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Discussion on "Experimental Identification of Engine-to-Slip Dynamics for Traction Control Applications in a Sport Motorbike"

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1 Introduction

Vehicle dynamics is today of great importance in automotive industry. Indeed, over the past few years, automotive engineering has been characterized by rapid growth in active systems. Many research works have therefore been devoted to the control of such active subsystems, as braking, steering or suspension actuators. In particular the control of suspension systems still remains of interest since this subsystem influences comfort and road handling as well [1, 2, 3]. More recently the use of different actuators (braking, steering, suspension ...) has shown to allow for emergency situations such as rollover, too large lateral and yaw accelerations, slipping [4, 5, 6].

However, as emphasized by Matteo Corno and Sergio Savaresi much less work have been devoted to motorbike control, in particular in sport industry. The aim of the paper is then to bring some contribution for Traction Control applications. Indeed some new methodology for experimental identification of engine-to-slip dynamics is proposed, leading to the analysis of the interest of throttle or spark-advance actuators for slip control respectively.

First, the authors present two algorithms that can be used for wheel speed measurements. It is emphasized that both solutions lead to some estimation delays, which depends on the type and characteristics of the sensor. The core of the paper concern the identification of engine-to-slip dynamics using as input variable, either the throttle position, or the spark advance.

2 About Modelling

Here some comments on the identified models are drawn. In the paper two identification methods are proposed, for both actuator cases,

- first a frequency method (describing functions) is considered, with time-varying multi-frequency sinusoidal signals. Three harmonics model are obtained through an optimization procedure: the first is the linear system. The second and third harmonic generator correspond to the generation of twice and three times the input frequency. The sum of these three transfer functions composes the identified model, accounting for the "non linear" harmonic generation.

- on the other hand, a "step" method is proposed to identify a switched linear system to account for the closing and opening phases of the actuator.

In the paper the frequency-responses of the three harmonics model are analyzed, and it is shown that this model allows to better represent the slip dynamics in higher frequencies. The author then explain that a switching system allows to represent the asymmetric behavior of the system, and is shown to be closer to the real experiments than the first harmonic model.

Here an insightful analysis is provided through the comparison of both identification results. In the following the first harmonic and full harmonic (first+second+third ones) models are compared with both modes of the switching system, in the case of the throttle-to-slip dynamical model. Here ω_c is chosen as 1rad/s and the time-delay is $h = \frac{35 \cdot \pi}{180 \omega_c} = 610\text{ms}$.

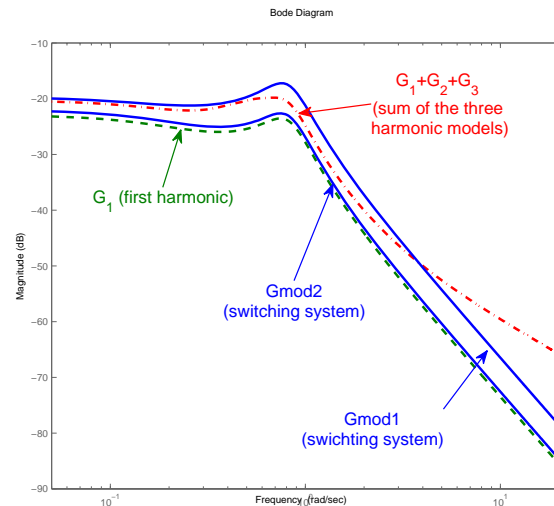


Figure 1: Comparison of harmonics and switching models

The comparison is also evaluated through step responses, as shown in Fig. 2.

As illustrated in Fig. 1 and Fig. 2 the "real" full harmonic model is better approximated by the 2 modes switching system, while the first harmonic model only corresponds to a single mode of the switching system.

This emphasizes the interest of the switching model that frames the "real" system. To conclude, this switching model should be used for control design.

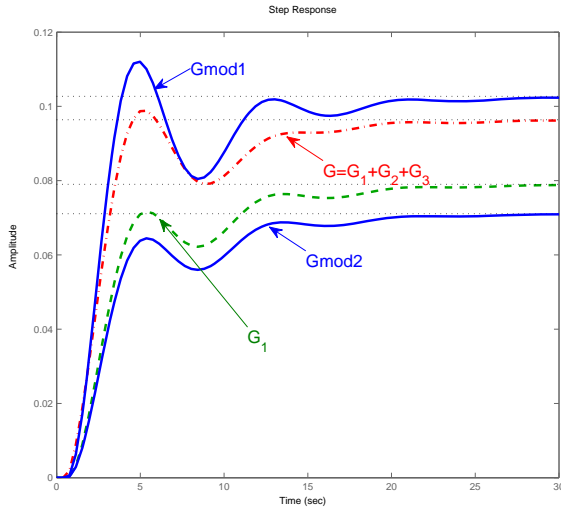


Figure 2: Model step response

3 Has the delay an influence on control performance ?

In the paper it is emphasized that the throttle-to-slip dynamics includes a pure (input) time-delay representative of the air-box dynamics. As shown above choosing the normalized frequency $\omega_c = 1rad/s$, the input time-delay is

$$h = \frac{35 \cdot \pi}{180 \omega_c} = 610ms$$

Note that the sensor delay due to the speed measurement method (and depending on the number of teeth of the sensor) should be added and varies between 0 to 30ms.

In terms of delay modelling it can be then assumed that the system includes an uncertain delay:

$$d = h + \delta, \quad \delta \in [0, 30]ms$$

Here, a usual H_∞ control (see [7]) is proposed, assuming that the control model G is the linear first harmonic one (G_1 in Fig. 1 and 2), which is much simpler (order 2) for control synthesis than the full harmonic one (order 11). The H_∞ control consists in finding a controller that internally stabilizes the closed-loop system and ensures: $\|N_{ew}(s)\|_\infty \leq \gamma$ where $N_{ew}(s)$ is the closed-loop transfer matrix from the exogenous inputs to the controlled outputs. The minimal value γ_{opt} is then obtained by solving an LMI problem. Here the considered H_∞ problem is:

$$\left\| \begin{array}{cc} W_e S & W_e \cdot S \cdot G \\ W_u K S & W_u \cdot T \end{array} \right\|_\infty \leq \gamma \quad (1)$$

with $T(s) = \frac{K(s)G(s)}{1+K(s)G(s)}$ and $S(s) = \frac{1}{1+K(s)G(s)}$.

The choice of the weighting functions W_e, W_u is a key issue in the H_∞ problem. Here simple first order functions have been chosen, in order to ensure a settling time twice lower than the open-loop system. The obtained sensitivity functions are given in Fig. 3. It shows that the closed-loop system satisfies the required performances (in terms of bandwidth, disturbance rejection, robustness margin and actuator limits).

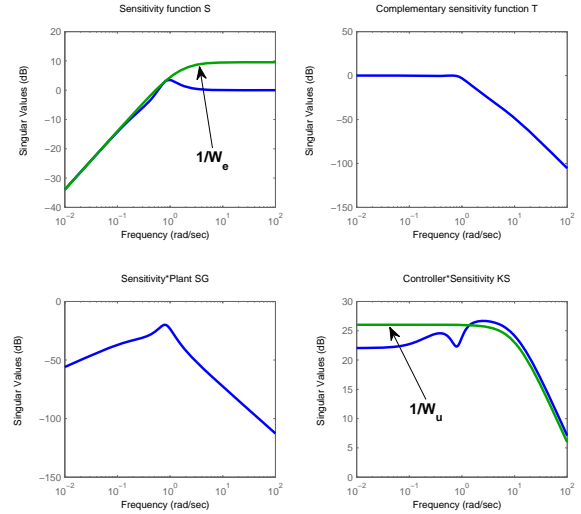


Figure 3: Sensitivity functions and weighting functions

In Fig. 4 the delay influence on performances in analysed: the following step responses are studied:

- Ideal case: without input delay
- Input delay case: when the H_∞ controller, designed without accounting for the delay, is implemented with an input time-delay h .

It is clear that, while here the H_∞ controller meets a delay margin equal to 1.8sec, the delay deteriorates the closed-loop performances, as shown below:

Criteria \ Case	Delay-free	Input Delay
Settling time	10.6 sec.	18.8 sec
Overshoot	6.25 %	29.5 %

It then should be taken into account for control synthesis.

4 A Smith-predictor approach

Let me recall that the objective of the Smith-Predictor is to reduce the "presence" of the delay in the closed-loop system, as if the delay were shifted outside the feedback loop [8, 9, 10].

Consider

$$H(s) = e^{-sh}G(s)$$

Denote $K(s)$ the H_∞ controller designed using $G(s)$ only, obtained in the previous section. The Smith Predic-

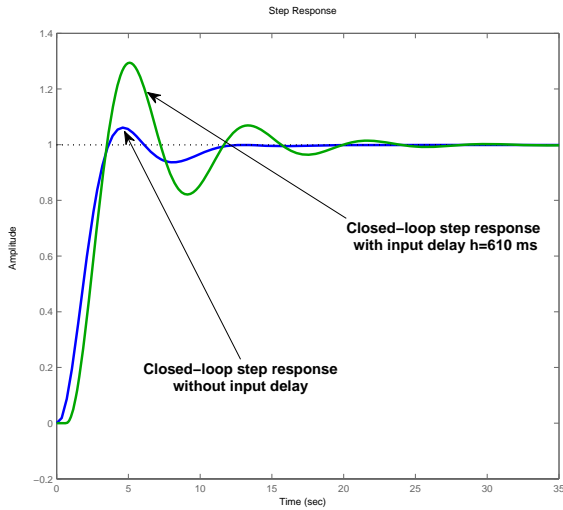


Figure 4: Step responses in closed-loop: delay-free and input-delay cases

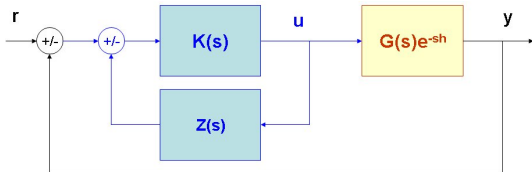
tor controller is defined by (see Fig. 4):

$$C(s) = \frac{K(s)}{1 + K(s)Z(s)} \quad (2)$$

$$Z(s) = G(s) - e^{-sh}G(s) \quad (3)$$

and ensures that the closed-loop system is:

$$T(s) = \frac{K(s)G(s)}{1 + K(s)G(s)} e^{-sh}$$



In Fig. 5 the time-domain simulations of the closed-loop systems, in the "Ideal case", in the "Input delay case", and in the Smith Predictor case, are given. Clearly the simulations prove the interest of the Smith-Predictor for time-delay compensation, which allows to get a closed-loop response as the one for the Ideal case, but delayed of h sec. Note also that some simulations have shown that the control scheme is very robust w.r.t delay uncertainties of $30ms$ (sensor dependent delay).

In the last simulations, the time-delay is twice the previous value, corresponding to a normalized frequency $\omega_c = 0.5rad/s$. The results in Fig. 6 emphasize that the induced-delay performance deteriorations are the least for the Smith Predictor controller.

This simple methodology emphasizes that the time-delay cannot be neglected to satisfy the performance objectives. Notice that this is a common case in engine and traction control where the delays are due to the engine cycles and/or the sensor locations.

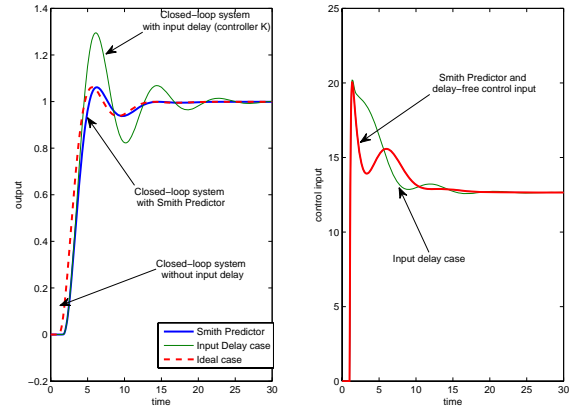


Figure 5: Step responses in closed-loop: interest of Smith Predictor

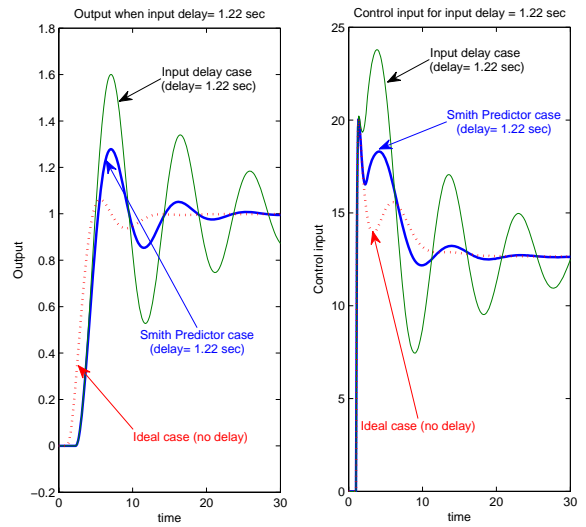


Figure 6: Step responses in closed-loop: robustness analysis for large delay uncertainties

5 Concluding remarks

First it has been shown in this paper that the modelling of the throttle-to-slip system can be approached by a switching system with two modes, since it better approximates the full "harmonics" model.

Then the delay issue has been discussed and the importance of taking into account the time-delay in control design has been emphasized. It appears that some recent methodologies in observation and control of time-delay systems, could be planned, as the ones proposed in [11, 12, 13].

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