ON-BOARD DETERMINATION OF THE FRICTION COEFFICIENT BETWEEN TIRE AND ROAD USING STANDARD-APPLICATION VEHICLE DYNAMICS SENSORS

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ABSTRACT: With increasing automation of driving tasks, reliable information on the tire and road conditions is required to ensure safe automated transport. A method is presented to determine the maximum coefficient of friction between tire and road surface during driving based on measurements of the vehicle's dynamic state using a model-based approach. Using almost only standard sensors as installed in a vehicle with electronic stability control (ESC), it is demonstrated that the tire and road conditions can be estimated in many driving conditions with a high confidence.

METHOD

A particle filter, which is a Baysian state estimator suitable to observe non-linear states, was used to estimate the most probable maximum tire-road friction coefficient. The measurement input **z** contains estimates of the longitudinal tire forces for each tire, see Figure 1. It is estimated using measurements of the vehicle and wheel dynamics. Within the particle filter, these inputs are compared to hypotheses of longitudinal tire forces for different coefficients of friction and for the current wheel slip, slip angle and tire load. Figure 2 shows an example for both **z** and different **h**(x_h) during an acceleration manoeuvre.

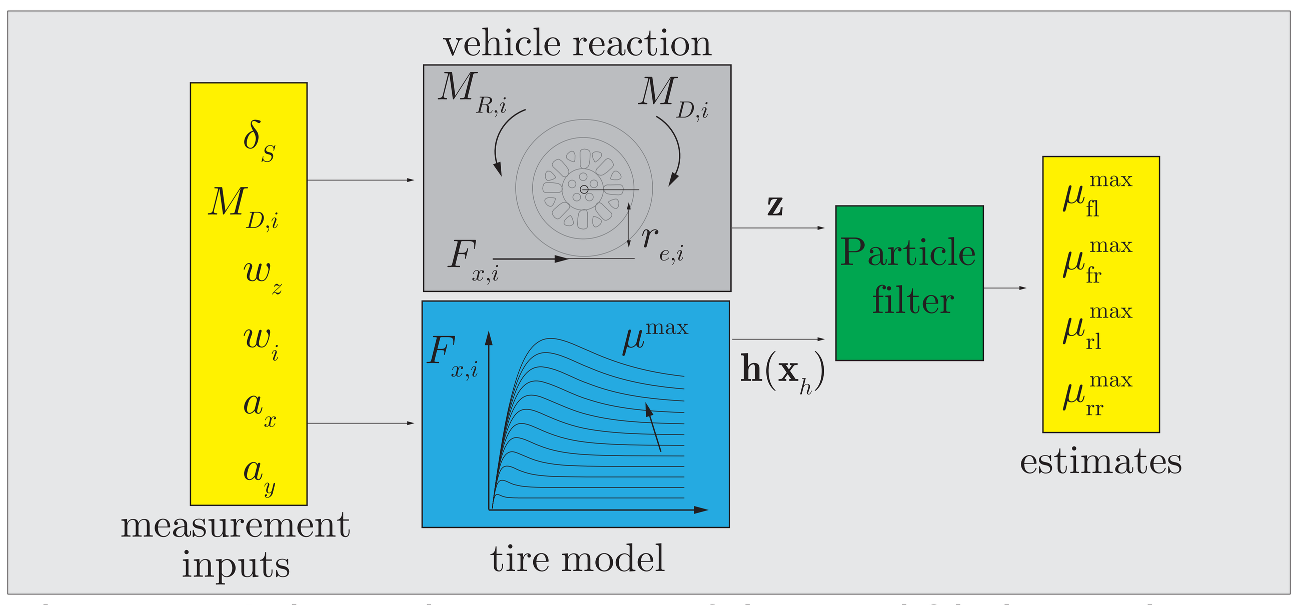

Figure 1 - Schematic structure of tire-road friction estimator

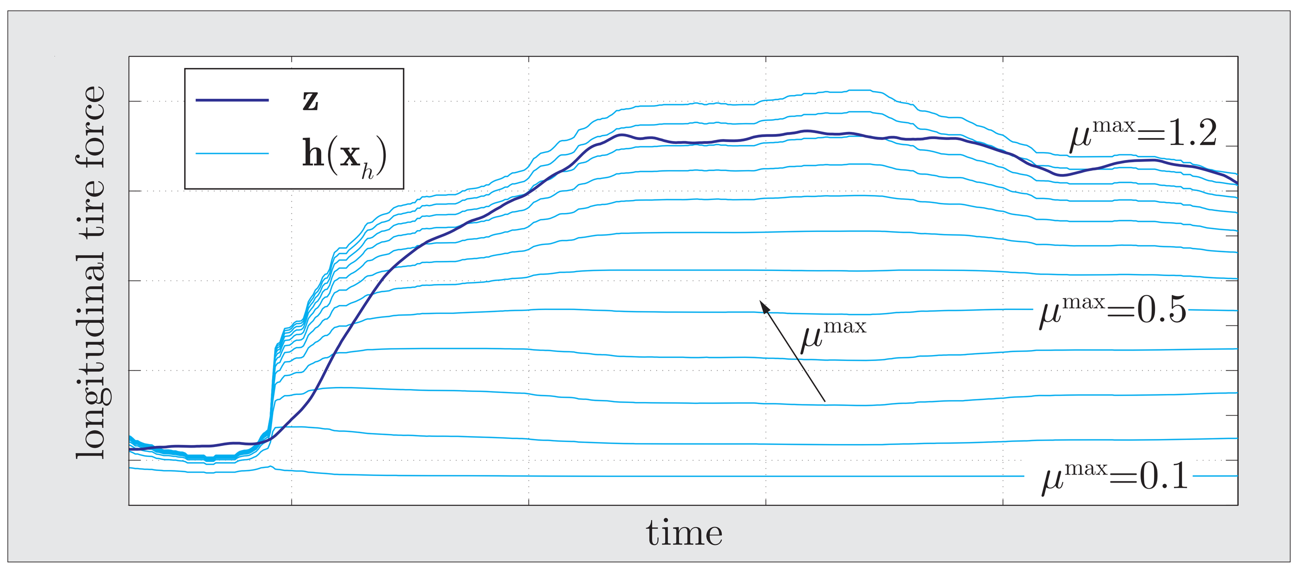

Figure 2 - Measurement vector z and particles h(x_h) for different maximum tire-road friction coefficients during an acceleration manoeuvre

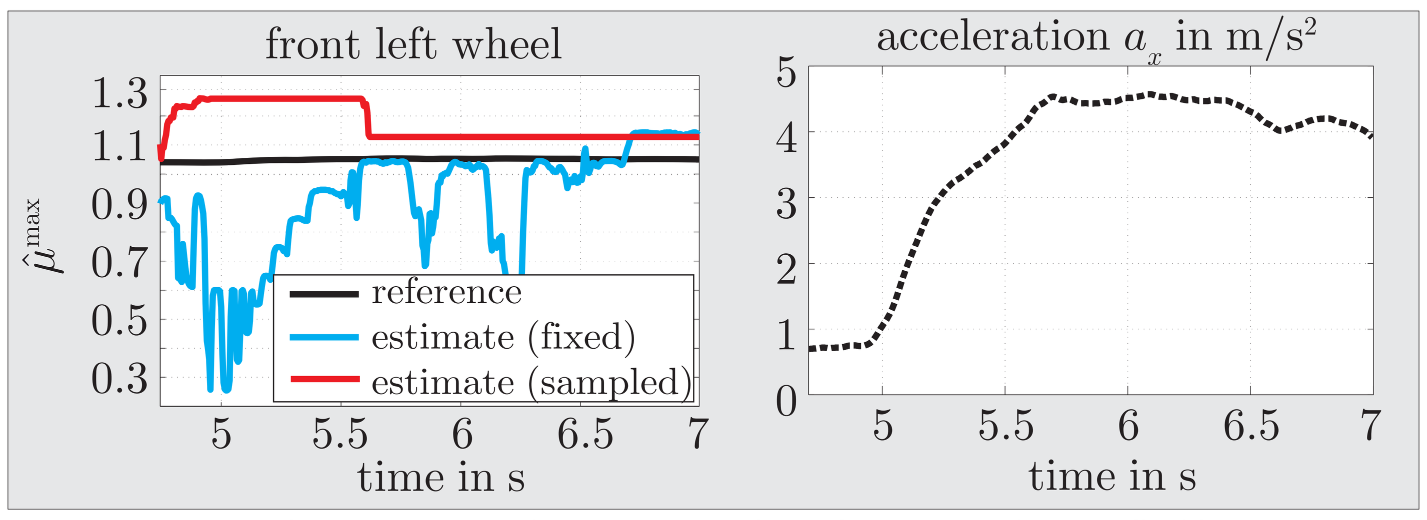

Figure 3 - Reference and estimates of μ^{max} (left) during acceleration manoeuvre (right)

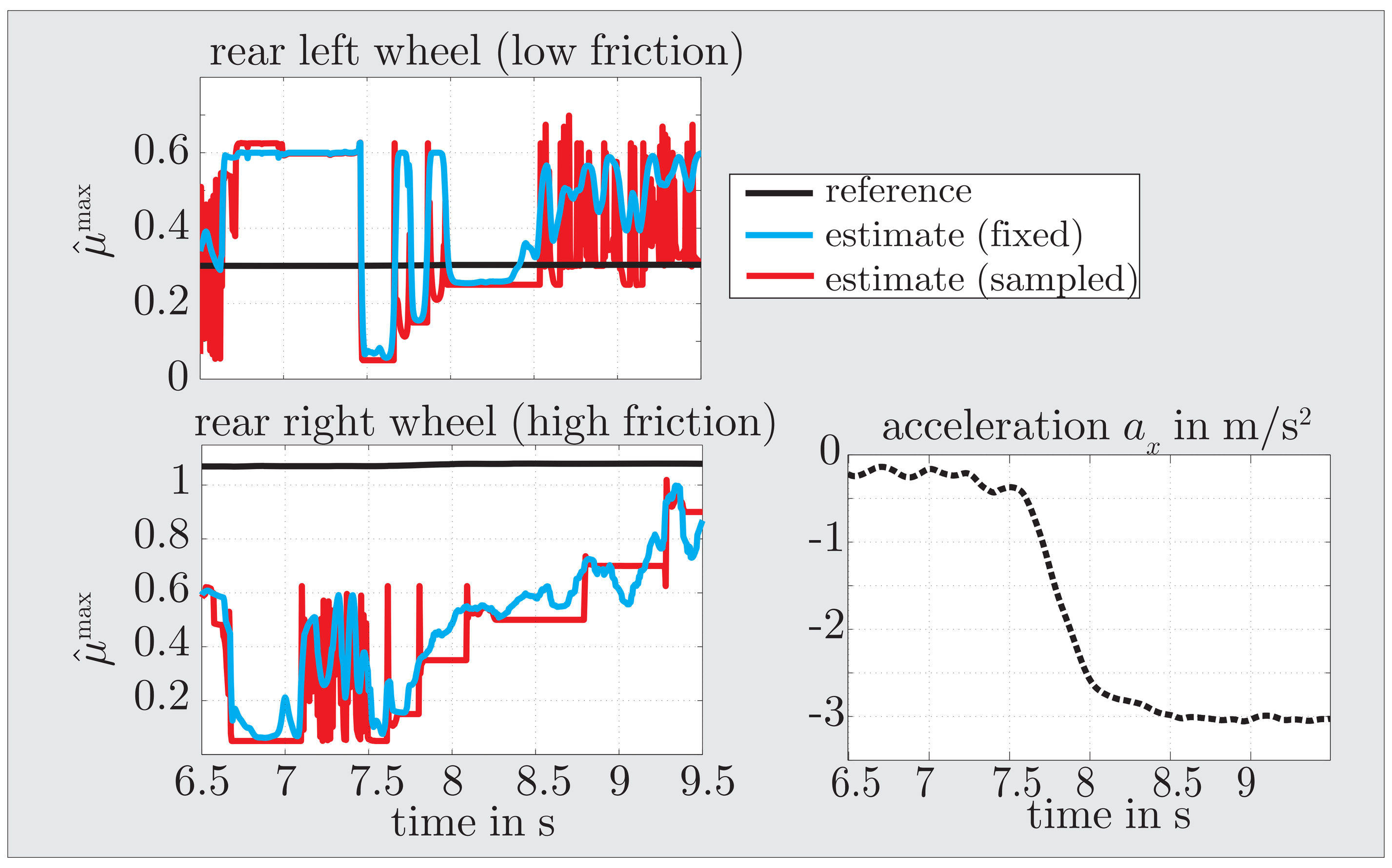

Figure 4 - Reference and estimates of μ^{max} (left) for left and right wheel on a μ *split* surface during a braking manoeuvre (right)

SELECTED RESULTS

Figure 3 left side shows the estimation results for the front left wheel during an acceleration manoeuvre on a high-friction surface, the acceleration history is displayed on the right side of Figure 3. The estimate based on fixed particles (non-converging) shows high deviations in the beginning and noisy characteristics, while the estimate using sampled particles rapidly converges. Figure 4 shows the estimates obtained during a braking manoeuvre on a split surface, with the left wheel being on the low-friction surface and the right wheel being on the high-friction surface. The high-friction surface cannot be detected at low body accelerations. On the low-friction surface, the estimates improve with increasing acceleration (at about 7.5 s).

ESTIMATON ERRORS

Table 1 shows an overview on the mean absolute errors (MAE) for different manoeuvres and road conditions. In the cases with sufficient dynamic excitation in relation to the physical limits, the MAE are mainly within 0.1. Since the proposed method is based on the measurement of the vehicle's dynamic reaction, the estimation accuracy increases with the dynamic excitation. Apart from measurements of the vehicle's longitudinal velocity, the sensor signals of a vehicle equipped with electronic stability control were sufficient.

manoeuvre	road condition	particles	MAE
acceleration	constant	fixed	0.17
acceleration	constant	sampled	0.08
braking, strong	μ *step*	fixed	0.06
braking, strong	μ *step*	sampled	0.1
braking, gentle	μ *step*	fixed	0.3
braking, gentle	μ *step*	sampled	0.36
braking	μ *split* (low friction)	fixed	0.2
braking	μ *split* (low friction)	sampled	0.16
braking	μ *split* (high friction)	fixed	0.6
braking	μ *split* (high friction)	sampled	0.65

Table 1 - Mean absolute errors (MAE) for estimates

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