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 applications. Thus, it is necessary to design physically-grounded intelligent agents that autonomously plan and coordinate their actions. Towards this objective, this project aims to develop frameworks and general solutions for autonomous planning and coordination especially for networks of cyber-physical systems. This work is inspired by related challenges and techniques in algorithmic motion planning, multi-agent systems, sensor networks, learning and control. The focus during the second year of the project has been on the following tasks:

- Methods for approximating optimum cost-to-go metrics in the state-space of non-holonomic and underactuated systems. An offline learning-phase in obstacle-free environments is utilized and combined with multi-dimensional scaling for the efficient online utilization of the learned information. The technique requires access only to a forward propagation model of the system [Li, Bekris, ICRA 11].
- Methods for computing asymptotically near-optimal paths. Asymptotically optimal planners guarantee solutions approach optimal but roadmaps with this property can be slow to construct and grow too large for storage or fast online query resolution. Utilizing results from graph theory, i.e., graph spanners, which provide near-optimal paths, asymptotically near-optimal planners have been developed. They result in large reductions in construction time, roadmap density and online-query resolution with a small sacrifice in path quality [Marble, Bekris ISRR 11-IROS 11].
- Safe motion coordination for multiple vehicles in the same environment, which recompute their trajectories in an asynchronous manner. Planning must guarantee a robot's safety by ensuring collision-free paths and by not bringing the robot to states where collisions cannot be avoided in the future. The safe operation of multiple communicating second-order vehicles, whose replanning cycles do not coincide, can be guaranteed through an asynchronous, distributed planning and communication framework [Grady, Bekris, Kavraki WAFR 10 – Bekris, Grady, Moll, Kavraki IJRR 11].
- Beyond planning–based solutions, the project has also investigated control-based approaches for decentralized conflict resolution that aim to minimize the amount of communication exchanged between the agents while guaranteeing the eventual resolution of a problem, i.e., providing liveness guarantees [Krontiris, Bekris IROS 11].
- Fundamental methods for sequential multi-agent path planning on graph-based abstractions. It has been shown that complete but sub-optimal algorithms that have polynomial complexity exist for this problem. This allows the efficient resolution of larger-scale path planning instances than before with competitive path lengths by employing two high-level primitives [Luna, Bekris IJCAI 11-IROS 11].

In parallel with the above activities, important outreach efforts were pursued including the development of open-source software. In particular, the project involved, trained and mentored undergraduate and graduate students, including women, in research activities related to CPS. The PI organized special meetings related to the project's objectives and integrated research outcomes in the educational material of courses at the PI's institute. K-12 students were exposed to the results of this work through cooperation with the Davidson Academy of Nevada, a free public school for gifted K-12 students.