International Journal of Automotive Technology, Vol. 24, No. 2, pp. 347–365 (2023)
DOI 10.1007/s12239–023–0029–2

pISSN 1229–9138/ eISSN 1976–3832

VEHICLE STABILITY CONTROL THROUGH PRE-EMPTIVE BRAKING

Giuseppe Guastadisegni[1)], Kai Man So[1)], Alberto Parra[2)], Davide Tavernini[1)], Umberto Montanaro[1)], Patrick Gruber[1)], Leonardo Soria[3)], Giacomo Mantriota[3)] and Aldo Sorniotti[1)*]

[1)]Centre of Automotive Engineering, School of Mechanical Engineering Sciences, University of Surrey, Guildford GU2 7XH, UK
[2)]Tecnalia Research and Innovation, Basqua Research and Technology Alliance, Donostia-San Sebastián 20009, Spain
[3)]Department of Mechanical Engineering, Mathematics and Management, Politecnico di Bari, Bari 70125, Italy

(Received 7 December 2021; Revised 13 July 2022; Accepted 2 August 2022)

ABSTRACT–Next-generation accurate vehicle localization and connectivity technologies will enable significant improvements in vehicle dynamics control. This study proposes a novel control function, referred to as pre-emptive braking, which imposes a braking action if the current vehicle speed is deemed safety-critical with respect to the curvature of the expected path ahead. Differently from the implementations in the literature, the pre-emptive braking input is designed to: a) enhance the safety of the transient vehicle response without compromising the capability of reaching the cornering limit, which is a significant limitation of the algorithms proposed so far; and b) allow – in its most advanced implementation – to precisely constrain the sideslip angle to set levels only through the pre-emptive control of the longitudinal vehicle dynamics, without the application of any direct yaw moment, typical of conventional stability control systems. To this purpose, a real-time-capable nonlinear model predictive control (NMPC) formulation based on a double track vehicle prediction model is presented, and implemented in its implicit form, which is applicable to both human-driven and automated vehicles, and acts as an additional safety function to compensate for human or virtual driver errors in extreme conditions. Its performance is compared with that of: i) two simpler – yet innovative with respect to the state-of-the-art – pre-emptive braking controllers, namely an NMPC implementation based on a dynamic point mass vehicle model, and a pre-emptive rule-based controller; and ii) a benchmarking non-pre-emptive rule-based trail braking controller. The benefits of pre-emptive braking are evaluated through vehicle dynamics simulations with an experimentally validated vehicle model, as well as a proof-of-concept implementation on an automated electric vehicle prototype.

KEY WORDS : Nonlinear model predictive control, Stability control, Pre-emptive control, Braking, Sideslip angle constraint, Reference curvature

1. INTRODUCTION

Vehicle stability control systems have been introduced in the 1990s (van Zanten *et al*., 1995), to generate feedback direct yaw moment and braking actions in case of large yaw rate errors or sideslip angles, conditions in which the driver steering inputs are not able to significantly influence the total yaw moment (van Zanten, 2000). Stability controllers keep the sideslip angle within safe thresholds, such that the driver can control the cornering level through the steering action (Tseng *et al*., 1999). These systems have brought a significant road accident reduction in the last decades (Ferguson, 2007; Lie *et al*., 2006).

The stability control function is typically based on the feedback control of yaw rate and sideslip angle (Ataei *et al*., 2020; Goggia *et al*., 2015; Parra *et al*., 2018; Tahouni *et al*., 2019; Zhang *et al*., 2020), and can be actuated through the friction brakes (which is the common solution of production passenger cars), or the individual control of electric powertrains or torque-vectoring devices, where the last two options allow continuous and seamless operation of direct yaw moment control, and can also be used for agility enhancement (De Novellis *et al*., 2015). Modern vehicle stability controllers can include roll-over prevention (Wielenga, 2000), and control of the hitch angle oscillations when the car tows a trailer (Abroshan *et al*., 2021; Zanchetta *et al*., 2019).

Zarkadis *et al*. (2018) shows the potential stability control benefits of active trail braking, which manages the balance between longitudinal and lateral dynamics. Active trail braking is inspired by the trail braking technique, used by expert human race drivers for negotiating corners at high speeds, typically during rally competitions. Trail braking adopts simultaneous braking and steering actions to regulate the vehicle speed to the feasible value for the specific corner, and imposes an oversteering and more agile response through the exploitation of weight transfer effects

**Corresponding author*. e-mail: a.sorniotti@surrey.ac.uk