CPM Vehicle Parameter Identification and Model Predictive Control

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1 Vehicle Dynamics Model

This is an end-to-end, grey-box model for the vehicle dynamics. The model parameters are not measured directly, but optimized to best fit the vehicle behavior.

$$\boldsymbol{x} = [p_x, p_y, \psi, v]$$
$$\boldsymbol{u} = [f, \delta_{ref}, V]$$

p_x	IPS x-position
p_y	IPS y-position
ψ	IPS yaw angle
v	Odometer Speed
f	Dimensionless motor command
δ_{ref}	Dimensionless steering command
V	Battery voltage

$$\dot{p}_x = p_1 \cdot v \cdot (1 + p_2 \cdot (\delta_{ref} + p_9)^2) \cdot \cos(\psi + p_3 \cdot (\delta_{ref} + p_9) + p_{10})$$
$$\dot{p}_y = p_1 \cdot v \cdot (1 + p_2 \cdot (\delta_{ref} + p_9)^2) \cdot \sin(\psi + p_3 \cdot (\delta_{ref} + p_9) + p_{10})$$
$$\dot{\psi} = p_4 \cdot v \cdot (\delta_{ref} + p_9)$$
$$\dot{v} = p_5 \cdot v + (p_6 + p_7 \cdot V) \cdot \text{sign}(f) \cdot |f|^{p_8}$$

This is a kinematic bicycle model with some added terms to account for various errors.

- p_1: Compensate calibration error between IPS speed and odometer speed.
- $(1+p_2 \cdot \delta^2)$: Compensate for speed differences due to different reference points between the IPS and odometer. The formulation is simplified with a second-order Taylor approximation.
- p_3: Side slip angle (Schwimmwinkel) due to steering.
- p_{10}: IPS Yaw calibration error.
- p_4: Unit conversion for the steering state.
- p_5: Speed low pass (PT1).
- p_6, p_7: Motor strength depends on the battery voltage.
- p_8: Compensate non-linear steady-state speed.
- p_9: Steering misalignment correction.

2 Parameter Identification

Optimal parameter estimation problem for the vehicle dynamics. The optimization tries to find a set of model parameters, that best explain/reproduce the experiment data.

$$
\begin{aligned}
\underset{\boldsymbol{x}_k^j, \boldsymbol{p}}{\text{minimize}} \quad & \sum_{j=1}^{n_{experiments}} \sum_{k=1}^{n_{timesteps}} E(\boldsymbol{x}_k^j - \hat{\boldsymbol{x}}_k^j) \\
\text{subject to} \quad & \boldsymbol{x}_{k+1}^j = \boldsymbol{x}_k^j + \Delta t \cdot f(\boldsymbol{x}_k^j, \hat{\boldsymbol{u}}_k^j, \boldsymbol{p}) \\
& k = 1..(n_{timesteps} - 1) \\
& j = 1..n_{experiments}
\end{aligned}
$$

$\hat{\boldsymbol{x}}_k^j$	Measured States
$\hat{\boldsymbol{u}}_k^j$	Measured Inputs
f	Vehicle dynamics model
$\boldsymbol{p}$	Model parameters
Δt	Constant timestep $0.02s$
E	Error penalty function

Error penalty E: Weighted quadratic error with model specific extensions. The yaw error function has a period of 2π, so that a full rotation does not count as an error. This is done using $\sin(\Delta\psi/2)$.

Delays: This kind of optimization problem is not well suited for identifying the delay times (Totzeiten). The delays are solved in an outer loop. The delay is guessed/assumed and the measurement data is modified by appropriately shifting it in the time index k. This optimization problem is solved many times for combinations of delay times. The delays that create the lowest objective value are taken as the solution.