ESTIMATION OF BRAKE FRICTION COEFFICIENT FOR BLENDING FUNCTION OF BASE BRAKING CONTROL

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Agenda

Motivations

Objectives

- Compensation of variations in the Brake Linings' Coefficient of Friction (BLCF)

BLCF Estimator

Results

Conclusions

Motivations

Increasing stiffening of driving safety and emission regulations has led the automotive industry to widen the fleet of EV and HEV

Improved vehicle safety and driving comfort

Reduction of global emissions

Electric Propulsion and Enhanced Mechatronics

EV and HEV features Electric Propulsion and Enhanced Mechatronic Subsystems, such as brake-by-wire

Driver Input

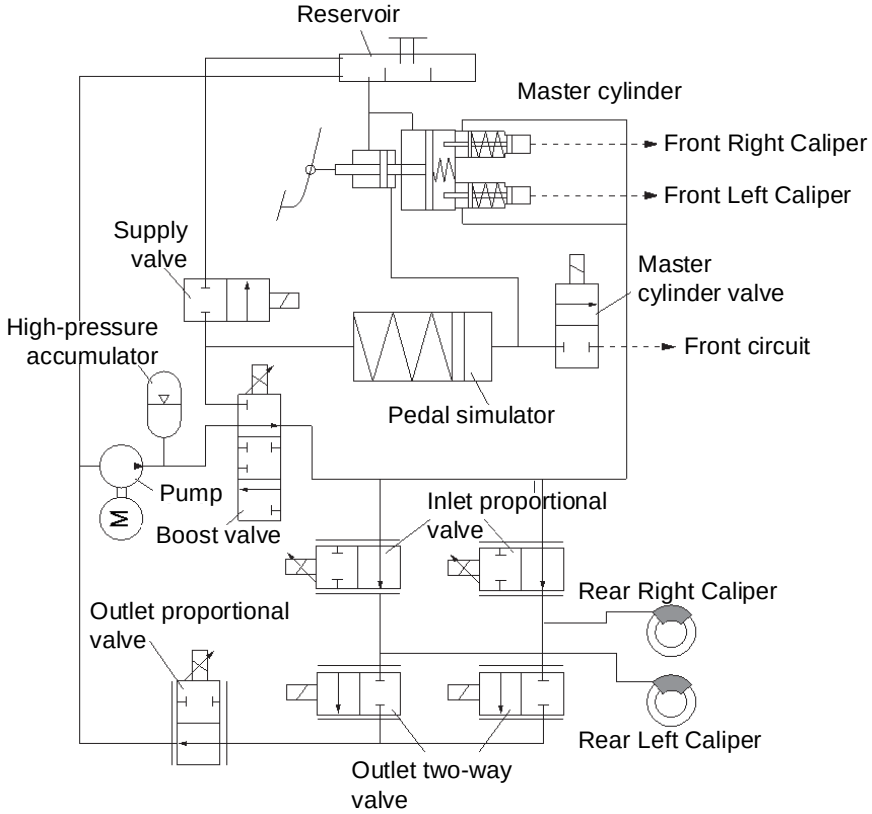
The coordination between conventional and electric brakes has to occur without driver noticing

Brake-by-wire: EHB

1) The brake pedal travel is measured and the pedal simulator creates the required feedback force to the driver

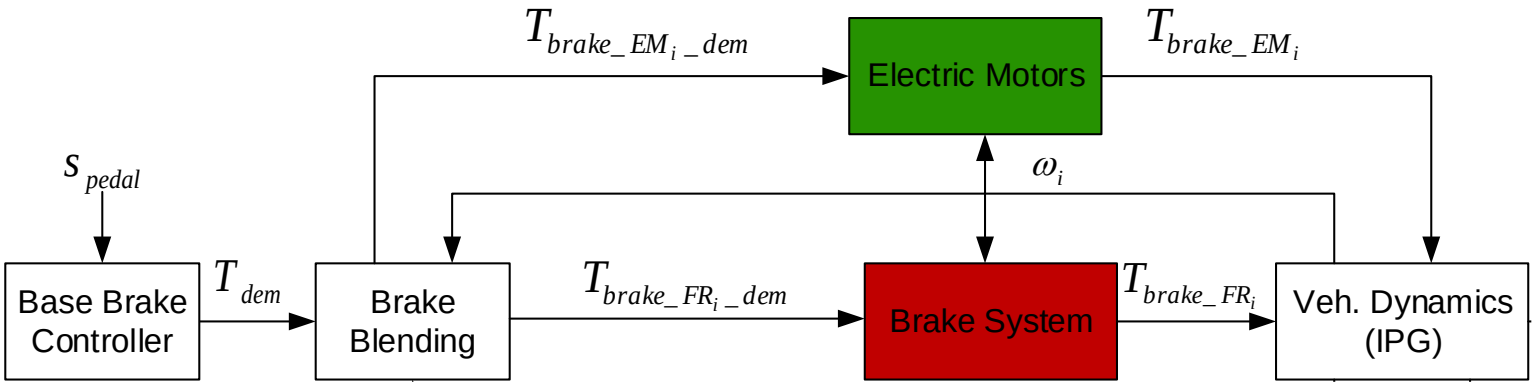
2) The VCU calculates the demanded brake pressure for each caliper and transfers the data to the EHCU

3) The EHCU realizes the actuation of wheel brake cylinders by setting the demanded pressure level in the wheel calipers through the proportional valves



Brake Controller

$$T_{dem} = m_v \cdot a_x^{ref}(s_{pedal}) \cdot r_w \longrightarrow p_{b,dem} = \frac{(1-\alpha) \cdot m_v \cdot a_x^{ref}(s_{pedal}) \cdot r_w}{2 \cdot \hat{\mu}_b \cdot A_{pad} \cdot r_{cl}}$$



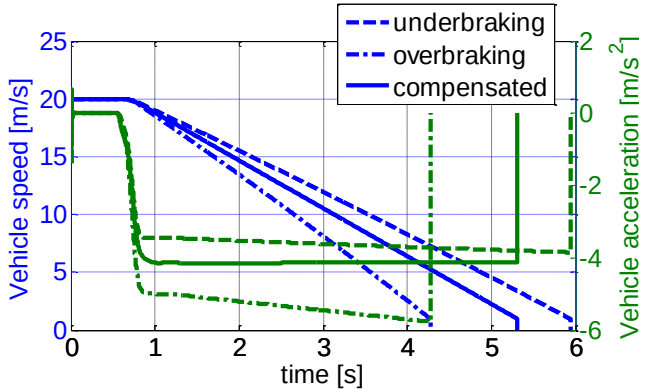
Objective: BLCF compensation

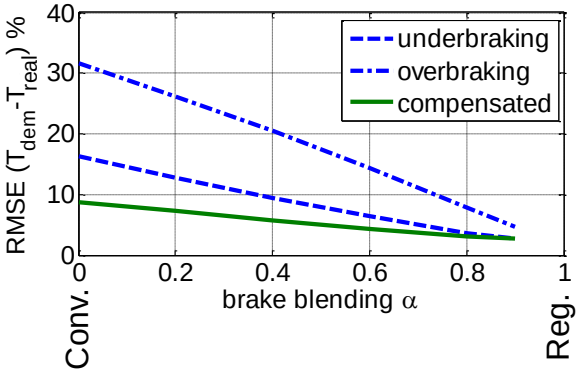
- Large BLCF deviations from the reference value employed in the controller can lead to unpredictable vehicle behavior, namely:

  $\hat{\mu}_{b_i} > \mu_{b_i}$ under-braking behavior

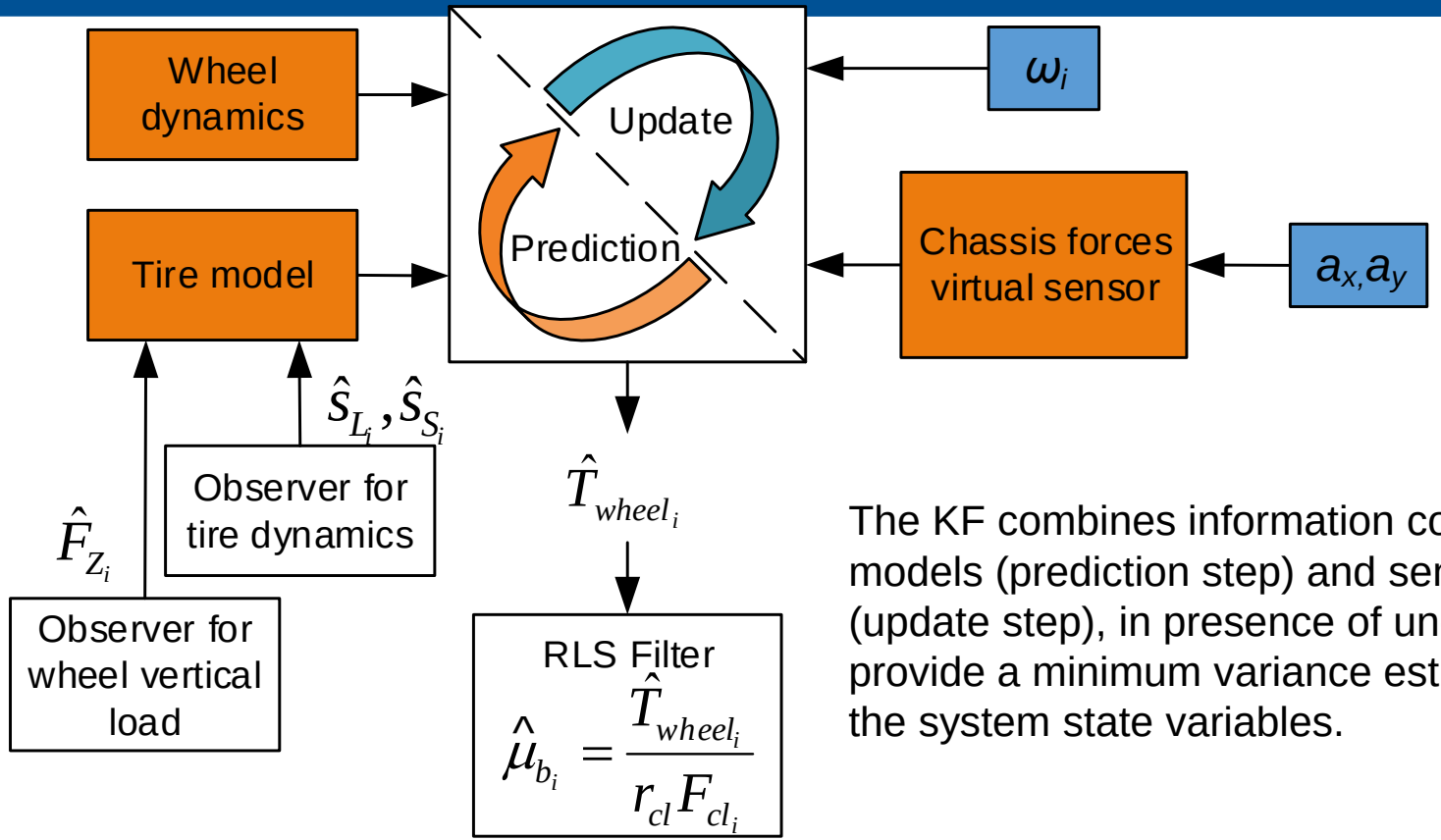
  $\hat{\mu}_{b_i} < \mu_{b_i}$ over-braking behavior

- The <u>disturbance compensation</u> abates the error between the demanded and the real deceleration level, resulting in an improved driving comfort and better system response





Virtual Sensor of BLCF



The KF combines information coming from models (prediction step) and sensors (update step), in presence of uncertainty, to provide a minimum variance estimation of the system state variables.

Wheel Torque Observer

1st order Euler

Random walk

- $x(t) = \{\omega_1, \dots, \omega_4, \dot{\omega}_1, \dots, \dot{\omega}_4, F_{L_1}^*, \dots, F_{L_4}^*, T_{wh}$

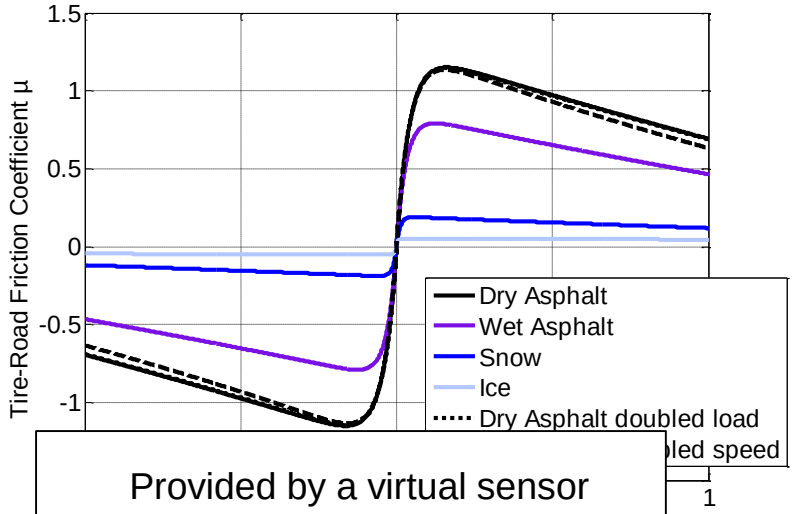
Eq. of wheel dyn.

$$\dot{\omega}_i = \frac{T_{wheel_i} - F_{L_i}^* \cdot r_w}{I_w}$$

Tir

μ_{re}

s_{re}



- $y(t) = \{\omega_1^s, \dots, \omega_4^s, F_{L_1}^{*\,vs}, \dots, F_{L_4}^{*\,vs}\}^T$

Measured quantities

Provided by a virtual sensor

$$F_x^{\,vs} = \underbrace{ma_x}_{\text{accelerometer}} - \underbrace{F_{a_x} - mg \cdot \sin(\vartheta)}_{\text{model}}$$

Wheel Torque Observer

$$\dot{\omega}_i = \frac{T_{wheel_i} - r_w F_{L_i}^*}{I_w}$$

Tire model

$$\mu_i = f(s_{res_i}, V_x, F_{z_i})$$

T_{wheel_i} Random walk

Prediction

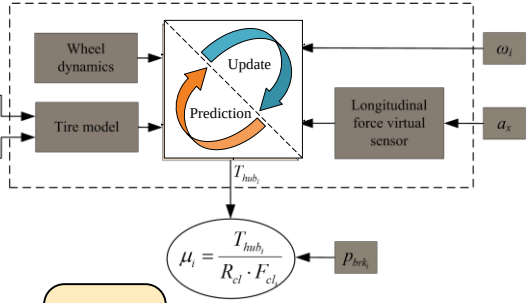
Update

Virtual sensor

$$\begin{Bmatrix} F_{L_i}^{*vs} \\ F_{S_i}^{*vs} \end{Bmatrix} = \bar{\bar{A}}_{(\alpha_i, \delta_w)} \cdot \begin{Bmatrix} K \cdot F_x^{vs} \\ K \cdot F_y^{vs} \end{Bmatrix}$$

$$F_x{}^{vs} = ma_x - F_{a_x} - F_{slope_x}$$

$$F_y{}^{vs} = ma_y$$



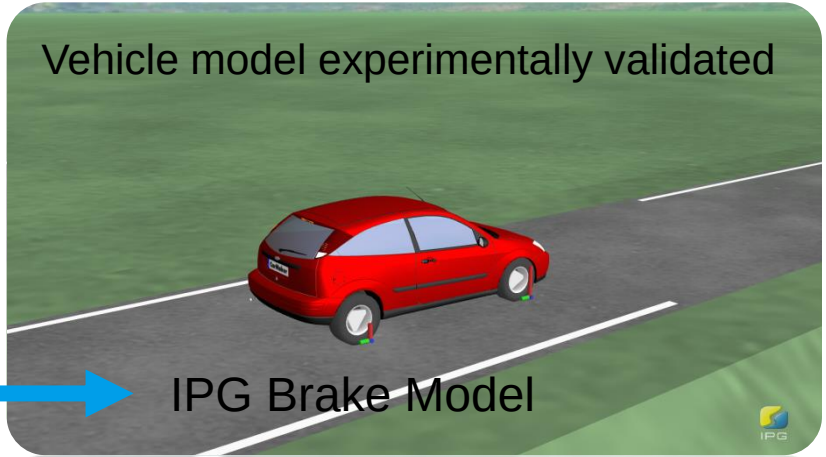
$u(t)$

$y(t)$

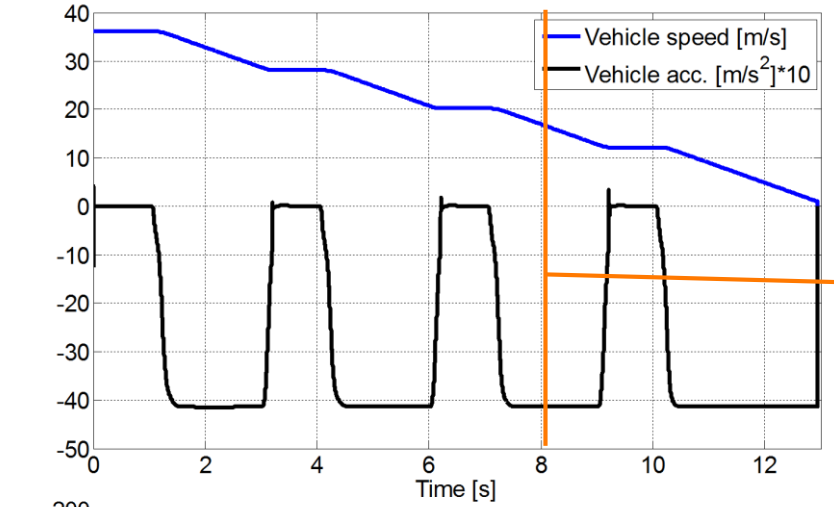
Simulation – IPG CarMaker

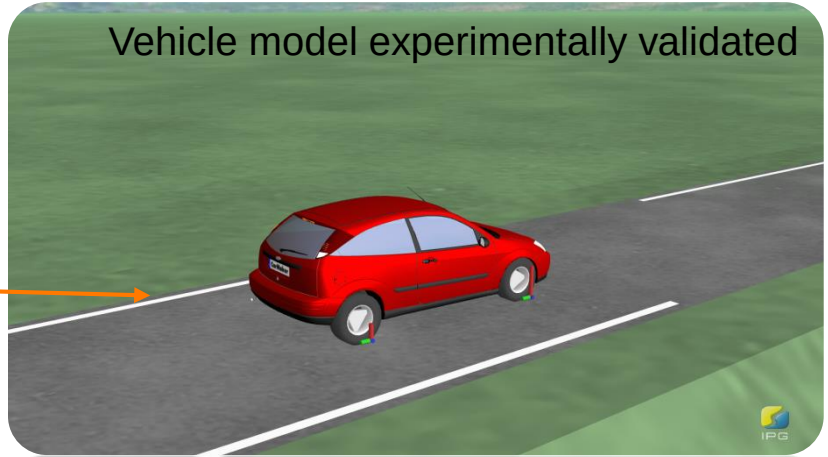
V	r full hicle
Total vehicle mass	1463 kg
Powertrain type	AWD
D	n-wheel
B	EHB
T	5

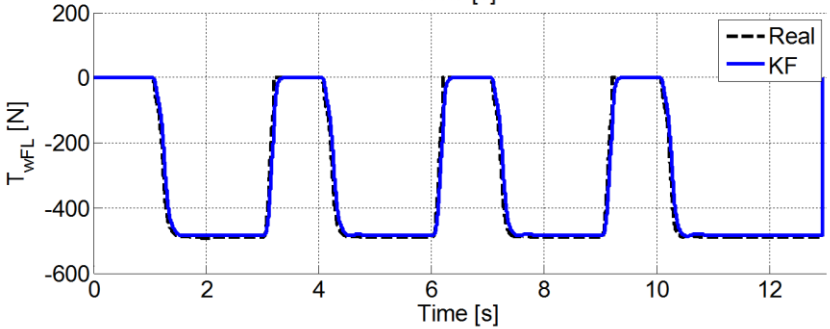
IPG Tire Model

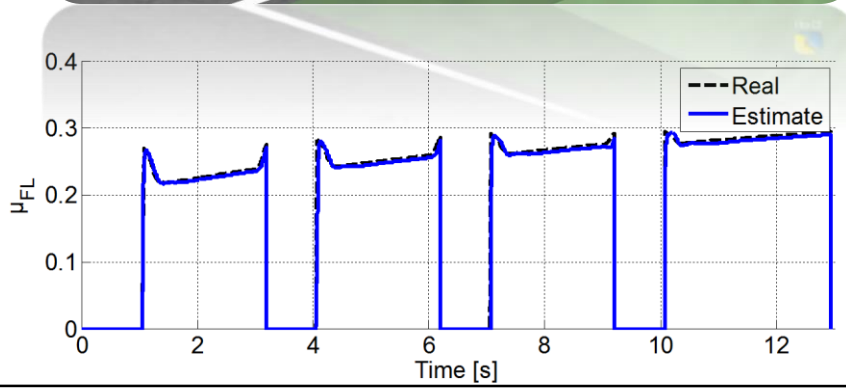


BLCF Estimation – Dry Road – No blending

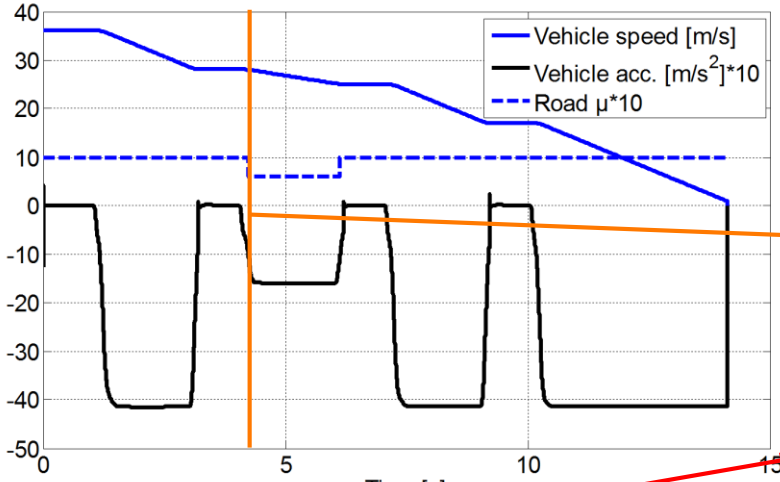


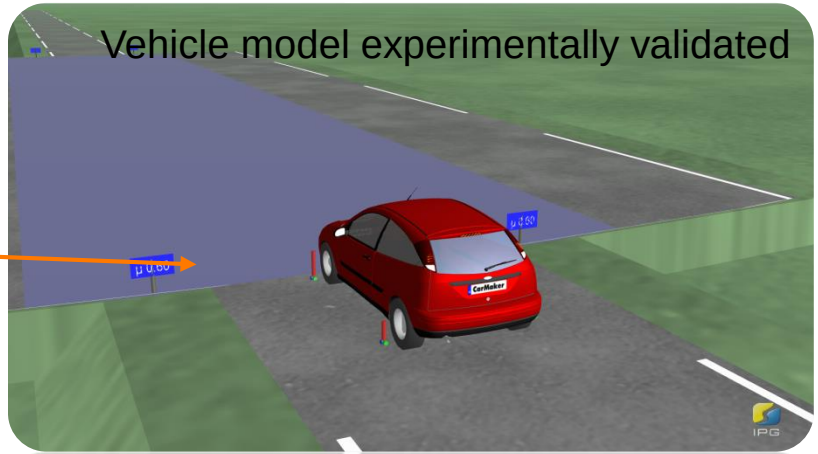


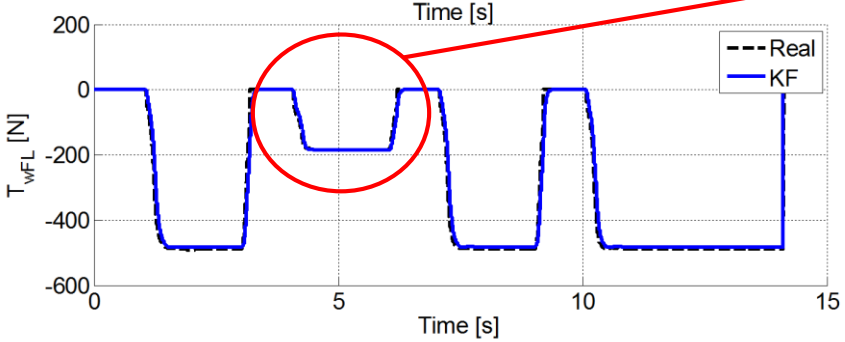




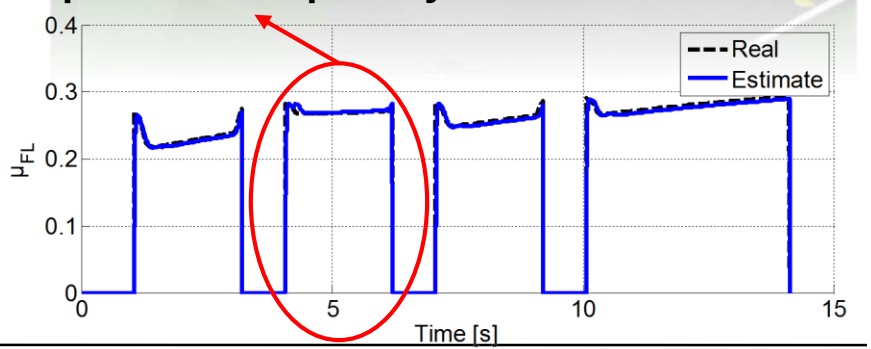
BLCF Estimation – Changing road conditions – No blending







Compensation capability

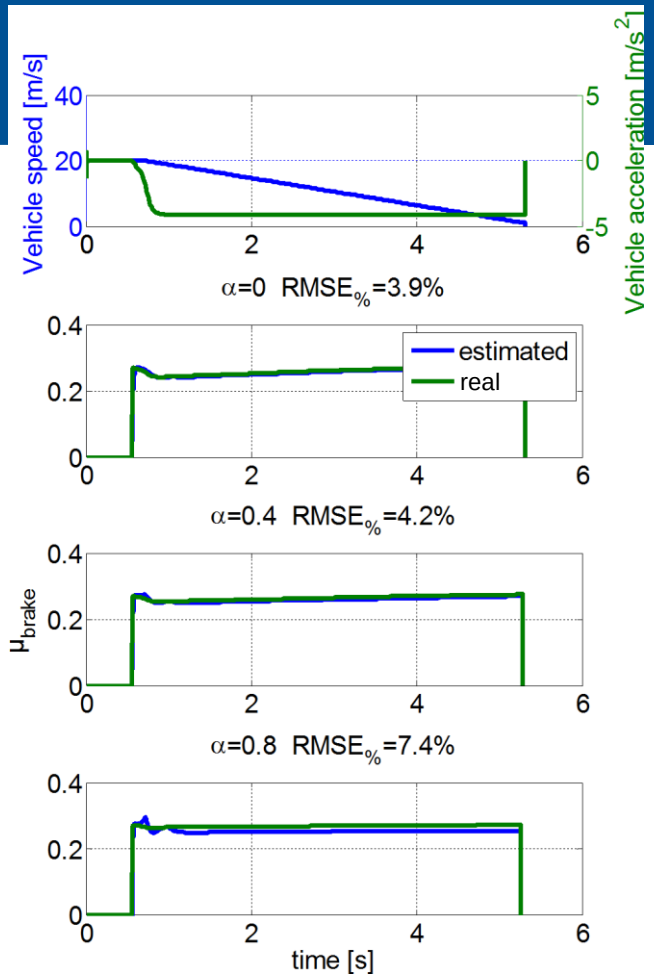


BLCF Estimation – Blending

$$V_0 = 72\ km/h$$

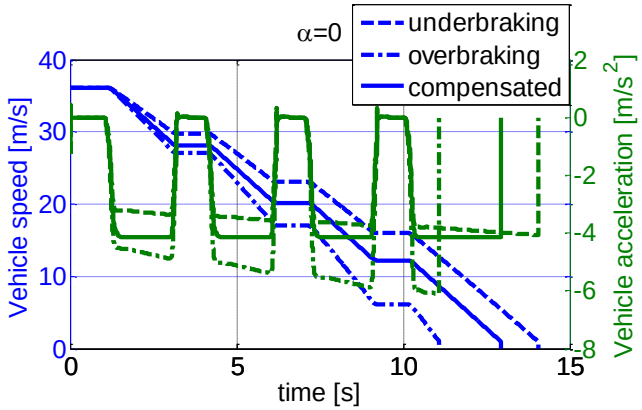
$$T_0 = 150\ °C$$

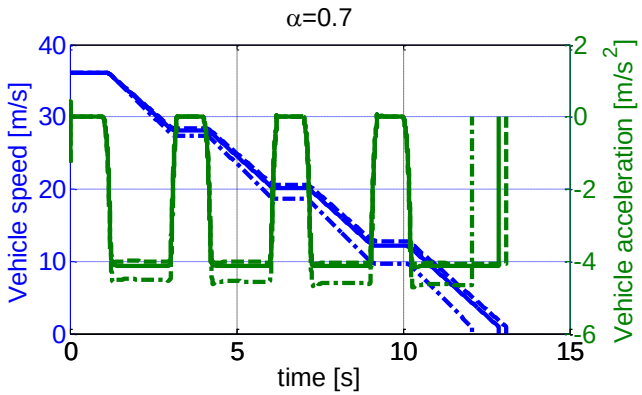
$$s_{pedal} = 60\%$$

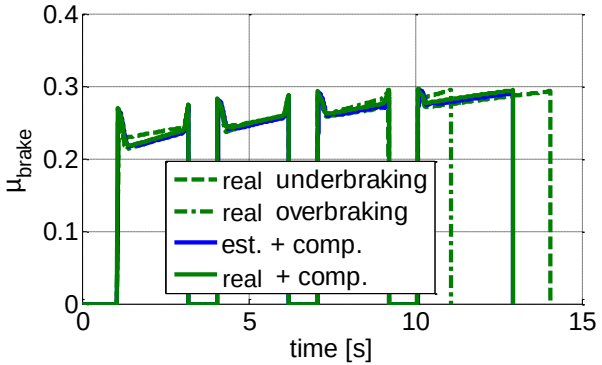


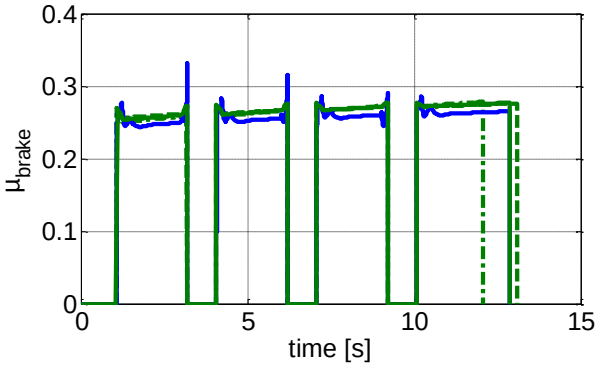
The estimation accuracy deteriorates for lower excitation levels

BLCF Compensation – Constant deceleration level









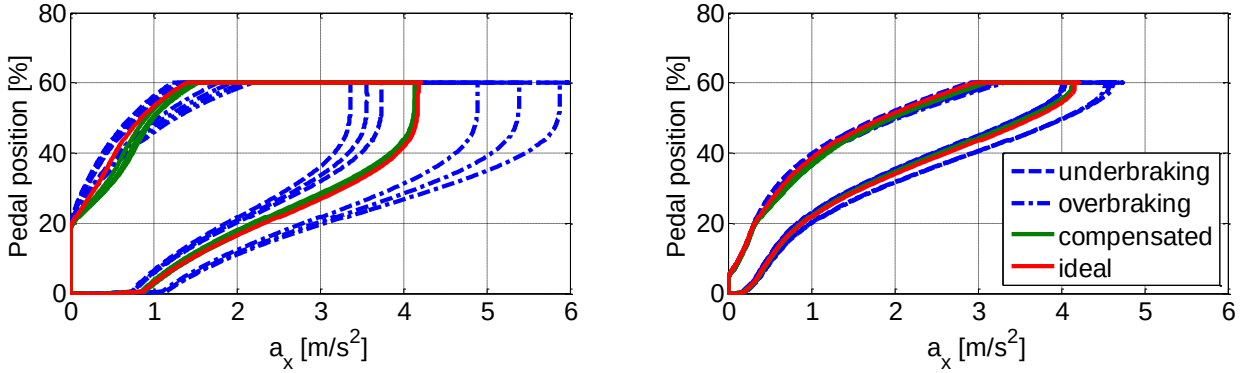
$V_0 = 130\ km/h$

$T_0 = 150\ °C$

$s_{pedal\_max} = 60\%$
(base braking)

The BLCF compensation allows attaining a constant vehicle deceleration level

BLCF Compensation – Improved brake pedal feel



- In the under-braking case (dash line), higher brake pedal travel must be applied to realize the same deceleration level.
- In the over-braking case (dash-dot line), the same pedal actuation produces higher deceleration levels.
- The compensation algorithm detecting a friction loss event aligns the pedal travel-deceleration curve to the ideal profile reducing the driver workload

Conclusion

- A state observer based on Kalman Filter is implemented to estimate the friction coefficient
- The observer features a compensation capability against changing road conditions and is easily tunable in case of variation of plant characteristics
- The knowledge of the current BLCF is necessary for enabling the compensation function within the EHB control unit
- The BLCF compensation allows to attain a constant vehicle deceleration level with simultaneous improvement of brake pedal feel.

Contact Information

Thank you for your kind attention

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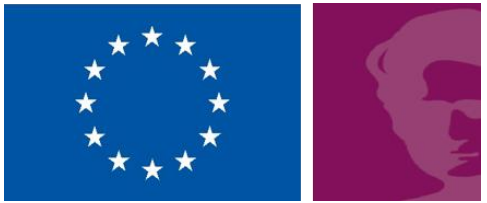
Acknowledgement



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