Rethinking the Engineering Design Task: Tolerance Optimization via Adaptive Learning and Semi-Infinite Programming

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This work presents a unified framework for robust design and tolerance optimization that integrates adaptive learning techniques with semi-infinite programming to address complex engineering design tasks involving parametric uncertainties and manufacturing tolerances. A novel formulation of robust optimization is introduced, which generalizes existing approaches by identifying the largest feasible tolerance set within a design space defined by black-box performance measures. The feasibility of these tolerance sets is evaluated using Gaussian process (GP) models, which are iteratively refined during the optimization process. New candidate designs are selected through constrained optimization, leveraging semi-infinite programming to efficiently explore the design space [4].

In contrast to the state-of-the art nominal design optimization, which aims at finding an isolated point, the tolerance optimization method accounts for the production tolerances, aging or wear, which can lead to significant variations from the nominal design and costly rejects [1, 3, 6, 2]. The presented GP-based adaptive learning approach enables the direct solution of the associated semi-infinite programs, enhancing sample efficiency and avoiding multi-stage problems in tolerance optimization.

The proposed method is applied to two distinct engineering problems. First, it is employed for the automatic tuning of nonlinear model-predictive controllers under parametric uncertainty, demonstrating superior performance compared to expert manual tuning. Second, the framework is employed to the simultaneous optimization of the nominal design and manufacturing tolerances for a proportional electromagnetic actuator. The goal is to ensure consistent force characteristics across all tolerance combinations while minimizing the number of finite element method (FEM) simulations.

A comparison to the state-of-the-art tolerance optimization reveals that the simultaneous optimization of nominal values and tolerances yields feasible designs with reasonable computational overhead, whereas separate optimization of the nominal values and the tolerances often leads to specification violations. Overall, this research highlights the effectiveness of combining learning-based models with semi-infinite programming for robust and efficient design optimization under uncertainty [5].

Literatur

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