

## Quantification of Geometric Uncertainty using Isogeometric Analysis and Interval Methods

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Geometric uncertainty presents a significant challenge in engineering fields such as structural design and manufacturing, often due to variations in production methods and operating conditions. When combined with geometric complexity, these uncertainties can lead to significant discrepancies between numerical predictions and real system behavior. In early design phases, limited information often results in epistemic uncertainty, making robust numerical modeling difficult. Set-based methods, such as interval analysis, address these uncertainties by defining parameters with lower and upper bounds, see e.g. [1]. However, traditional approaches like finite element analysis (FEA) face computational limitations due to the need for iterative analyses and repeated remeshing, which disrupts optimization continuity and increases computational costs.

This work explores Isogeometric Analysis (IGA), cf. e.g. [2], for quantifying geometric uncertainties defined by intervals, while exploiting variational design sensitivity analysis (VDSA) for the derivation of gradient information, cf. e.g. [3]. IGA employs Non-Uniform Rational B-Splines (NURBS) to approximate solution fields, offering precise geometric representations without remeshing. By manipulating NURBS control points, the model geometry can be adjusted directly, significantly reducing computational demands. A gradient-based optimization (GBO) algorithm propagates uncertainties, determining system response bounds through sensitivity analysis derived from the IGA model. Case studies demonstrate the accuracy of the approach in estimating uncertain stress triaxiality for linear systems.

**Key Words:** *Shape optimization, Sensitivity Analysis, Isogeometric Analysis, Interval methods*

### REFERENCES

- [1] M. Faes, M. Broggi, E. Patelli, Y. Govers, J. Mottershead, M. Beer, D. Moens, A multivariate interval approach for inverse uncertainty quantification with limited experimental data, *Mechanical Systems and Signal Processing* 118 (2019) 534–548. doi:10.1016/j.ymssp.2018.08.050.
- [2] T. Hughes, J. Cottrell, Y. Bazilevs, Isogeometric analysis: Cad, finite elements, nurbs, exact geometry and mesh refinement, *Computer Methods in Applied Mechanics and Engineering* 194 (39–41) (2005) 4135–4195. doi:10.1016/j.cma.2004.10.008.
- [3] F.-J. Barthold, A short guide to variational design sensitivity analysis, in: *6th World Congress on Structural and Multidisciplinary Optimization*, 2005.