sensitivities are computed from the IGA model. A case study involving a linear hook system with two uncertain geometric parameters demonstrates that the proposed strategy accurately estimates uncertain stress triaxiality.

Keywords: Isogeometric analysis (IGA), Uncertainty quantification, Geometrical uncertainty, Interval analysis, Stress Triaxiality.
