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Global chassis control using braking and suspension systems

P. Gáspár*, Z. Szabó*, J. Bokor*, C. Poussot-Vassal**, O. Sename**, L. Dugard**†

*Computer and Automation Research Institute, Hungary

**Laboratoire d'Automatique de Grenoble, France

1 Motivation

In the current design practice several individual active control mechanisms are applied in road vehicles to solve different control tasks, see e.g. [1,5,6,7]. As an example, the suspension system is the main tool to achieve comfort and road holding for a vehicle whilst the braking system is the main tool applied in emergency situations. Since there is a certain set of dynamical parameters influenced by both systems, due to the different control goals, the demands for a common set of dynamical parameters might be in conflict if the controllers of these systems are designed independently. This fact might cause a suboptimal actuation, especially in emergencies such as an imminent rollover. For example, the suspension system is usually designed to merely improve passenger comfort and road holding although its action could be used to improve safety [2]. The aim of the global chassis design is to use the influence of the systems in an optimal way, see [4,9].

The goal is to design a controller that uses active suspensions all the time to improve passenger comfort and road holding and it activates the braking system only when the vehicle comes close to rolling over. In extreme situations, such as imminent rollover, the safety requirement overwrites the passenger comfort demand by executing a functional reconfiguration of the control goals by generating a stabilizing moment to balance an overturning moment. This reconfiguration can be achieved by a sufficient balance between the performance requirements imposed on the suspension system. In the presentation an integration of the control of braking and suspension systems is proposed.

2 LPV modeling for control design

The model for control design is constructed in a Linear Parameter Varying (LPV) structure that allows us to take into consideration the nonlinear effects in the state space description, thus the model structure is nonlinear in the parameter functions, but linear in the states. In the control design the performance specifications for rollover and suspension problems, and the model uncertainties are taken into consideration.

In normal operation suspension control is designed based on a full-car model describing the vertical dynamics and concentrating on passenger comfort and road holding. The state vector includes the the vertical displacement, the pitch angle and the roll angle of the sprung mass, the front and rear displacements of the unsprung masses on both sides and their derivatives. The measured signals are the relative displacements at the front and rear on both sides. Since the spring coefficient is a nonlinear function of the relative displacement and the damping coefficient also depends nonlinearly on the relative velocities these parameters are used as the scheduling variables of our LPV model. The performance outputs are the heave acceleration, pitch and roll angle accelerations to achieve passenger comfort and the suspension deflections and tire deflections for road holding.

The design for emergency is based on a full-car model describing the yaw and roll dynamics and contains as actuators both the braking and the suspension systems. The state components are the side slip angle of the sprung mass, the yaw rate, the roll angle, the roll rate and the roll angle of the unsprung mass at the front and rear axles. The measured signals are the lateral acceleration, the yaw rate and the roll rate. The forward velocity has a great impact on the evaluation of the dynamics, thus this parameter is chosen as a scheduling variable in our LPV model. The performance demands for control design are the minimization of the lateral acceleration and the lateral load transfers at the front and the rear.

In order to monitor emergencies the so-called normalized lateral load transfers R , which are the ratio of lateral load transfers and the mass of the vehicle at the front and rear axles, are introduced. An adaptive observer-based method is proposed to estimate these signals [3].

*Corresponding author: Péter Gáspár, Kende u. 13-17, H-1111 Budapest, Hungary; Fax: (+36-1) 466-7503; Phone: (+36-1) 279-6171; E-mail: gaspar@sztaki.hu

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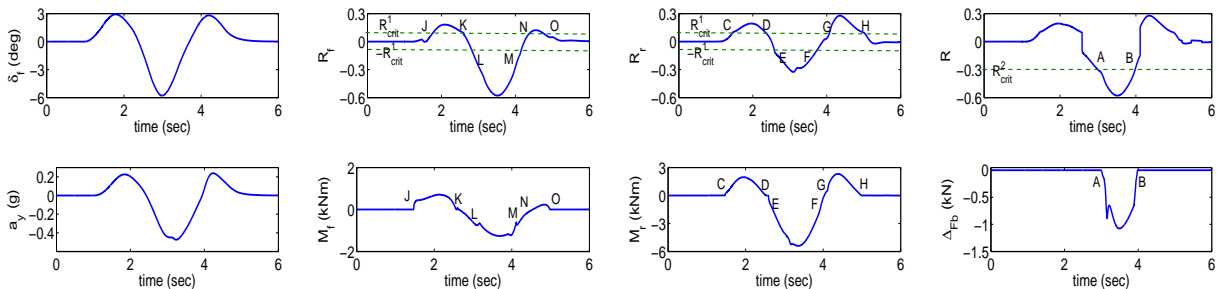
3 Integrated control design based on the LPV method

The control design is performed in an \mathcal{H}_∞ setting where performance requirements are reflected by suitable choices of weighting functions. In an emergency one of the critical performance outputs is the lateral acceleration. A weighting function $W_a(R)$, which depends on the parameter R is selected for the lateral acceleration. It is selected to be small when the vehicle is not in an emergency, indicating that the control should not focus on minimizing acceleration. However, $W_a(R)$ is selected to be large when R is approaching a critical value, indicating that the control should focus on preventing the rollover. As a result of the weighting strategy, the LPV model of the augmented plant contains additional scheduling variables such as the parameter R . The weighting function $W_z(R)$ for the heave displacement and heave acceleration must be selected in a trade-off with the selection of $W_a(R)$.

The \mathcal{H}_∞ controller synthesis extended to LPV systems using a parameter dependent Lyapunov function is based on the algorithm of Wu et al. [8]. The control design of the rollover problem results in the stabilizing roll moments at the front and the rear generated by active suspensions and the difference between the braking forces between the left and right-hand sides of the vehicle. A sharing logic is required to distribute the brake forces for wheels to minimize the wear of the tires. The control design of the suspension problem is to generate suspension forces which are modified by the demand of the stabilizing moment during an imminent rollover. The full version of the paper contains all the details concerning the analysis of this design.

4 An illustrative simulation example

The operation of the integrated control is illustrated through a double lane changing maneuver based on a model of a real vehicle. The time responses of the steering angle, the normalized load transfer at the front and the rear and their maximum, the lateral acceleration, the roll moments at the front and the rear and the difference of the braking forces are presented in the figure. When a rollover is imminent the values R increase and reach a lower critical limit (R_{crit}^1) and suspension forces are generated to create a moment at the front and the rear to increase the stabilization of the vehicle. When this dangerous situation persists and R reaches the second critical limit (R_{crit}^2) the active brake system generates unilateral brake forces in order to reduce the risk of the rollover. The detailed analysis of the example is included in the full paper.



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