

STOCHASTIC OPTIMAL CONTROL UNDER PARAMETRIC UNCERTAINTY USING A PDD-NARX SURROGATE MODEL

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Abstract

Multibody dynamical systems inherently contain parametric uncertainties due to manufacturing tolerances, component wear, and variations in physical properties. The system response thus characterized by a trajectory distribution. To meet safety and performance requirements, quantitative analysis of these response distributions and the optimal control strategies to reduce their variability are required. In this work, we present a novel stochastic model predictive control (SMPC) method that uses a polynomial dimensional decomposition – nonlinear autoregressive with exogenous input (PDD-NARX) model in a multi-input multi-output (MIMO) structure. The PDD-NARX model efficiently approximates dynamical systems using a few training samples, enabling computationally efficient propagation of parametric uncertainty over time. Using the developed surrogate model, we formulate actuator optimal control problem that minimizes both sprung mass displacement and its distribution under pothole road excitation for a quarter-car suspension system with parametric uncertainties. A multi-scenario SMPC framework is designed in which the cost function simultaneously penalizes the mean and variance of the response. The results show that the proposed approach significantly reduces the integral of the variance by 47%, and the peak standard deviation decreased by about 26.62%, indicating improved robustness against parametric uncertainty. Compared with an SMPC implementation that directly uses the original ODE model for system propagation, the proposed PDD-NARX-based SMPC reduces computational time by approximately 57.2%.