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A double-layered nonlinear model predictive control based control algorithm for local trajectory planning for automated trucks under uncertain road adhesion coefficient conditions

Key words: Automated truck; Trajectory planning; Nonlinear model predictive control; Longitudinal slip

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Motivation

- For electric vehicles equipped with hub motors, the actual vehicle acceleration provided by the hub motor torque is always affected by the road surface condition in a real environment, causing tires to lock up during braking or excessively slip during traction.
- The current trajectory planning methods for autonomous vehicles are usually executed under the assumption that the exact knowledge of the environment is known in a trajectory planning system. However, in the real world, the system may be disturbed by information errors such as road surface conditions and weather conditions. These errors may impact vehicle's dynamic limits and even its safety.

Main idea

- The secondary layer nonlinear model predictive control (SLN-MPC) controller is designed to limit the longitudinal slip of four wheels within a stable zone to ensure truck safety, making these control issues time-domain constraints of a nonlinear MPC problem.
- The main layer nonlinear model predictive control (MLN-MPC) controller is applied to plan the trajectory features of two system inputs: one is the yaw rate of the truck and the other is truck acceleration. The real-time information of the yaw rate can be obtained by sensors, and the acceleration is determined by the hub motor torque. This torque is one of the system inputs of the SLN-MPC controller.

Method

1. SLN-MPC block diagram

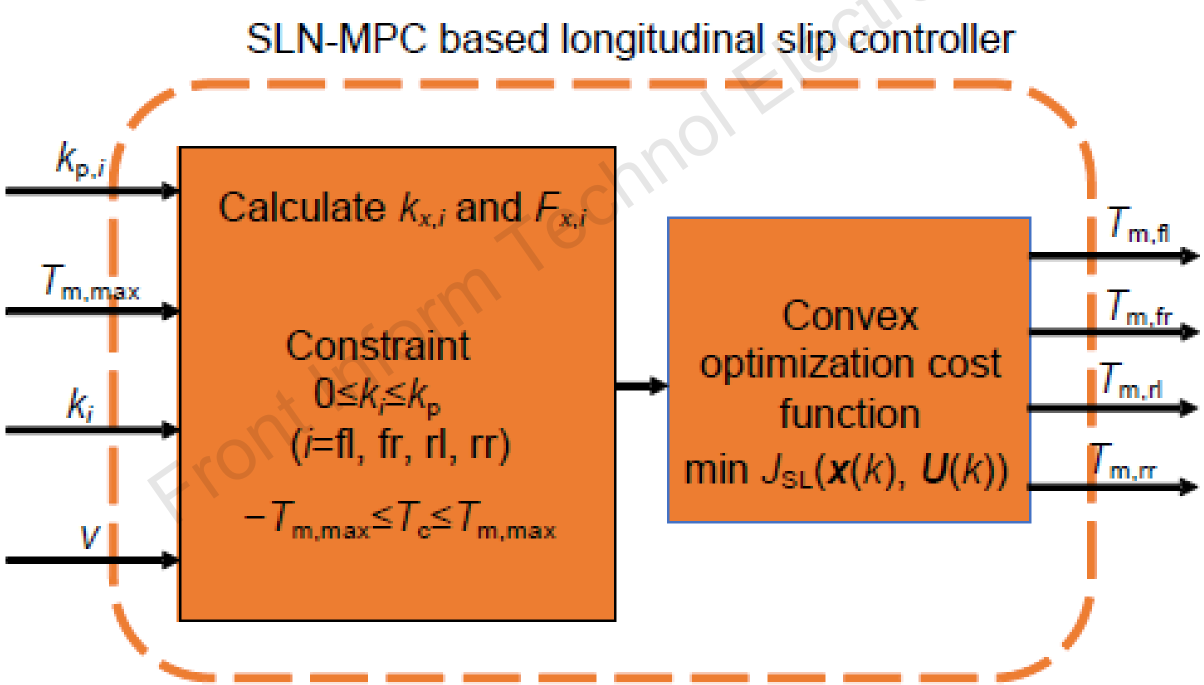

Fig. 2 SLN-MPC block diagram

2. MLN-MPC block diagram

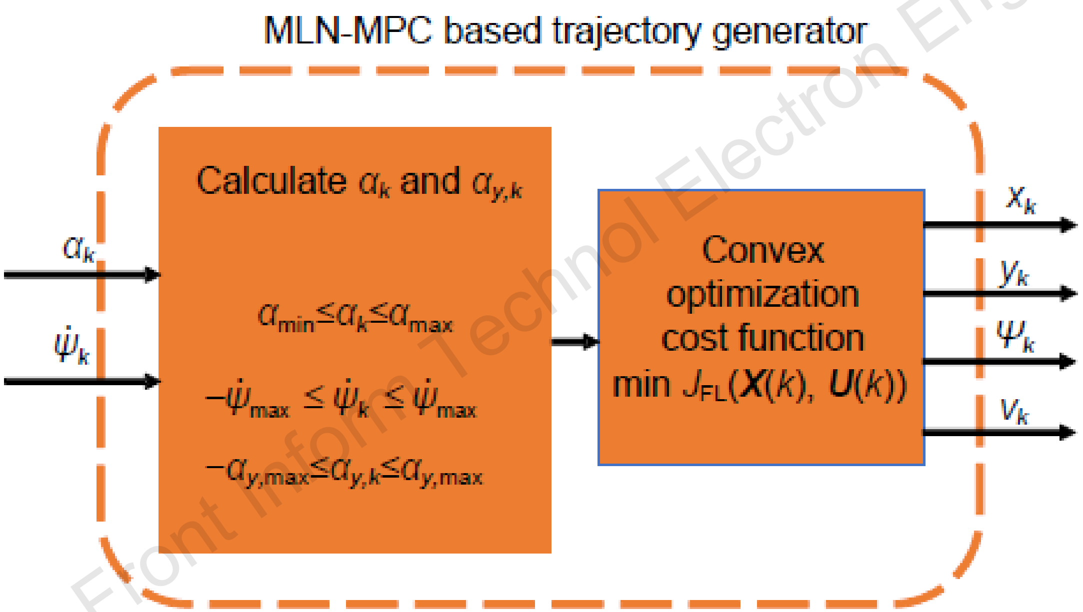

Fig. 4 MLN-MPC block diagram

3. The general map of the simulation environment

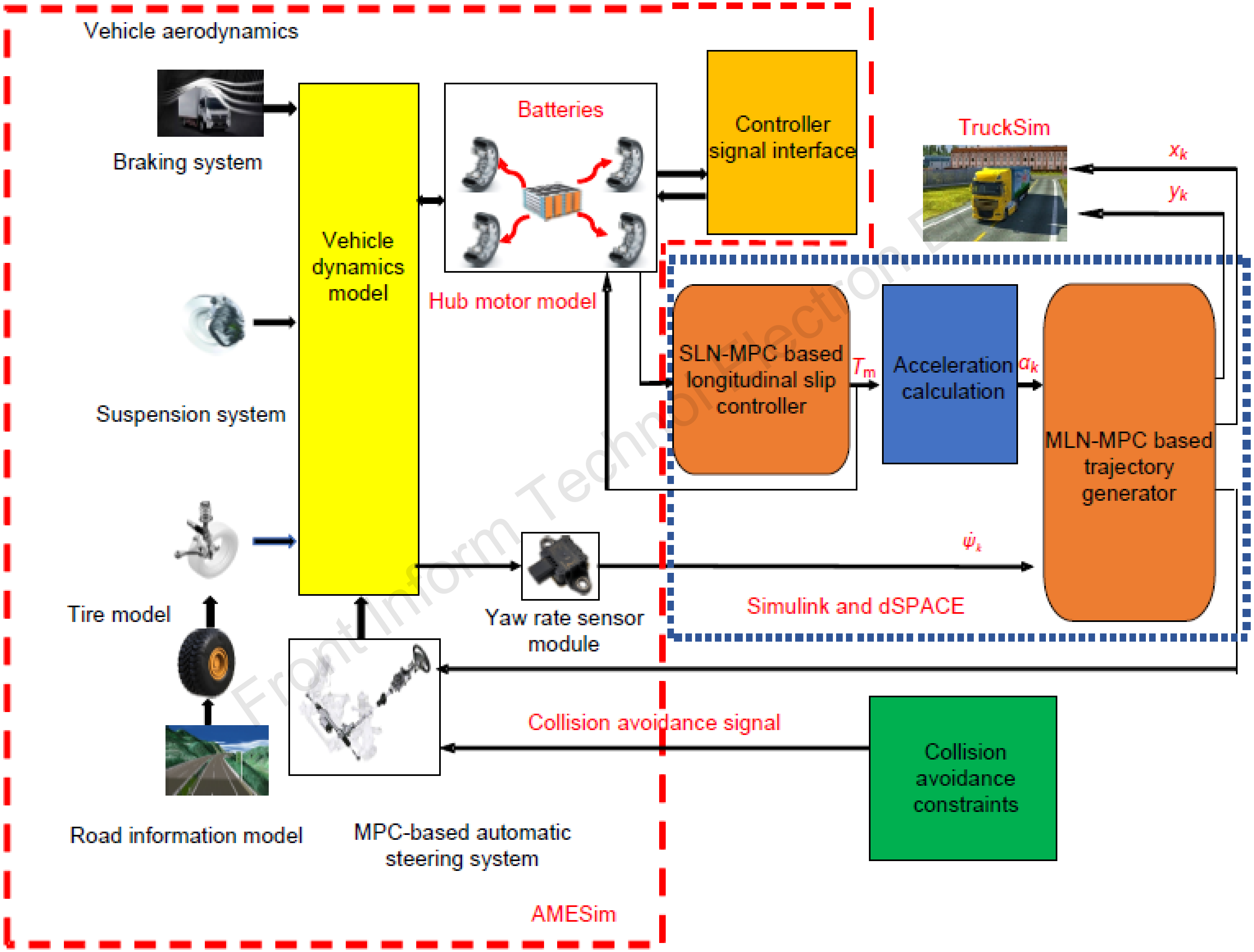

Fig. 6 General map of the simulation environment

Major results

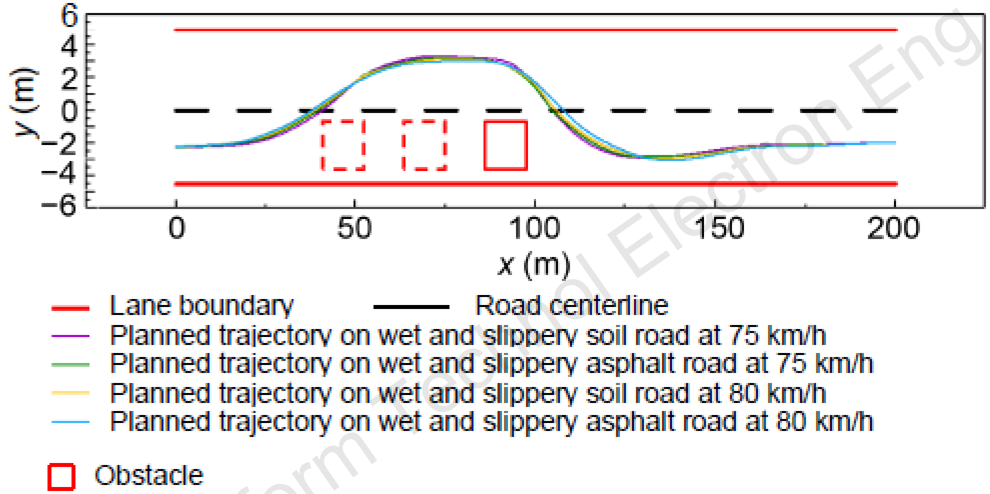

Fig. 7 Generated trajectories under different initial speeds and road conditions

References to color refer to the online version of this figure

Major results (Cont’d)

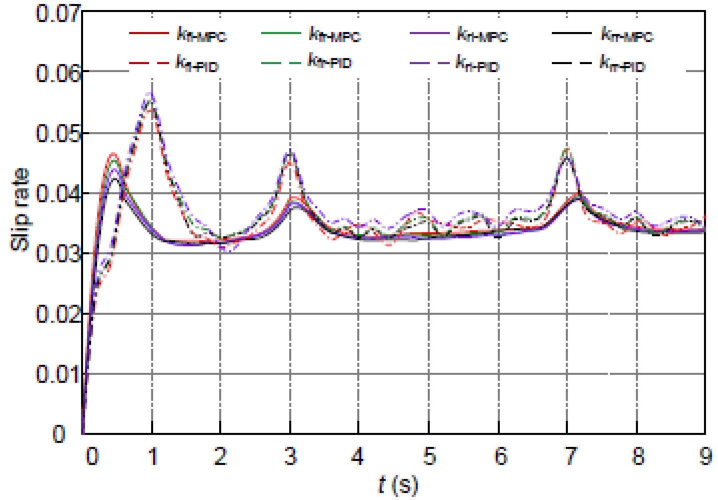

Fig. 13 Ego truck slip rate with the initial speed of 75 km/h during overtaking on a wet and slippery soil road

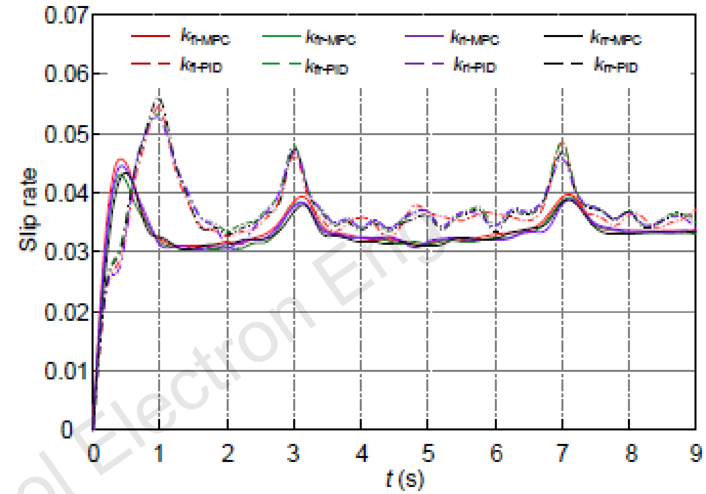

Fig. 14 Ego truck slip rate with the initial speed of 75 km/h during overtaking on a wet and slippery asphalt road

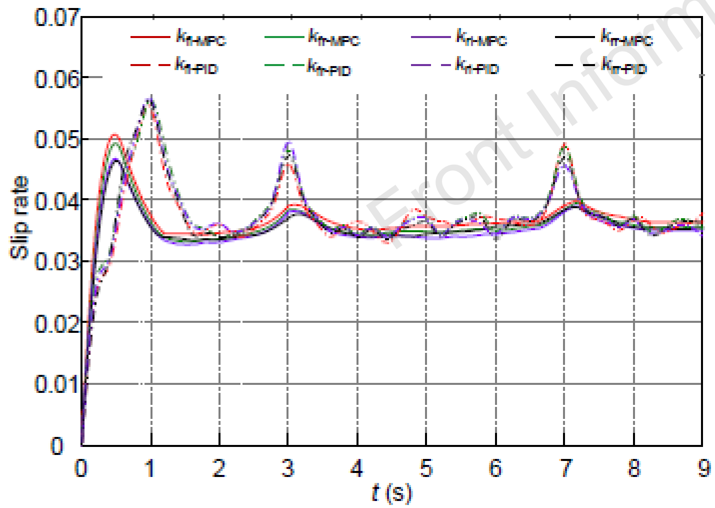

Fig. 15 Ego truck slip rate with the initial speed of 80 km/h during overtaking on a wet and slippery soil road

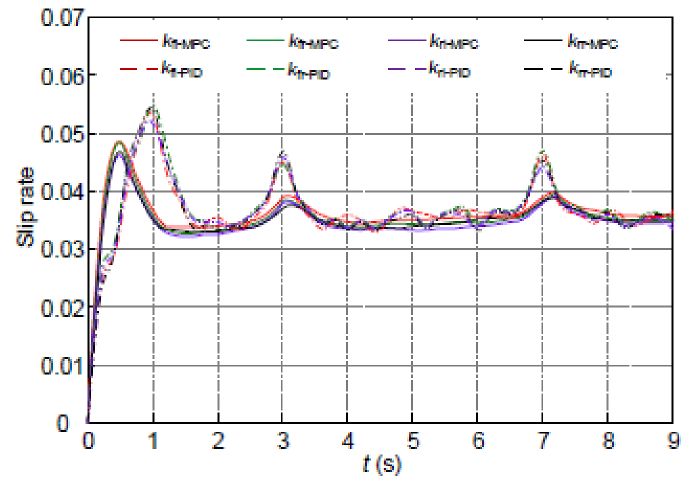

Fig. 16 Ego truck slip rate with the initial speed of 80 km/h during overtaking on a wet and slippery asphalt road

Major results (Cont’d)

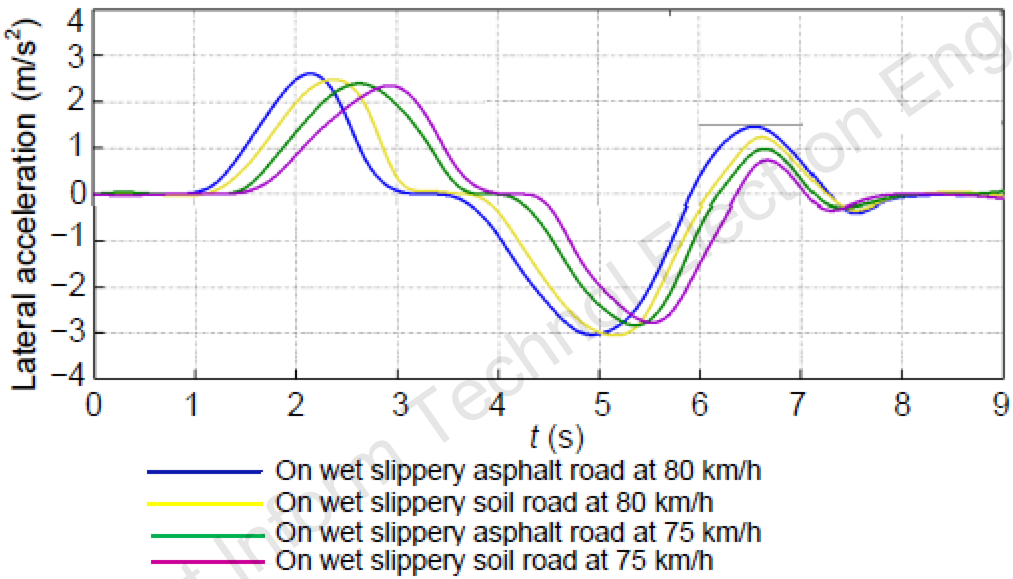

Fig. 18 Lateral acceleration changes of the truck during the overtaking maneuver

Major results (Cont'd)

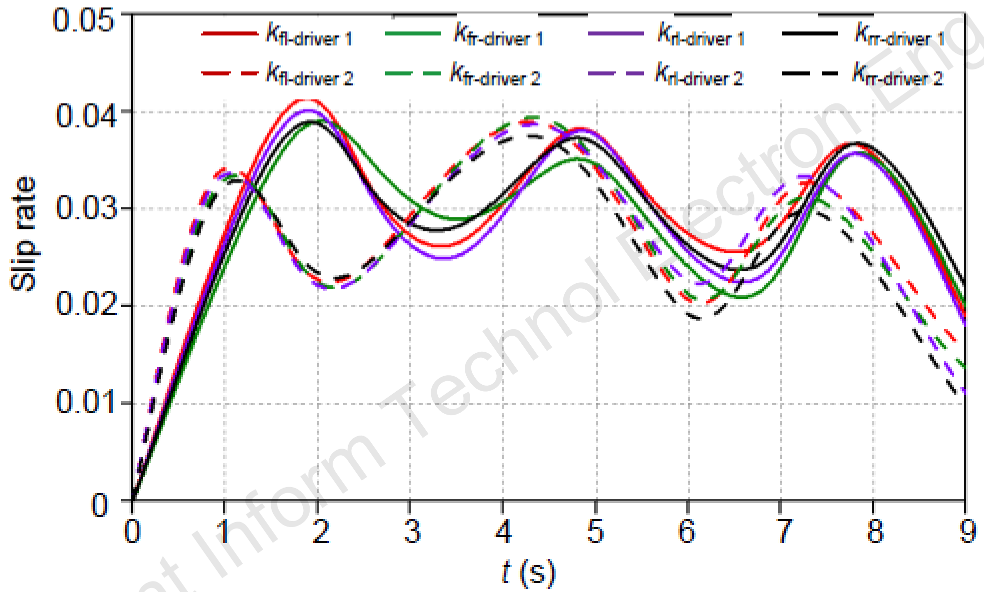

Fig. 21 Ego truck slip rate produced by the driver model

Conclusions

- The longitudinal wheel slip controlled by the SLN-MPC controller in uncertain road conditions can be accurately controlled within a stable zone. This slip had a smaller maximum and smoother fluctuation than those of the conventional PID-based control method.
- In overtaking maneuver, the lateral acceleration of the truck is limited to a safety range to avoid truck side slipping. Thus, the ego truck can complete overtaking maneuver safely under the formulated avoidance constraints.
- Co-simulation results showed that this method guarantees that the truck will operate safely, satisfy its driving requirements, and provide a feasible reference basis for applications in the real world.