CHALMERS
UNIVERSITY OF TECHNOLOGY

Motion Control of a 6 × 4 Heavy Vehicle: Autonomous Collision Avoidance Using Integrated Chassis Control

Citation for the original published paper (version of record):
Asiabar, A., Gordon, T., Gao, Y. et al (2024). Motion Control of a 6 × 4 Heavy Vehicle: Autonomous
Collision Avoidance Using Integrated
Chassis Control. Lecture Notes in Mechanical Engineering: 144-150.
http://dx.doi.org/10.1007/978-3-031-70392-8_21

Motion Control of a 6 × 4 Heavy Vehicle: Autonomous Collision Avoidance Using Integrated Chassis Control

Aria Noori Asiabar[1(✉)], Timothy Gordon[1], Yangyan Gao[2], Leon Henderson[3,4], and Leo Laine[3,4]

[1] University of Lincoln, Brayford Way, Lincoln LN6 7TS, UK
anoori@lincoln.ac.uk
[2] Volvo Trucks North America, 7900 National Service Rd, Greensboro, NC 27409, USA
[3] Volvo Group Trucks Technology, SE-405 08 Gothenburg, Sweden
[4] Chalmers University of Technology, Chalmersplatsen 4, 412 96 Gothenburg, Sweden

Abstract. This paper considers the coordinated chassis control of a 6 × 4 HGV tractor unit using a multivariable nonlinear controller for a transient handling manoeuvre under friction-limited conditions. The controller's performance is evaluated through simulation. It receives Centre of Gravity (CG) longitudinal and lateral acceleration targets, corresponding to curvature and longitudinal acceleration requests, and aims for the CG to track the target accelerations. It employs the Modified Hamiltonian Algorithm (MHA) to generate steering and braking commands for the tractor. A combined-slip Magic Formula tyre model used within the algorithm allows for simultaneous stability control and path tracking, even in scenarios where the vehicle is operating at the limits of tyre adhesion. The manoeuvre is an autonomous obstacle avoidance on a packed snow. Results show the advantages and possible limitations of tracking acceleration targets for integrated chassis control.

Keywords: Vehicle Control · Handling Limits · Autonomous Obstacle Avoidance

1 Introduction

Heavy goods vehicles (HGVs) are an essential part of modern society for the transportation of goods. Despite their widespread and long-established use, heavy vehicles contribute significantly to severe accidents, necessitating a continuing focus on safety enhancement [1].

Future vehicle advancements and increasing availability of actuators such as independent wheel braking control and steer-by-wire can improve vehicle safety.

Supported by Volvo Trucks and University of Lincoln.

G. Mastinu et al. (Eds.): AVEC 2024, LNME, pp. 144–150, 2024.
https://doi.org/10.1007/978-3-031-70392-8_21

Various chassis control algorithms - including optimization-based control allocation algorithms, such as Model Predictive Control (MPC), and Nonlinear MPC (NMPC), have been explored in the literature to realize these improvements [2]. These approaches typically reference a suitable desired motion path, which can be undesirable when reaching the limits of adhesion. The selected path may be too conservative or not achievable, as this depends on the details of the vehicle dynamics, the control actuators and the road surface. In other approaches, a CG acceleration reference is determined [3,4] (e.g. using a simple particle model). Assuming the acceleration target has been appropriately defined, e.g., to follow a collision-free path within the capabilities of the vehicle and the road surface, the key question is the vehicle's performance in tracking that reference. Acceleration magnitude will be set according to the adhesion limits of individual tyres, so the vehicle will normally be in a condition where it needs to maximize the available CG acceleration in the desired direction.

The main focus of this paper is on maximising the available CG acceleration in a direction that is computed by the algorithm. The general approach, as well as the use of acceleration targets, was developed from the more formal optimal control-based method of QLOC [3] while avoiding any significant optimization or nonlinear simulation within the control loop.

MHA has previously been shown to be a robust motion control methodology for light vehicles, operating effectively up to the friction limits [4], and the present paper makes a contribution towards its development as a control method for HGVs. It includes a high-level reference generator, as well as a low-level control allocator. Indeed MHA splits the motion control problem into parallel sub-problems, to be solved locally for each wheel. This is achieved based on Pontryagin's minimum principle [5], with control signals being obtained by minimization of a linear Hamiltonian function. The general control architecture is shown in Fig. 1.

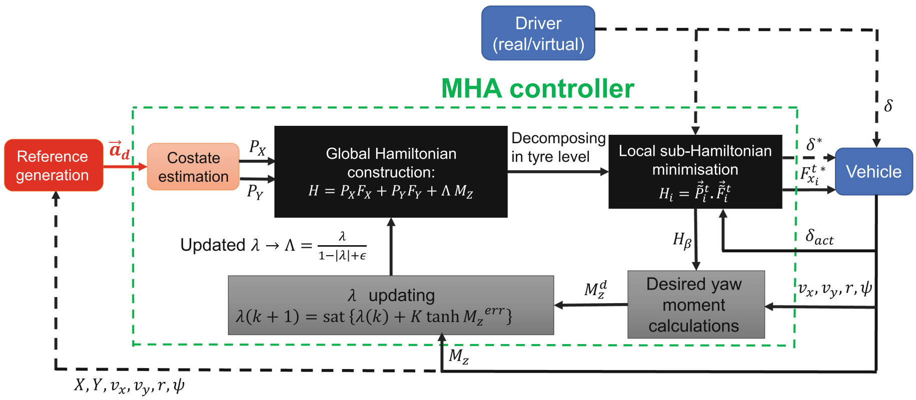

Fig. 1. MHA controller structure.

We consider an emergency lane-change scenario from two perspectives. In the first case, the acceleration request is pre-computed and does not change during the manoeuvre (open-loop). The second case uses an updating reference (closed-loop) obtained from a particle subject to sliding mode control - see [3,7,8] for details. Furthermore, in the MHA algorithm, the tracking performance is strongly influenced by the lambda adaptation gain, K, [4] with larger values of K being beneficial during severe transient demands. we will investigate this through simulation results for an open-loop case.

2 Scenarios

This section examines both open-loop and closed-loop scenarios for an evasive lane change, with control performance evaluated in simulation. It makes use of a high-fidelity truck model (Volvo Transport Models - VTM [9]) for a 6×4 Volvo FH tractor. In all cases a low-friction surface is assumed, representing packed snow and with $\mu = 0.3$.

2.1 Scenario 1 - Simulated Open-Loop Evasive Lane-Change

The chosen manoeuvre assumes a desired lateral acceleration of 2.5 m/s^2 occurring from 5 to 6.5 s, followed by a rightward desired lateral acceleration of -3 m/s^2 from 6.5 to 9.5 s.

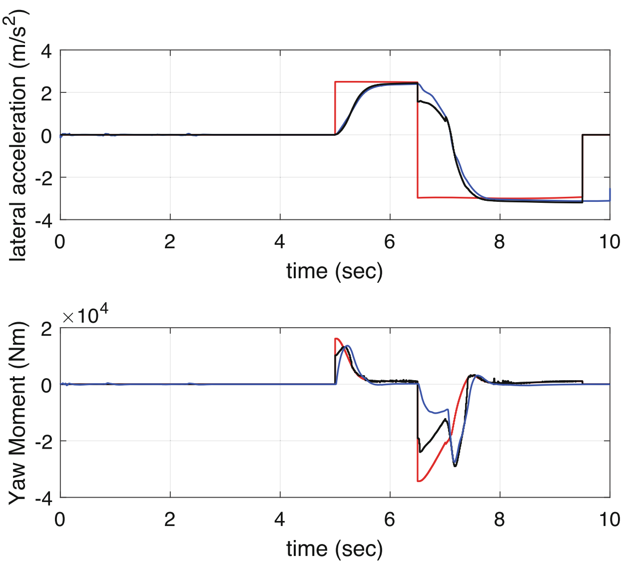

Fig. 2. Top: lateral acceleration tracking performance in vehicle coordinates. Bottom: yaw moment performance diagnostics. Red: desired Blue: from simulation Black: MHA internal estimation

The initial speed is set at 80 km/h, and a PID speed controller is used to maintain this speed before the manoeuvre begins, while it is deactivated during and after the manoeuvre. This open-loop desired acceleration vector roughly emulates an obstacle avoidance lane change. The lateral acceleration tracking performance in vehicle coordinates is shown in Fig. 2. It is seen that lateral acceleration targets are tracked well, though with some delay due to the yaw dynamics being required to establish slip angles at the rear tyres. The yaw moment plot is to confirm that MHA drives the yaw dynamics in a suitable way. This provides a diagnostic check on the algorithm, in which precise tracking of M_z is neither expected nor required.

2.2 Scenario 2 - Simulated Closed-Loop Evasive Lane-Change

Here, a closed-loop lane change is executed, with a target window of three seconds, where a Sliding Mode Controller approach is used to provide a lateral acceleration reference based on a predefined path [7]. Pure Pursuit is employed before and after the lane change manoeuvre as a steering controller [8]. The reference speed is 50 km/h and again the speed control is disconnected at the start of the manoeuvre. Figure 3 shows time histories for the vehicle speed, lateral acceleration tracking, vehicle sideslip angle and CG lateral offset.

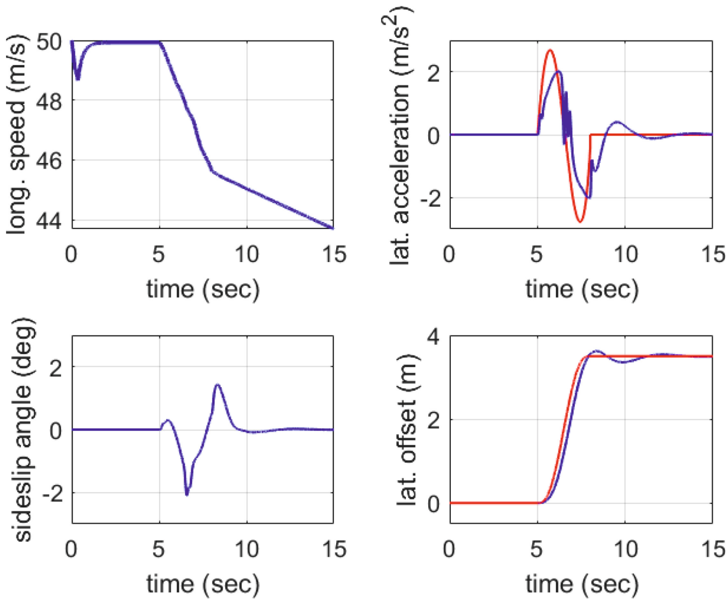

Fig. 3. Lateral acceleration and vehicle motion variables. Red: desired blue: from simulation

Even though the target acceleration request is purely lateral, the vehicle speed is seen to reduce due to the use of differential braking for yaw control.

Note that MHA effectively controls the rear lateral tyre forces via yaw moments and body sideslip corrections.

3 Impact of λ Updating Gain (K) on MHA Performance

Referring to Fig. 1, parameter lambda is adjusted in real-time to control the yaw dynamics, while parameter K controls the speed of response of this parameter. Here we briefly investigate the effect of K on acceleration tracking, and for simplicity, the open-loop manoeuvre of scenario 1 is used. Results are shown in Fig. 4.

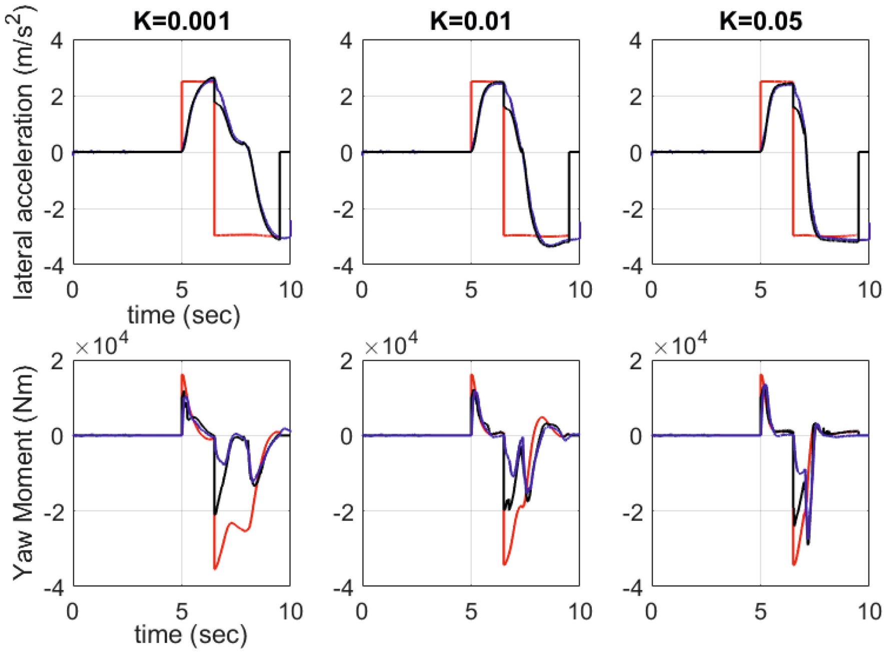

Fig. 4. Lateral acceleration in vehicle coordinate and yaw moment diagnostic plots. Blue: from simulation Black: MHA internal estimation Red: desired

It is seen that the larger value of K is required to achieve the speed of response necessary for tracking highly transient lateral acceleration demands. Moreover, the yaw moment diagnostic curves are more convergent in the case where K is larger, indicating the overall satisfactory performance of the algorithm. Further increases in K is however not desirable because of a tendency towards high-frequency chattering in the actuator commands.

4 Conclusion

This paper considered the coordinated chassis control of a 6 × 4 HGV tractor using MHA to control transient manoeuvres under friction-limited conditions. It is understood that the control of lateral acceleration is crucial in these kinds of scenarios, with the speed of its tracking response being equally vital during evasive lane change manoeuvres. By examining the MHA internal diagnostic plots, we could assess the controller's performance and how it was realized from the vehicle's perspective. We also found that while MHA is effective for integrated chassis control, the parameter K needs to be adjusted and tuned. Additional experimental results, obtained using a lower K value, closely matched the simulation results; however, due to space constraints, these details were not included in this paper. Although MHA was applied to a three-axle HGV tractor, it can be easily adapted for use in two- or four-axle vehicles and deals with such changes in a straightforward manner.

References

1. Woodrooffe, J., Blower, D.F., Gordon, T., Green, P.E., Liu, B., Sweatman, P.: Safety Benefits of Stability Control Systems for Tractor-Semitrailers. National Highway Traffic Safety Administration, Washington (2009)
2. Sinigaglia, A., Tagesson, K., Falcone, P., Jacobson, B.: Coordination of motion actuators in heavy vehicles using model predictive control allocation. In: 2016 IEEE Intelligent Vehicles Symposium (IV), pp. 590–596 (2016)
3. Yang, D., Gordon, T.J., Jacobson, B., Jonasson, M.: Quasi-linear optimal path controller applied to post impact vehicle dynamics. IEEE Trans. Intell. Transp. Syst. **13**, 1586–1598 (2012)
4. Gao, Y., Lidberg, M., Gordon, T.: Modified Hamiltonian algorithm for optimal lane change with application to collision avoidance. MM Sci. J., 576–584 (2015)
5. Kirk, D.E.: Optimal Control Theory: an Introduction. Courier Corporation, Chelmsford (2004)
6. Noori Asiabar, A., Gordon, T., Gao, Y., Henderson, L., Laine, L.: On the control allocation performance of longer combination vehicles. In: The IAVSD International Symposium on Dynamics of Vehicles on Roads and Tracks, pp. 757–766. Springer, (2021)
7. Noori Asiabar, A., Gordon, T., Gao, Y., Henderson, L., Laine, L.: Coordinated chassis control of a tractor-semitrailer combination operating at its handling limits using the MHA methodology. Veh. Syst. Dyn. 1–26 (2024). https://doi.org/10.1080/00423114.2024.2367612
8. Noori Asiabar, A., Gordon, T., Gao, Y., Henderson, L., Laine, P.J.: Integrated motion control of heavy goods vehicles using multiple actuators. In: Advances in Dynamics of Vehicles on Roads and Tracks II: Proceedings of the 28th Symposium of the International Association of Vehicle System Dynamics, IAVSD 2023, August 21–25, Ottawa, Canada (2023)
9. Model, V.T.: Simulink Library Developed at Volvo Group Trucks Technology. Department BF72991 (2014)