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Advanced robust and predictive approaches for active chassis control

Olivier SENAME
GIPSA-lab - Department of Control Systems,
ENSIEG, BP 46,
38402 Saint Martin d'Heres Cedex, France
olivier.sename@inpg.fr

I. SESSION TOPIC

Over the past few years, automotive engineering has been characterized by rapid growth in active systems. In particular efforts to improve driving safety and comfort under all driving conditions have been naturally focused on the chassis behavior.

During the last decade, active control of vibration isolation in automotive vehicle has known a growing interest in research [1], [2]. In particular the interest of robust control approaches (such as H_∞ approach for Linear Parameter Varying systems), and of predictive ones (such as Model Predictive control) has been recently emphasized in the context of active suspension [3], [4], [5], [6].

Besides new control methods have been developed for driving safety, using different actuators (braking, steering, differential ...) to tackle emergency situations such as slipping (ABS, Anti-locking Braking System) [7], [8] or important lateral and yaw accelerations, when the driver might loose control of the vehicle (ESC/ESP, Electronic Stability Control / Program).

On the other hand, the complex and multivariable inherent nature of the vehicle asks for the need of integrated approaches, in order to account for the coupling dynamics (roll, yaw, pitch, vertical, longitudinal and lateral behaviors) and to deal with different actuators.

The aim of this invited session is to give some recent results on vehicle dynamics control using robust and predictive control approaches. In particular the use of different actuators to improve vehicle safety is investigated, and the vehicle/road interaction is considered.

II. SESSION GOALS AND COHESIVENESS

The session goal is to present various recent and innovative works where the vehicle efficiency and stability are improved using different kind of actuators (suspension, braking, steering, differential ...). An overview of the recent research topics on this field is therefore given and the interest of robust control and model predictive control approaches is emphasized.

The cohesiveness of the session consists in providing new results where the vehicle stability and the interaction between the vehicle and the road are considered. Papers 1, 2 and 3 propose new control methods to ensure vehicle stability through different actuators. Papers 4, 5 and 6 take into account the road/vehicle interaction to improve vehicle efficiency. Moreover in papers 3 and 6 the robust control approach allows to propose a fault tolerant control when a fault occurs at one of the braking or suspension actuators.

- In Paper 1 a Model Predictive Control (MPC) approach is used to control the vehicle dynamical behavior by a steering actuator and to account for roll dynamics.
- In Paper 2 a Fast MPC is considered for controlling the yaw rate dynamics using a rear active differential.
- Paper 3 deals with global chassis control, in the LPV/ \mathcal{H}_∞ framework, using braking and steering actuators, in order to increase the vehicle safety.
- Paper 4 investigates the interaction between braking control design and speed estimation performance, in particular during slipping.
- Paper 5 deals with active cruise control where different road interactions (road slope, rolling resistance, aerodynamic forces) are considered as unmodelled dynamics.
- Paper 6 proposes a suspension control strategy in the LPV/ \mathcal{H}_∞ context, where the change of the adhesion coefficient between the tire and the road is taken into consideration to improve safety during various maneuvers.

III. PAPERS OF THE SESSION

A. Paper 1

Title: Effects of Roll Dynamics in Advanced Model Predictive Control for Autonomous Vehicles

Authors: P. Falcone, G. Palmieri, F. Borrelli, H. E. Tseng

A Model Predictive Control (MPC) approach for autonomous vehicles is presented. We formulate a predictive control problem in order to best follow a given path by controlling the front steering angle. We start from the results presented in [9], [10], where the MPC problem formulation relies on a simple bicycle model, and reformulate the problem by using a more complex vehicle model including roll dynamics. We present and discuss simulations of a vehicle performing high

speed double lane change maneuvers where roll dynamics become relevant. The results demonstrate that the proposed model based design is able to effectively stabilize the vehicle by using a three dimensional vehicle model at the cost of a higher computational load.

B. Paper 2

Title: Vehicle yaw control using a fast NMPC approach

Authors: M. Canale and L. Fagiano

A model predictive control approach to improve vehicle yaw rate dynamics by means of a rear active differential is introduced. In particular, the use of nonlinear predictive controllers is investigated to show their effectiveness in the vehicle stability control context. In order to allow the online implementation of the designed predictive control law, a fast technique based on Set Membership approximation methodologies is adopted. Improvements on understeering characteristics, stability in demanding conditions such as μ -split braking and damping properties in impulsive maneuvers are shown through simulation results performed on an accurate nonlinear model of the vehicle.

C. Paper 3

Title: A Global Chassis Controller for Handling Improvements Involving Braking and Steering Systems

Authors: C. Poussot-Vassal, O. Senname, L. Dugard

To improve safety on commercial cars, a reconfigurable fault tolerant multivariable Global Chassis Controller (GCC) design, involving braking and steering systems is proposed. In case of emergency (e.g. loss of manoeuvrability), the GCC uses the braking system to handle the problem. But, in case of inefficiency of the braking system (e.g. due to low road adherence, large yaw rate error or actuator failure), detected by a brake efficiency measure, the proposed integrated controller activates the front steering system in order to handle the unlike vehicle dynamic. The proposed control structure is performed in the LPV/ \mathcal{H}_∞ framework.

D. Paper 4

Title: Analysing the interaction between braking control and speed estimation: the case of two-wheeled vehicles

Authors: Mara Tanelli, Maria Prandini, Sergio M. Savaresi, Fabio Codec and Alessandro Moia

In road vehicles, wheel locking can be avoided by means of electronic Anti-lock Braking Systems. In four-wheeled vehicles, the current trend in braking control systems design is to formulate the control problem as the regulation of the wheel slip. This is encouraged by the new braking systems technology, which allows to continuously modulate the braking torque. This possibility is becoming true also on two-wheeled vehicles, especially considering the last generation of electric scooters, where electric motors are used both as propulsion and braking systems. These actuators are capable of a very fine-grained modulation of both traction and braking torque. As the wheel slip cannot be directly measured, to employ it as controlled variable the vehicle longitudinal speed must be estimated. This paper investigates the interaction between braking control design and speed estimation performance. Specifically, we analyze in detail the half-car model dynamics and show that, assuming perfect speed knowledge, a slip controller can be designed which guarantees a unique closed-loop equilibrium which is globally asymptotically stable for all choices of the set point at the front and rear wheels and for all road conditions. Conversely, when such a controller is used together with an estimation of the vehicle speed taken from the fastest wheel - this is the common speed estimation method in two-wheeled vehicles - stability properties of the closed-loop system are lost. The obtained results suggest that great care must be taken in a coordinate design of the controller and the estimation algorithm, activities which, in the industrial reality, are often carried on by different teams.

E. Paper 5

Title: Robust grey-box closed-loop stop-and-go control

Authors: Jorge Villagra, Brigitte d'Andra-Novel, Michel Fliess, Hugues Mounier

This paper presents a robust stop-and-go control law, specially well adapted to car following in urban environments. Since many vehicle/road interaction factors (road slope, rolling resistance, aerodynamic forces) are very poorly known and measurements are quite noisy, a robust strategy is proposed within an algebraic framework. On one hand, noisy signals will be processed in order to obtain accurate derivatives, and thereafter, variable estimates. On the other hand, a grey-box closed-loop control will be implemented to compensate all kind of unmodeled dynamics or parameter uncertainties.

E Paper 6

Title: Design of reconfigurable and fault-tolerant suspension systems based on LPV methods

Authors: P. Gaspar, Z. Szabo, J. Bokor

Abstract: This paper proposes the design of reconfigurable suspension systems in road vehicles. The purpose of the suspension system is to improve passenger comfort and road holding during travel and improve safety during various maneuvers. In the modeling the nonlinearities in the suspension system, the changes in the forward velocity and the change of the adhesion coefficient between the tire and the road are taken into consideration. The effects of the longitudinal or lateral load transfers during maneuvers or abrupt hard brakings are monitored in order to reduce their harmful effects on handling and comfort. When a fault (loss in effectiveness) occurs at one of the suspension actuators a reconfiguration is required in order to guarantee fault-tolerant operation. The design of the proposed reconfiguration and fault-tolerant control is based on an H_∞ Linear Parameter Varying (LPV) method that uses monitored scheduling variables of the travel.

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