SIDRA Ph.D. School 2017

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

Bertinoro, July 3-5, 2017

Coordinators:

- Maria Domenica Di Benedetto
- Giordano Pola

Speakers:

- Alessandro Borri (IASI, CNR, Rome, Italy)
- Maria Domenica Di Benedetto (DISIM Dept., University of L'Aquila)
- Pierdomenico Pepe (DISIM Dept., University of L'Aquila)
- Giordano Pola (DISIM Dept., University of L'Aquila)

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

L1: Introduction to large-scale networked nonlinear systems and control with logic specifications

Speaker: Maria Domenica Di Benedetto

Slides L1

L2: Review on internal and external stability notions for nonlinear systems

Speaker: Pierdomenico Pepe

Lecture notes L2 L9

L3: Metric systems as a unifying framework for modeling plants, controllers and specifications

Speaker: Maria Domenica Di Benedetto

Lecture notes L3

L4: Regular languages

Speaker: Giordano Pola

Lecture notes L4

L5: Relations for metric transition systems

Speaker: Maria Domenica Di Benedetto

Lecture notes L5

Tuesday, July 4th, 2017

L6: Symbolic models for stable nonlinear systems

Speaker: Giordano Pola

Lecture notes L6a

Slides L6b

L7: Control design with logic specifications and efficient algorithms

Speaker: Alessandro Borri

Lecture notes L7a

Slides L7b

L8: Symbolic models and control for nonlinear systems with disturbances and applications

Speaker: Alessandro Borri

Slides L8

L9: Nonlinear time-delay systems: basic theory and stability

Speaker: Pierdomenico Pepe

Lecture notes L2 L9

Wednesday, July 5th, 2017

L10: Symbolic models for time-delay systems

Speaker: Giordano Pola

Slides L10

L11: Symbolic models for unstable nonlinear systems

Speaker: Giordano Pola

Slides L11

L12: Symbolic models for networked nonlinear systems

Speaker: Alessandro Borri

Slides L12

L13: Decentralized control of networks of nonlinear systems

Speaker: Giordano Pola

Slides L13

L14: Tools

Speaker: Alessandro Borri

Slides L14

L15: Conclusions

Speaker: Giordano Pola

Slides L15