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On Linear-Parameter-Varying Roll Angle Controller Design for Two-Wheeled Vehicles

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Abstract

In the past several years, strong efforts have been put forward to derive accurate mathematical models of two-wheeled vehicles [1, 2]. Accurate simulation of two-wheeled vehicle dynamics is often not enough; a model of the driver is also required to study the response on the vehicle during demanding maneuvers.

The literature on two-wheeled vehicle rider models is recent [4, 7, 8]. In most cases a two-layer controller is adopted: an *external* control law computes the control input that would track the reference ground trajectory, and an *inner controller* stabilizes the dynamics. In [5, 6], an extra step is added where an optimal trajectory is computed. The *Optimal Maneuver Method* is used to compute the reference ground path and speed to be followed. The reference optimal trajectory is then stabilized using two independent loops for controlling speed and lateral deviation. Currently the optimization phase, because of computational limitations, can be carried out only on a simplified model. To simulate the maneuver on the complete model, the optimal maneuver is computed on the simplified model and then the inner stabilizing loop is used to track the reference on the complete model. This approach is successfully applied in many conditions; but as the maneuvers become more extreme (with hard accelerations and high lean angles) the inner PID controllers cannot track the reference in a satisfactory way.

The scope of the present paper is that of improving the above internal controller by using a gain-scheduled roll-angle controller. Accordingly, it will be assumed to have an optimal roll angle reference.

By linearizing the complete nonlinear model around different values of forward velocity and lateral acceleration, it can be noted that the transfer function from steering torque to roll angle is subject to a strong variability. The velocity mainly affects the weave and wobble modes and the lateral acceleration affects the low frequency gain. A fixed structure controller has to compromise the achievable performance in order to cope with the time-variability of the system. Given these premises, a Linear-Parameter-Varying (LPV) approach [3] represents a good solution as it provides tools to design scheduled controllers which are guaranteed to retain stability and performances.

Two controllers are designed: a fixed structure $\mathcal{H}_\infty$ controller and an LPV controller. The use of

the $\mathcal{H}_\infty$ design tools enables a fairer comparison as the two controllers optimize the same cost function. The LPV controller is designed using a grid-based technique; in particular a dual grid synthesis is employed in order to improve the numerical properties of the final controller without increasing the computational complexity.

Figure 1 plots the responses of the two controllers to a roll angle reference that simulates high speed cornering. The motorcycle enters the corner at constant speed, when the apex of the corner is reached the motorcycle is accelerated to full throttle. A maximum lean angle of 60° is reached. The LPV controller successfully negotiates the maneuver whereas the fixed structure controller cannot stabilize the system during the acceleration phase.

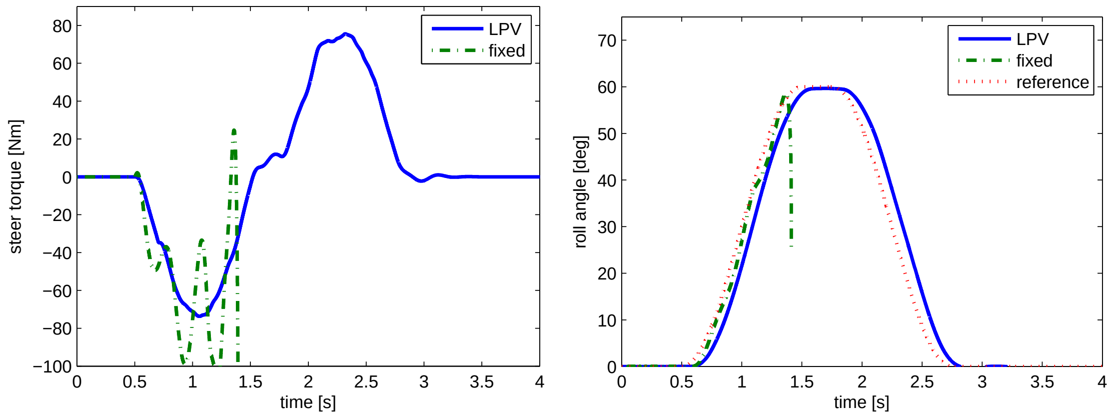

Figure 1. Simulation results of a cornering maneuver carried out with the two discussed controllers. Applied steer torque (left) and roll angle (right).

References

[1] R. Sharp, D. Limebeer, “A motorcycle model for stability and control analysis”, *Multibody System Dynamics* **6** (2001), pp. 123–142.

[2] V. Cossalter, R. Lot, “A motorcycle multi-body model for real time simulations based on the natural coordinates approach”, *Vehicle Systems Dynamics* (2002).

[3] M. Corno, S.M. Savaresi, “On linear-parameter-varying (LPV) slip-controller design for two-wheeled vehicles”, *International Journal of Robust and Nonlinear Control* (2008).

[4] A. Saccon, J. Hauser, A. Beghi, “A virtual rider for motorcycles: an approach based on optimal control and maneuver regulation”, *in International Symposium on Communications, Control and Signal Processing*, St. Julians, Malta. March 2008.

[5] R. Lot, M. Massaro, V. Cossalter, “Advanced motorcycle virtual rider”, *Vehicle System Dynamics*, **46** (2008), p 215-224.

[6] R. Lot, V. Cossalter, “A nonlinear rider model for motorcycles”, *in FISITA 2006 World Automotive Congress* Yokohama, Japan. October 2006.

[7] R. Sharp, “Motorcycle steering control by road preview”, *Journal of Dynamic Systems, Measurement, and Control* **129** (2007), pp. 373–381.

[8] S. Rowell, A. A. Popov, J. P. Meijaard, “Application of predictive control strategies to the motorcycle riding task”, *Vehicle Syst. Dyn.* **46** (2008), pp. 805Ð814.