Mechanical Engineering Doctoral Defense

Set Membership Overapproximation of Hybrid Systems with Applications to Analysis and Estimator/Controller Design

School for Engineering of Matter, Transport and Energy

Syed Muhammad Hassaan

Advisor: Sze Zheng Yong

Abstract

The introduction of assistive/autonomous features in cyber-physical systems, e.g., self-driving vehicles, have paved the way to a relatively new field of system analysis for safety-critical applications, along with the topic of controlling systems with performance and safety guarantees. The different works in this thesis explore and design methodologies that focus on the analysis of nonlinear dynamical systems via set-membership approximations, as well as the development of controllers and estimators that can give worst-case performance guarantees, especially when the sensor data containing information on system outputs is prone to data drops and delays.

For analyzing the distinguishability of nonlinear systems, building upon the idea of set membership over-approximation of the nonlinear systems, a novel optimization-based method for multi-model affine abstraction (i.e., simultaneous set-membership over-approximation of multiple models) is designed. This work solves for the existence of set-membership over-approximations of a pair of different nonlinear models such that the different systems can be distinguished/discriminated within a guaranteed detection time under worst-case uncertainties and approximation errors. Specifically, by combining mesh-based affine abstraction methods with T-distinguishability analysis in the literature yields a bilevel bilinear optimization problem, whereby leveraging robust optimization techniques and a suitable change of variables result in a sufficient linear program that can obtain a tractable solution with T-distinguishability guarantees.

Moreover, the thesis studied the designs of controllers and estimators with performance guarantees, and specifically, path-dependent feedback controllers and bounded-error estimators for time-varying affine systems are proposed that are subject to delayed observations or missing data. To model the delayed/missing data, two approaches are explored; a fixed-length language and an automaton-based model. Furthermore, controllers/estimators that satisfy the equalized recovery property (a weaker form of invariance with time-varying finite bounds) are synthesized whose feedback gains can be adapted based on the observed path, i.e., the history of observed data patterns up to the latest available time step.

Finally, a robust kinodynamic motion planning algorithm is also developed with collision avoidance and probabilistic completeness guarantees. In particular, methods based on fixed and flexible invariant tubes are designed such that the planned motion/trajectories can reject bounded disturbances using noisy observations.

April 10, 2023; 9 AM; ECG G218;

Zoom Link: https://asu.zoom.us/j/86261341369?pwd=cWJrclg3Vlg3NER5bFNHbHBUVzdvUT09

Passcode: 116677