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Ulm University, Institute of Measurement, Control and Microtechnology

A Two-wheel Driven Power Train for Improved Safety and Efficiency in Electric Motorbikes EVS 2016

Background – Project Description

- Collaborative research project
- Safety chassis for electric all-wheel driven e-bikes & electric motorcycles



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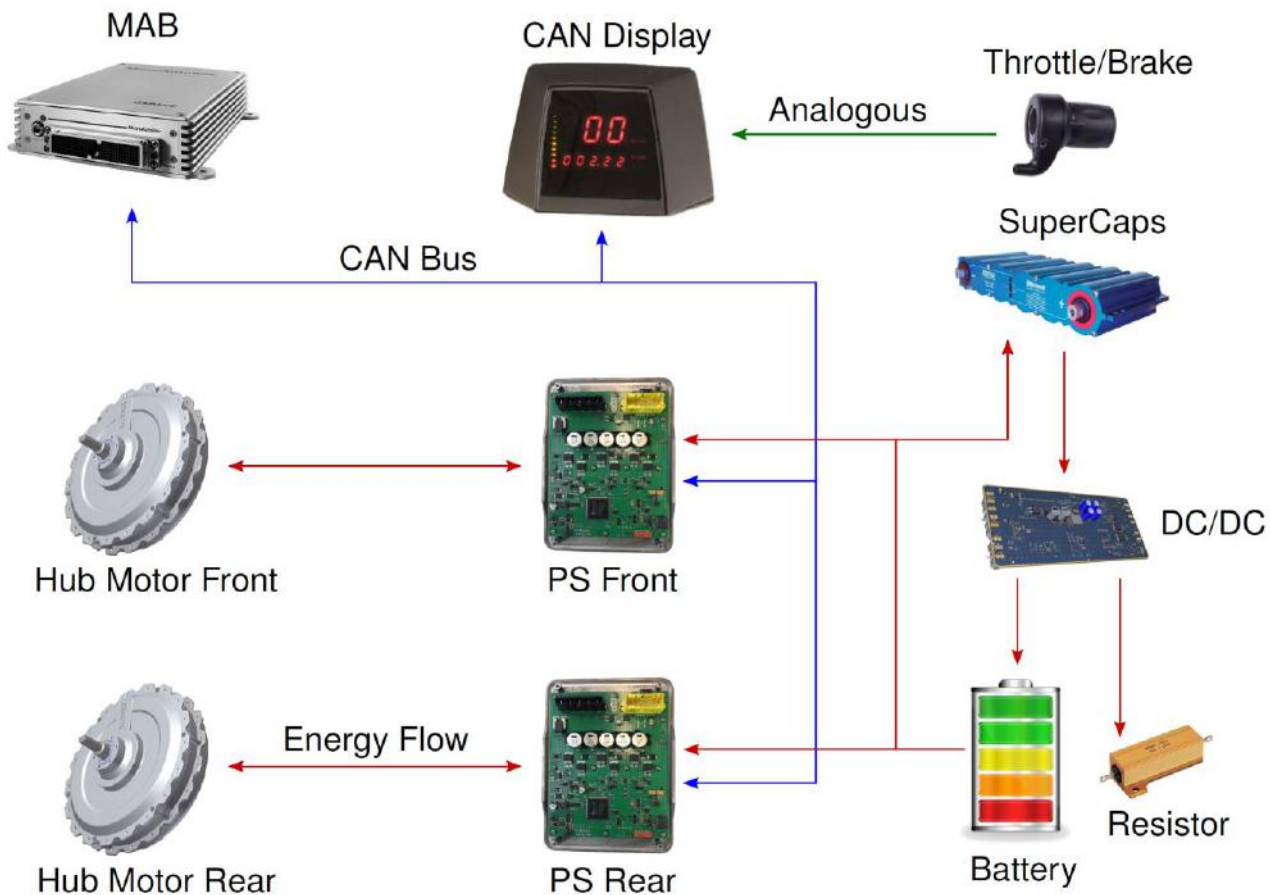
Test Vehicle

- Full electric two-wheel driven motorcycle



Test Vehicle

■ System Architecture



Operational Strategy

- Additional degree of freedom due to second independent power train
- Longitudinal force demand given by the driver
- Strategy for torque distribution required
- Additional goals:
 - Recuperation and efficiency
 - Improvement of safety



Model Predictive Control Allocation

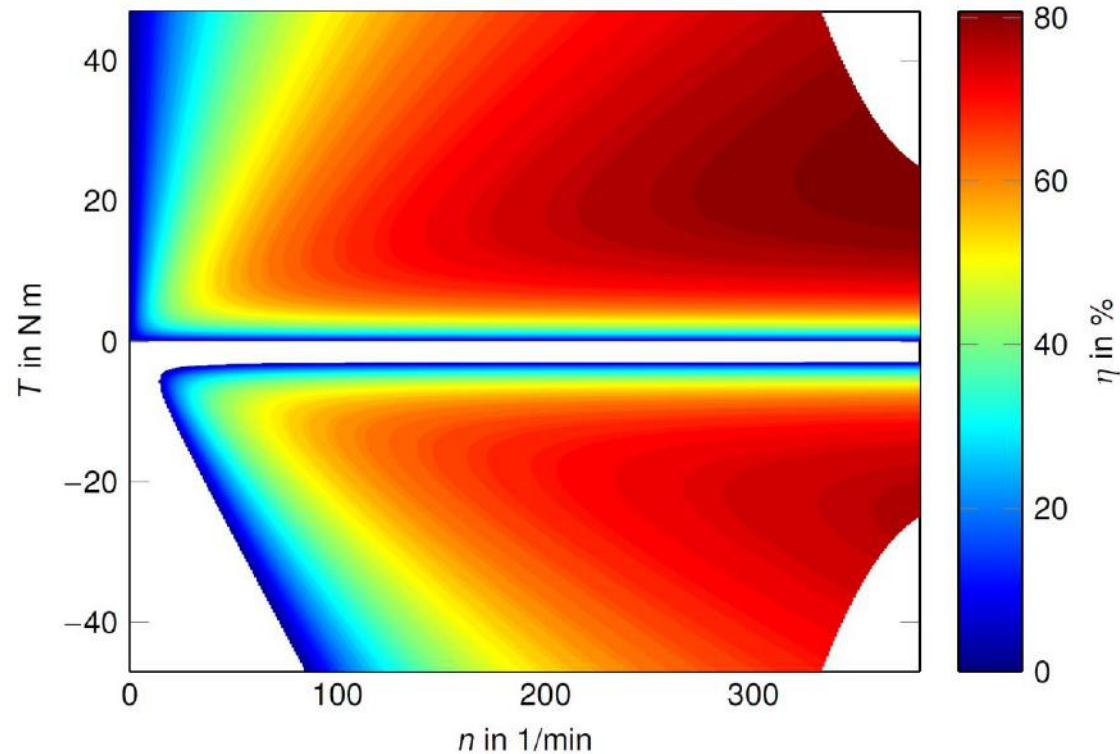
■ Optimal Control Problem (OCP)

$$\begin{aligned} \min \quad & J(\mathbf{x}_k, \bar{\mathbf{u}}) = \int_{t_k}^{t_k+T} l(\bar{\mathbf{x}}(t), \bar{\mathbf{u}}(t)) dt \\ \text{s.t.} \quad & \dot{\bar{\mathbf{x}}}(t) = \mathbf{f}(\bar{\mathbf{x}}(t), \bar{\mathbf{u}}(t)), \bar{\mathbf{x}}(t_k) = \mathbf{x}_k, \\ & \mathbf{u}(t) \in \mathcal{U} \end{aligned}$$

- Actuator dynamics within the system equations
- Operational strategy depends on cost function
- Efficiency maps of the power train needed
- Consideration of battery limits
- Using the real-time solver GRAMPC¹ for the OCP

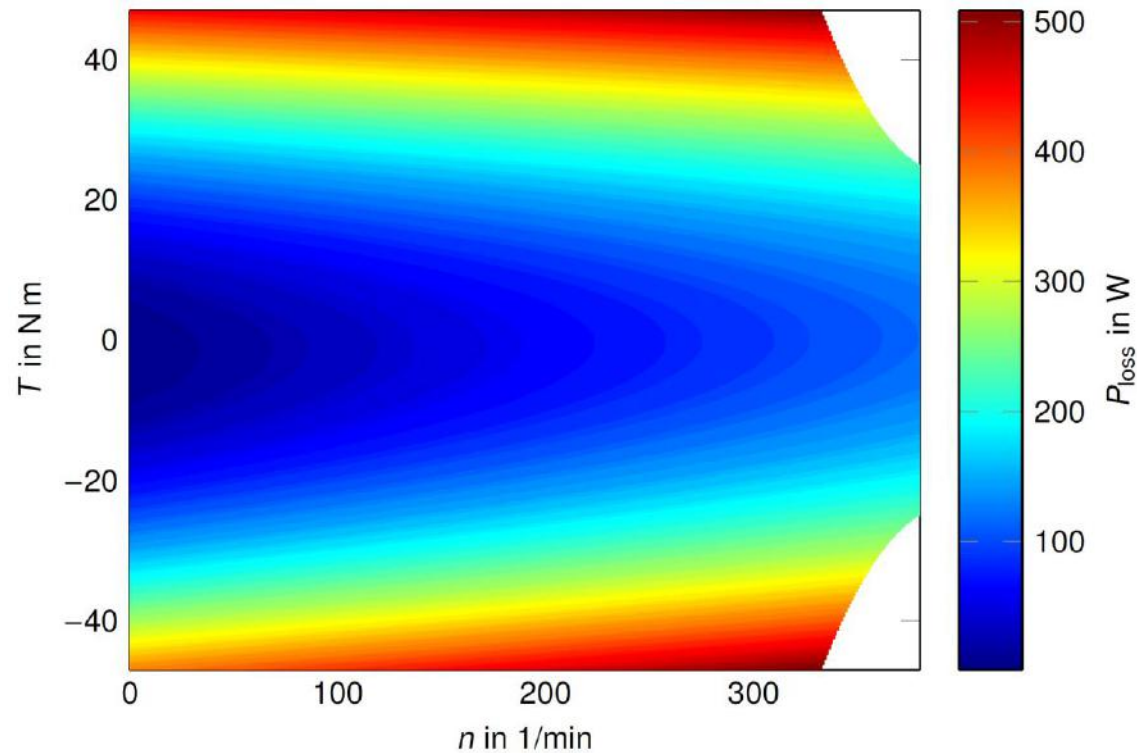
¹ Käpernick, B. and Graichen, K.: *The gradient based nonlinear model predictive control software GRAMPC*. In: European Control Conference (ECC), pages 1170–1175. IEEE, 2014

Efficiency Based Operational Strategy – Efficiency Map



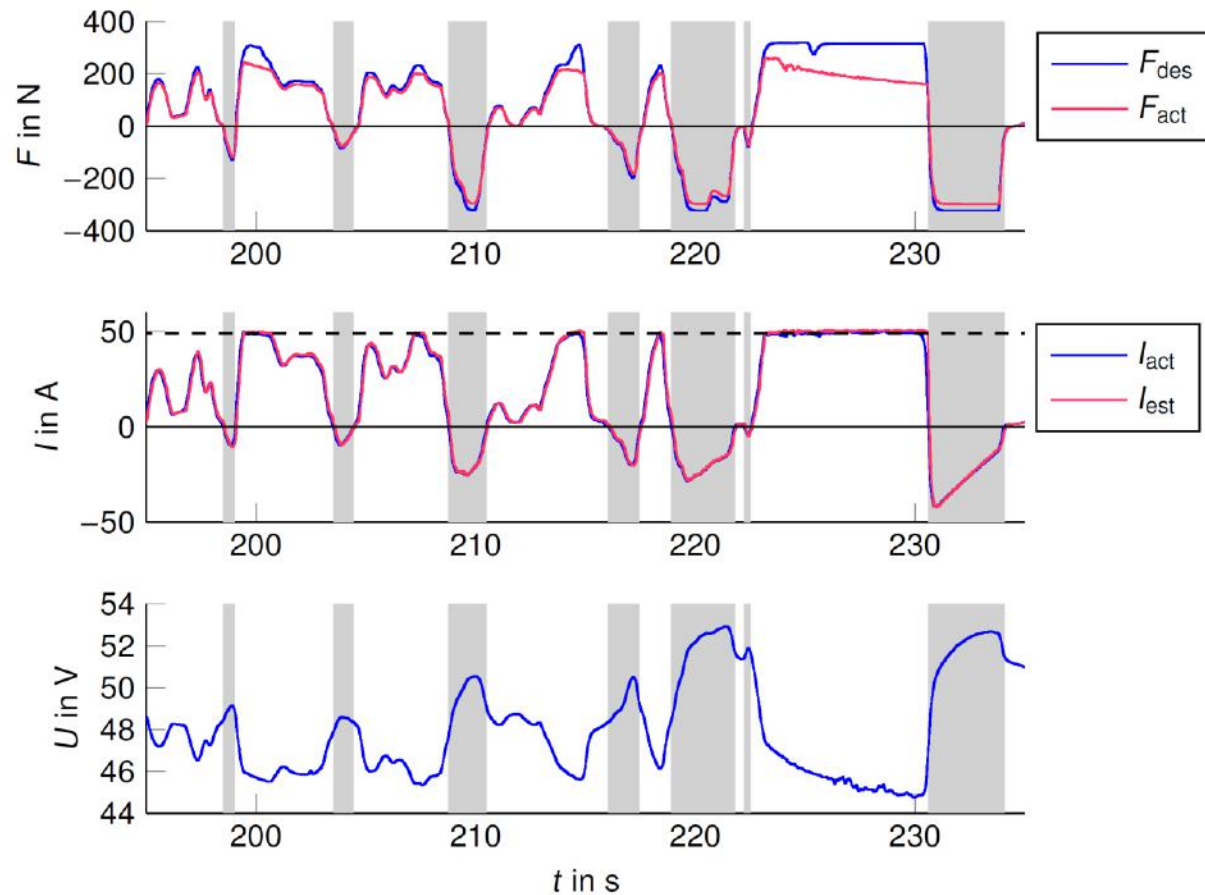
- Numerical problems by discontinuous function

Efficiency Based Operational Strategy – Power Losses



- Minimization of power losses using OCP

Efficiency Based Operational Strategy – Experimental Results



- Energy savings about 26% due to recuperation and higher acceleration

Anti-lock Braking System (ABS)

Idea

- Estimate the wheel accelerations
- Control input restriction of the OCP

Problem

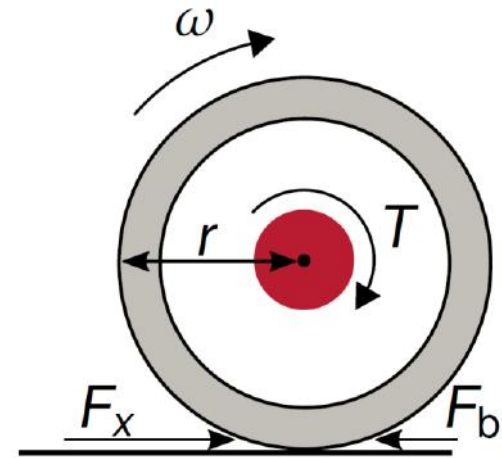
- Only the angular position is available

Procedure

- Using Kalman filtering
- Tire modeling is not needed

Requirement

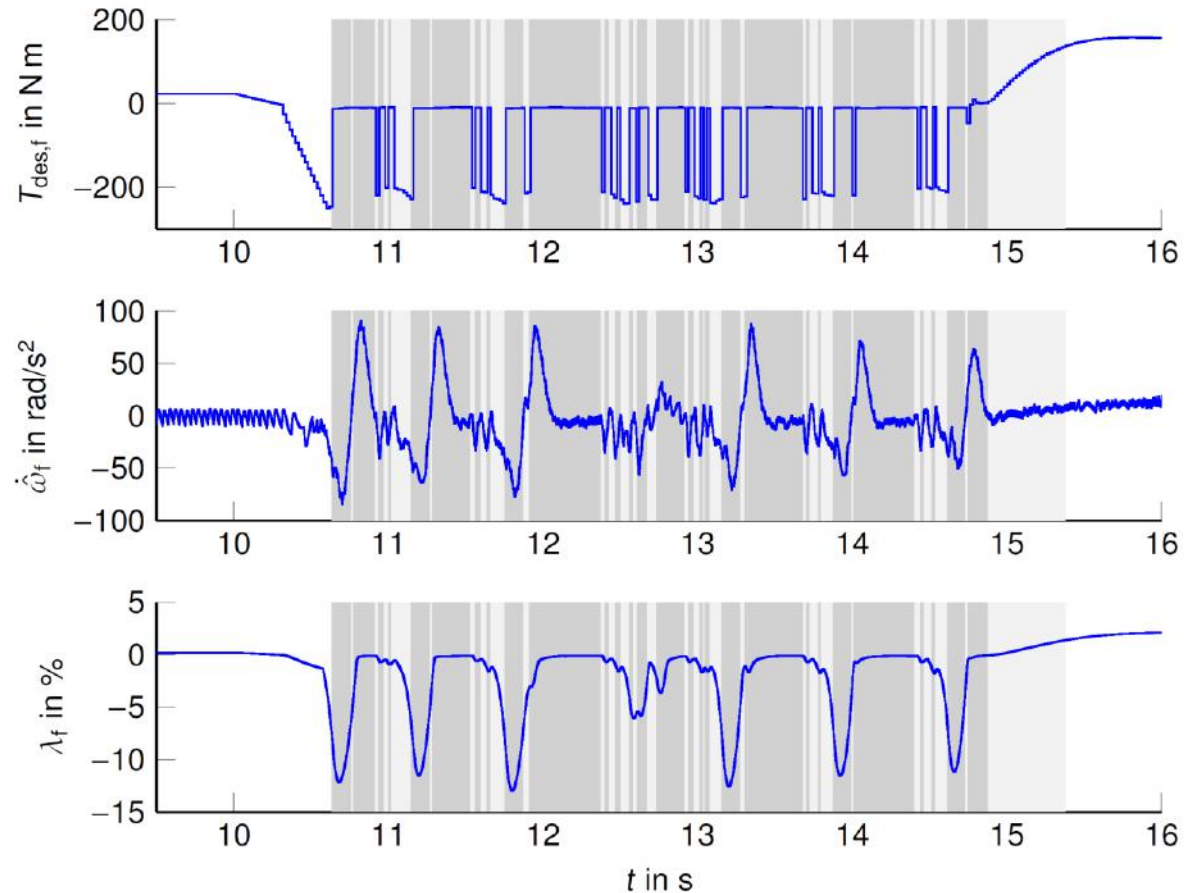
- Preventing wheels from locking up, independent of road surface



Anti-lock Braking System – Driving Straight Ahead



Anti-lock Braking System – Results



- Restriction of the desired torques to guarantee secure operation

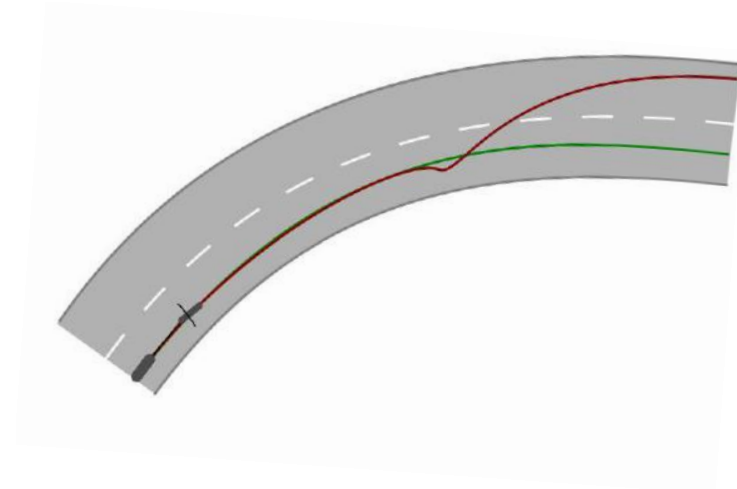
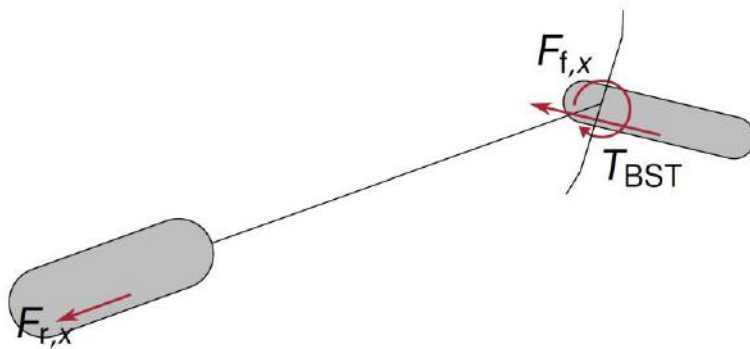
Anti-lock Braking System – During Cornering



Reduction of Brake Steer Torque

Problem

- Braking while cornering leads to torque around the steering axis

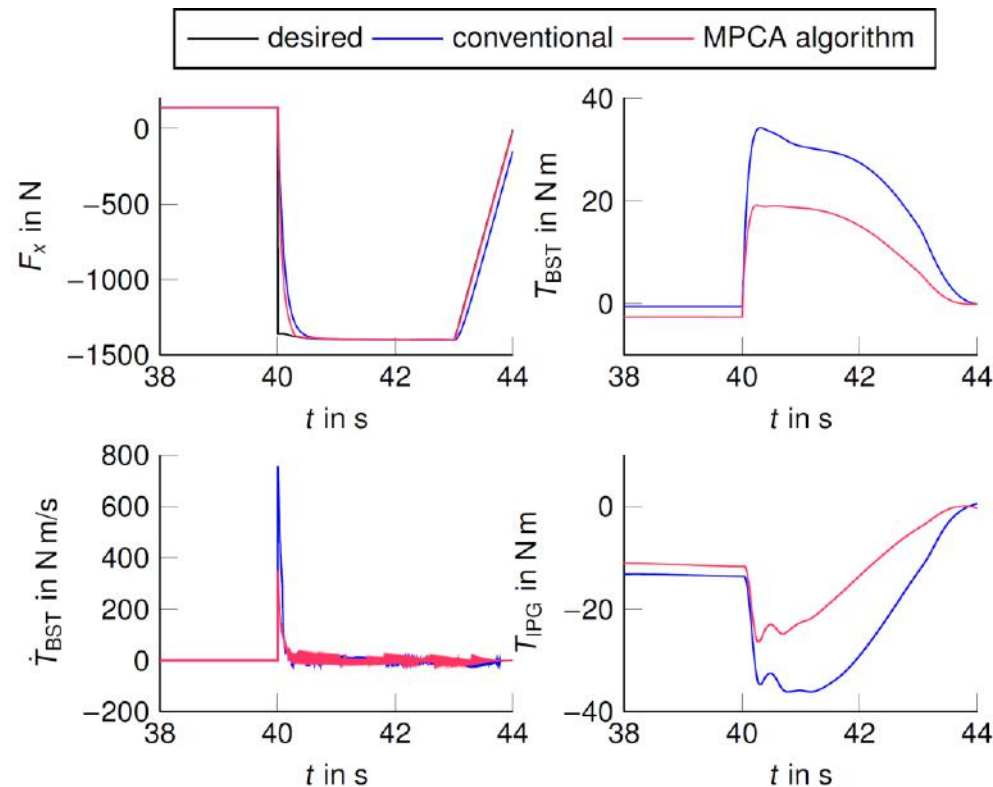


Procedure

- Modeling of the brake steer torque and its derivative
- Integration in cost function of the OCP

Reduction of Brake Steer Torque – Simulation Results

- Stationary circle turning
- Significant reduction of brake steer torque and its derivative



Conclusion

- Fully electric all-wheel driven motorcycle:
Allows for recuperation and additional safety features
- Torque distribution strategy based on power loss maps:
efficient driving
- Motorcycle ABS based on estimated wheel accelerations: Simple realization by electric motors
- Method for reducing the hazardous brake steering torque: Significant reduction by torque distribution



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Thank you for your attention!