Tutorial Proposal

Title: Developing Cyber-Physical Systems: Autonomous Vehicles in Regular Traffic

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Abstract: "*Cyber-physical systems (CPS) are engineered systems that are built from and depend upon the synergy of computational and physical components. Emerging CPS will be coordinated, distributed, and connected, and must be robust and responsive*." (From NSF – USA).

In this tutorial we will cover aspects of the analysis and synthesis of CPS, concentrating on the design of Autonomous Vehicles. We shall specifically consider autonomous and semi-autonomous cars in a street network, interacting with human-driven cars. Topics that will be covered are:

- Modeling of interconnected dynamic systems
- Information and coordination hierarchies
- Hybrid system modeling
- Autonomous vehicles
- Examples from
  - The Urban Challenge
  - An intersection approach
  - 4 communicating cars
- Testing large CPS

Intended Audience: This tutorial is intended for an audience ranging from graduate students in control theory to practicing control engineers and researchers.

Description:

In this tutorial, we will go over the broader description of Cyber-Physical Systems, and investigate design and implementation issues on various examples, with a specific focus on modeling and control of CPS. The following topics will be covered in this tutorial:

- *Modeling of interconnected dynamic systems:* Large-scale systems that combine multiple subsystems into a single interacting group have unique modeling and control challenges. Representing the way subsystems can exchange information and exert control on one another will be investigated.
- *Information and coordination hierarchies:* Hierarchical architectures enable a structured decomposition of a larger system into more manageable subsystems. The way the information is exchanged or how the subsystems coordinate can lead to structural or functional hierarchies.
- *Hybrid system modeling:* Computational (cyber) and mechanical (physical) parts of a system can have different state domains, with one part having continuous states, while the other part had discrete states. This separation naturally leads to Hybrid-State Systems (HSS). HSS models have been used in vehicle/computer, vehicle/driver, robot/controller systems and as they capture the inherent decomposition.
- *Autonomous vehicles:* Researchers from the Ohio State University Control and Intelligent Research (CITR) laboratory have extensive experience in autonomous vehicles and mobile robots. Unique challenges and solutions for this specific type of cyber-physical system will be discussed.
- *Examples from*
    - *The Urban Challenge:* OSU CITR competed in DARPA Urban Challenge 2007 [4,11,12], a continuation/evolution on earlier DARPA challenges (Grand Challenges 2004 and 2005 [1-3]). The developed vehicle was able to optimally plan and navigate an urban route, decide on lane changes or complete U-Turns according to partially or totally blocked roads, decide on and obey intersection precedence, and navigate to a parking spot in a parking lot to park and depark completely autonomously, obeying California traffic rules.

    - *An intersection approach:* Hybrid-State System models were built to capture driver behavior on intersection approaches and evaluate/detect/predict the maneuver and overall scenario using probabilistic analysis [5,13].
    - *4 communicating cars:* Vehicle-to-vehicle (V2V) communication technologies and how they can be utilized in autonomous, semi-autonomous and manual vehicles were investigated. One small-scale demo with actual vehicles was developed, with successfully semi-autonomous operation/interaction of two vehicles when two other human-controlled vehicles complicate the scenarios.
- *Testing large CPS:* Larger, multi-subsystem CPS models pose unique design and development challenges, one of which is adequate testing of tools, algorithms and methods. Since full-scale and outdoors tests are not always available or convenient for the systems illustrated above, we have developed an iterative design and testing process that makes use of simulated and emulated entities [6,8]. The process goes from fully simulated scenarios to semi-virtual ones with some portions emulated in computer; to final, full-scale tests.

Materials: The set of course slides and the corresponding annotated bibliography will be provided for printing and distribution.

Bio-sketches:

Prof. Ümit Özgüner has been the team-lead, coordinator, and major technical contributor to a number of high-tech team activities: Demo'97, two DARPA Grand Challenges [1, 2], and the DARPA Urban Challenge [4], all of which are relevant to the content of this proposal. He is an expert in Intelligent Vehicle technologies and control-related research on autonomous or coordinated complex systems. He is the author of over 400 publications, including the recent book "Autonomous Ground Vehicles," with Prof. Redmill as a co-author. His work has been supported by the automotive industries, AFRL, and DARPA. He has directed many efforts in applied control, advising students in developing several working software systems. He has been the PI of the CPS Project: "Autonomous Driving in Dense, Mixed Traffic Environments" (NSF #0931669) where a number of both basic and application issues (see http://cps.osc.edu for full list of publications) related to having autonomous vehicles in a dense, mixed traffic, urban environment was addressed. Safety issues from a range of viewpoints, including verification, timing, security of multiprocessor systems, task decomposition and sensor fusion were considered. Furthermore probabilistic models were used so as to include human behavior [5]. A design process going from simulation to lab level testing to outdoor (small-scale) testing was developed [6]. In this process an innovative lab that uses the concept of virtual sensing was introduced [7, 8]. The latest included two autonomous and two human driven cars in a small network with a traffic light and a stop sign. The project team also collaborated with a number of international groups, specifically with a team participating in the Grand Cooperating Driving Challenge (GCDC) in Holland, and AIST labs in Japan, developing 3 autonomous trucks, where we investigated the safety of automated convoys.

Prof. Keith Redmill has significant experience and expertise in intelligent transportation systems [7], intelligent vehicle control and safety systems, sensors and sensor fusion, wireless communication, multi-agent systems including autonomous ground [2, 4, 9] and aerial vehicles and robots [10] and control theory [3]. He has been a senior and integral part of research teams participating in DARPA autonomous vehicle challenges, and a co-PI in the CPS Project: "Autonomous Driving in Dense, Mixed Traffic Environments" mentioned above.

Dr. Arda Kurt's research has focused on Hybrid-State Systems [11], mobile robot [10] and autonomous vehicle control [12], and intelligent transportation systems in general. Dr. Kurt has been an integral part of multiple international research projects, including DARPA Urban Challenge 2007 [4] and MAGIC 2010 [10]. He has expertise in probabilistic models for driver behavior and intention estimation [5, 13] as part of his work in the CPS Project: "Autonomous Driving in Dense, Mixed Traffic Environments" mentioned above, and related vehicular autonomy testing and verification research [6,7] through both physical testbeds and semi-virtual scenarios.

References

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