SIDRA Ph.D. School 2017

Formal Methods for the Control of Large-scale Networked Nonlinear Systems with Logic Specifications

July 3-5, 2017

Coordinators:

- Maria Domenica Di Benedetto
- Giordano Pola

Speakers:

- Alessandro Borri
- Maria Domenica Di Benedetto
- Pierdomenico Pepe
- Giordano Pola

School Objectives

The primary objective of the course is to provide the students with advanced tools to address complex control problems for large-scale networked nonlinear systems with logic specifications.

We will consider a general framework where the plant to be controlled is distributed over the space. Each sub-system composing the plant is modelled as a nonlinear control system possibly subject to external disturbances and time-varying delays in the state. Non-idealities in the communication infrastructure conveying information from one sub-system to another, such as quantization, time-varying delays, limited bandwidth etc., are also considered.

We will consider a decentralized control architecture, meaning that each subsystem composing the plant is controlled through a local controller and local controllers are not allowed to communicate. Local controllers are assumed to be digital and quantized, as it is in modern engineering control applications where physical processes interact with software and hardware at the implementation level.

The logic specifications considered in this course can be formalized through regular languages over an alphabet in the state space of the spatially distributed plant. Regular languages, traditionally studied in the discrete-event systems research community, provide the means to model a rather wide variety of complex control specifications, such as for example safety, reachability, obstacle avoidance and motion planning, periodic orbits, state-based switching, as well as specifications involving sequences of smaller tasks that need to be performed according to a given order.

The theoretical tools needed to solve our control problem are based on advanced notions of stability for nonlinear and time-delay systems and advanced notions in formal methods. Regarding stability, we will review the notions of forward completeness, global asymptotic stability and input-to-state stability, and their incremental versions, for the class of nonlinear control systems; extensions of these notions to time-delay systems will be also presented. Regarding formal methods, after having introduced the basic concepts of transition systems, trace and bisimulation equivalences, we will illustrate how these notions can be extended to metric transition systems that are used as a unifying paradigm to represent continuous systems (describing physical processes), discrete systems (describing controllers at the implementation level) and logic specifications. Examples in the context of robotics, adaptive cruise control, vehicle platooning will be presented and an overview on existing automatic tools offered.

The presentations will be tutorial on the topics covered by the course. First, the solution to the control problem will be discussed in detail for a single nonlinear control system; efficient algorithms for the synthesis of the controllers will also be given. Then, the more general framework will be illustrated step-by-step. First, extensions to nonlinear control systems with disturbances and with state time-delays will be presented. Finally, non-ideal communication infrastructure conveying information between subsystems, and spatially distributed plants will be taken into account and the solution explained in this general case.

Schedule

Monday, July 3rd, 2017 (morning):

Introduction to large-scale networked nonlinear systems and formal methods: Heterogeneity, large-scale systems, logic specifications**.** Correct-by-design embedded control: motivating examples and methodology.

Control problem with logic specifications: Dealing with heterogeneity, Finite State Systems for modeling logic specifications, statement of the control problem, examples of logic specifications in robotics, adaptive cruise control, vehicle platooning, etc.

Review on internal and external stability notions of nonlinear control systems: Forward completeness, global asymptotic stability, input-to-state stability and their incremental versions, examples. Lyapunov characterization.

Monday, July 3rd, 2017 (afternoon):

Transition systems, equivalences, and symbolic models: Transition systems as a unifying framework for modeling plants, controllers and specifications; trace equivalence, simulation and bisimulation relations (exact, approximate and alternating), connections with equivalence of dynamical systems.

Construction of finite transition systems (symbolic models) approximately equivalent to nonlinear control systems.

Tuesday, July 4th, 2017 (morning):

Construction of symbolic models for nonlinear control systems (cont.).

Control design with logic specifications and examples. Efficient on-the-fly inspired algorithms for controller synthesis and examples.

Symbolic models for nonlinear control systems affected by disturbances.

Application to adaptive cruise control and vehicle platooning.

Tuesday, July 4th, 2017 (afternoon):

Time-delay nonlinear systems, stability and elements of spline analysis. Construction of symbolic models and examples.

Wednesday, July 5th, 2017 (morning):

Nonlinear control systems over networks: including non-idealities due to the communication infrastructure.

Dealing with large-scale systems: approximating networks of control systems via networks of symbolic models; design of decentralized controllers for enforcing logic specifications, efficient on-the-fly inspired algorithms for decentralized controller synthesis.

Applications and automatic tools.

Conclusions and outlook.