

Materials Science & Engineering Thesis Defense

Affine Abstraction of Nonlinear Systems with Applications to Active Model Discrimination

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abstract

This work considers the design of separating input signals in order to discriminate among a finite number of uncertain nonlinear models. Each nonlinear model corresponds to a system operating mode, unobserved intents of other drivers or robots, or to fault types or attack strategies, etc., and the separating inputs are designed such that the output trajectories of all the nonlinear models are guaranteed to be distinguishable from each other under any realization of uncertainties in the initial condition, model discrepancies or noise. We propose a two-step approach. First, using an optimization-based approach, we over-approximate nonlinear dynamics by uncertain affine models, as abstractions that preserve all its system behaviors such that any discrimination guarantees for the affine abstraction also hold for the original nonlinear system. Then, we propose a novel solution in the form of a mixed-integer linear program (MILP) to the active model discrimination problem for uncertain affine models, which includes the affine abstraction and thus, the nonlinear models. Finally, we demonstrate the effectiveness of our approach for identifying the intention of other vehicles in a highway lane changing scenario.

For the abstraction, we explore two approaches. In the first approach, we construct the bounding planes using a Mixed-Integer Nonlinear Problem (MINLP) formulation of the given system with appropriately designed constraints. For the second approach, we solve a linear programming (LP) problem that over-approximates the nonlinear function at only the grid points of a mesh with a given resolution and then accounting for the entire domain via an appropriate correction term. To achieve a desired approximation accuracy, we also iteratively subdivide the domain into subregions. Our method applies to nonlinear functions with different degrees of smoothness, including Lipschitz continuous functions, and improves on existing approaches by enabling the use of tighter bounds. Finally, we compare the effectiveness of our approach with existing optimization-based methods in simulation and illustrate its applicability for estimator design.