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EDITOR'S NOTE

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Integrated Control of Traffic Flow

Yihang Zhang

Abstract

Highway congestion is detrimental to traffic mobility, safety, and the environment. Numbers of studies have been conducted to avoid or relieve highway congestion with different traffic flow control strategies, such as variable speed limit (VSL), ramp metering (RM), and lane change (LC) recommendation. It is necessary to investigate the dynamical behavior of the traffic flow systems to find out the reasons of the chaotic behavior at the bottleneck, in order to find an integrated traffic flow control strategy that is able to provide consistent improvement in traffic mobility, safety, and environmental impact under different scenarios.

In this dissertation, we discover that one of the major reasons for the disordered behavior is the forced LCs at the vicinity of the bottleneck. An LC controller is proposed that provides LC recommendations to upstream vehicles to avoid the capacity drop. VSL and RM controllers are designed to improve the flow rate at highway bottlenecks together with the LC controller. The coordinated VSL, RM, and LC controller, which is built on the first-order cell transmission model, can analytically guarantee the global exponential convergence to the desired equilibrium point at which the maximum possible flow rate is achieved. Microscopic simulations show consistent improvement under different traffic demands and scenarios.

Furthermore, we modify the cell transmission model to include the effect of capacity drop and rigorously investigate its stability properties under all possible traffic flow scenarios. The analysis is used to motivate the design of VSL control to overcome capacity drop without LC control and achieve the maximum possible flow under all feasible traffic situations. We also consider the case in which the system disturbance is included and extend the VSL controller by adding the integral action to reject the disturbance while avoiding the capacity drop.

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Optimization-Based Motion Planning and Model Predictive Control for Autonomous Driving: With Experimental Evaluation on a Heavy-Duty Construction Truck

Pedro Filipe Lima

Abstract

This thesis addresses motion planning and control of autonomous heavy-duty industrial vehicles, such as trucks and buses, using

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optimization-based techniques. First, we propose a clothoid-based path sparsification algorithm to describe a reference path. The proposed approach relies on a reweighed l_1-norm approximation of the l_0-norm, resulting in a computationally inexpensive path description.

Second, we introduce a novel framework in which path-planning problems are posed in a convex optimization format, even when considering the vehicle dimension constraints, which maximizes the path-planning performance in very constrained environments. The proposed framework is extended for the path planning of large vehicles, such as buses. In these cases, the optimization objective aims to minimize the amount of vehicle overhang exiting the lane while ensuring that the paths are collision free with other obstacles.

Third, we address the problem of maximizing the progress (i.e., minimizing the traveling time) along a given path (e.g., the centerline of a road). This is formulated as a convex model predictive control (MPC) problem by linearizing the vehicle model and constraints and approximating a "*g-g*" diagram by an inscribed convex polytope.

Fourth, we design a smooth and accurate MPC design for lateral control of an autonomous truck. The controller effectiveness is benchmarked against a standard MPC approach and a pure-pursuit controller, both in simulation and experimentally. The experimental tests are performed in a Scania construction truck at Scania test track facilities near Södertälje, Sweden.

Last, we propose a novel terminal cost and terminal state set used in the design of a linear time-varying MPC (LTV-MPC) for lateral control of an autonomous vehicle. Closed-loop asymptotic stability of the LTV-MPC scheme is proved using Lyapunov arguments. The controller successfully stabilizes an autonomous Scania construction truck even when other controllers, with no or milder terminal cost and terminal state set, cannot stabilize the vehicle.

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Control and Communication Systems for Automated Vehicles Cooperation and Coordination

Ahmed Hussein

Abstract

The technological advances in intelligent transportation systems (ITS) have exponentially improved over the last century. The objective is to provide intelligent and innovative services for the different modes of transportation toward a better, safer, coordinated, and smarter transport network. The ITS focus is divided into two main categories: first, to improve existing components of the transport networks, and second, to develop intelligent vehicles that facilitate the transportation process. Accordingly, this thesis addresses the problem of cooperation and coordination of multiple automated vehicles.

The 3DCoAutoSim (3D simulator for cooperative advanced driver assistance systems and automated vehicles simulator) driving simulator was developed in the Unity game engine and connected to the Robot Operating System framework and Simulation of Urban Mobility. It was tested under different circumstances and conditions and validated through numerous controlled experiments, and the results were compared with their counterreality experiments. The obtained results showed the efficiency of the simulator to handle different situations, emulating real-world vehicles.

Next is the development of the intelligent campus automobile (iCab) platforms. The platforms are two electric golf carts that were modified mechanically, electronically, and electrically toward the goal of automated driving. Each iCab was equipped with several onboard embedded computers, perception sensors, and auxiliary devices to execute the necessary actions for self-driving.

Moreover, the platforms include several vehicle-to-everything communication schemes, applying three layers of control, utilizing cooperation architecture for platooning, executing localization, mapping, perception, and several planning techniques. Hundreds of experiments were performed for the validation of each system in the iCab platform. Results proved the functionality of the platform to self-drive from one point to another with minimal human intervention. Finally, the work in this thesis resulted in 34 peer-reviewed publications in books, journals, and

conferences, including two best article awards.

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Traffic Demand Management in the Era of Connected Vehicles

Charalambos Menelaou

Abstract

This Ph.D. thesis aims to develop a framework that eliminates traffic congestion while it maximizes the efficiency of the road network by combining existing control measures (such as route guidance and traffic flow control) with innovative demand management strategies. Demand management is achieved through a novel reservation architecture that grants access to the network only when it is ensured that the requested vehicle (or traffic flow) will travel only through congestion-free road segments (or network regions). The problem is investigated at macroscopic and macroscopic levels.

At the microscopic level, the proposed reservation architecture provides instructions to each vehicle regarding the route to follow and departure time from the origin to optimize one or more performance metrics (e.g., earliest destination arrival time and deviation from on-time arrival) without passing through congested road segments. This implies that vehicles may be instructed to delay their departure until some road segments become uncongested or even follow alternative routes that minimize the considered metrics.

At the macroscopic level, the proposed scheme aims to provide both regional route guidance and demand management to control vehicles in a multiregional network considering macroscopic traffic dynamics. Regional route guidance is used to identify the optimal transfer flows between neighboring regions so that the trip completion rate across all regions is maximized. Demand management is utilized to control the traffic flows entering the network by allowing a portion of the demand flows to wait at their origin.

All proposed methodologies and algorithms are evaluated through extensive realistic simulations considering different microscopic- and macroscopic-level traffic dynamics. The provided results demonstrate the significant improvements that can be realized by applying the proposed integration of routing guidance with demand management in terms of network efficiency and travel time reduction.

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