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COMPARISON OF CENTRALIZED AND MULTI-LAYER ARCHITECTURES FOR NONLINEAR MODEL PREDICTIVE TORQUE-VECTORING AND TRACTION CONTROL

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ABSTRACT–A significant body of literature discusses direct yaw moment controllers for vehicle stability control and torque-vectoring (TV), based on model predictive control. However, the available references lack an analysis of the effect of including or excluding the wheel dynamics in the prediction model in combined longitudinal and lateral acceleration conditions, which is related to the control system architecture. In fact, in the first case, the controller can also fulfill the wheel slip control function, according to a centralized architecture, while in the second case, the tire slip limitation has to be implemented externally, in a multi-layer approach. This study addresses the identified gap by proposing and comparing – through simulations with a high-fidelity vehicle model – centralized and multilayer real-time implementable architectures using nonlinear model predictive control (NMPC) for the TV and traction control (TC) of an electric vehicle with front in-wheel motors. An optimization routine calibrates the main controller parameters, to ensure fairness in the comparison during extreme accelerating-while-cornering maneuvers with transient steering inputs. The results show that the real-time implementable multi-layer architecture with wheel dynamics in the NMPC prediction model, and considering the externally generated TC torque reduction in the TV layer, provides equivalent performance to a centralized set-up.

KEY WORDS : Direct yaw moment control, Torque-vectoring, Wheel dynamics, Wheel slip control, Nonlinear model predictive control, Centralized architecture, Multi-layer architecture

1. INTRODUCTION

Passenger cars can experience lateral stability and agility issues in several situations, e.g., while traveling on slippery roads, or, in general, during emergency steering conditions, such as those of obstacle avoidance maneuvers. Critical vehicle behavior is caused by the saturation of the lateral tire forces when they reach the friction limit (Beal and Gerdes, 2013), which usually does not concurrently occur on the front and rear axles.

During the last three decades, vehicle dynamics control systems based on direct yaw moment control (DYC) have been widely implemented in production cars, to improve their active safety performance. While these systems traditionally rely on the actuation of the friction brakes only in emergency conditions (van Zanten *et al.*, 1995), a broad literature has also dealt with the benefits of continuously active torque-vectoring (TV), especially for electric vehicle architectures with two powertrains per axle (De Novellis *et al.*, 2015).

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The main targets of DYC systems (van Zanten, 2000) are: i) at the vehicle level, lateral and yaw dynamics control, via the attenuation of the yaw rate and sideslip angle peaks during limit handling operation, and, in case of TV, generation of desirable levels of vehicle understeer throughout the lateral acceleration range, e.g., to increase cornering agility; and ii) at the individual corner level, wheel slip control in traction and braking, which also contributes to i). With respect to (w.r.t.) ii), the higher control bandwidth and accuracy in torque generation of individually controlled electric motors enable continuous wheel torque modulation, which brings enhanced tire slip control, and thus the reduction of the vehicle stopping distances and acceleration times, see the experimental results in Murata (2012) and Ivanov *et al.* (2015).

In parallel, thanks to the rapidly increasing performance of the available computing hardware and numerical optimization algorithms, model predictive control (MPC) has become a popular technique for vehicle dynamics applications at the research level. MPC is based on the solution of an optimization problem minimizing a cost function evaluated by a model along a finite prediction horizon, subject to a set of constraints (Grüne and Pannek,