CPS: Small: Real-time, Simulation-based Planning and

Asynchronous Coordination for Cyber-Physical Systems

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Cyber-physical systems research aims to provide devices with autonomous decision-making that are robust enough to be employed in a variety of important applications. Thus, it is necessary to design physically-grounded intelligent agents that autonomously plan and coordinate their actions as they interact with complex physical processes. Physically-grounded means that the agents must model the physical world in a realistic manner and consider the effects of physical constraints.

To achieve this objective, this project aims to develop frameworks and general solutions for autonomous planning and coordination in networks of cyber-physical systems, and is inspired by related challenges and techniques in algorithmic motion planning, multi-agent systems, sensor networks, learning and control. The focus during the first year of the project has been on the following tasks:

* Developing abstractions and algorithms that plan efficiently for complex physical systems. Planning methods have been investigated for systems with differential constraints that improve the exploration of a system’s state space so as to find a solution trajectory. The methods have been tested on benchmark systems with interesting dynamics and underactuation. An important characteristic of the techniques is that they require access only to a forward propagation model of the system. This is important, as the next step in this direction is to integrate such approaches with physics-based simulation tools and model even more complex systems, including hybrid ones, that contain both discrete and continuous parameters.
* Studying safety considerations in real-time planning, dynamic environments and multi-agent coordination scenarios. The planning process must often be interleaved with sensing and execution and has a limited amount of time to return only a partial plan. This raises safety issues for second-order dynamical systems, since a partial plan can bring the system to an undesirable part of the state space from which it cannot escape. The problem becomes more challenging in dynamic environments, and in the general case is unsolvable if there is no trustworthy model of the environment’s future behavior. This project is especially focusing on the case of multiple cooperating physical agents that plan in real-time their operations in the same environment and have to respect such second-order dynamics. In this setup, the current work has shown that safety can be guaranteed for all agents by distributed and asynchronous protocols for the coordination process. The next step is to have teams of coordinating agents that are able to deal with non-coordinating dynamical systems.

The focus of this work so far has been on examples that stem mostly from the application areas of robotics, manufacturing and transportation. For instance, a specific challenge that is investigated is how wireless nodes can distributedly guide moving vehicles through a road network, where asynchronous and distributed protocols are again needed to address this challenge. A wider variety of applications related to cyber-physical systems will be investigated into the future.