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MODEL-BASED DESIGN OF THE STEER-BY-WIRE MODULES FOR AN ELECTRIC VEHICLE WITH ALL-WHEEL STEERING

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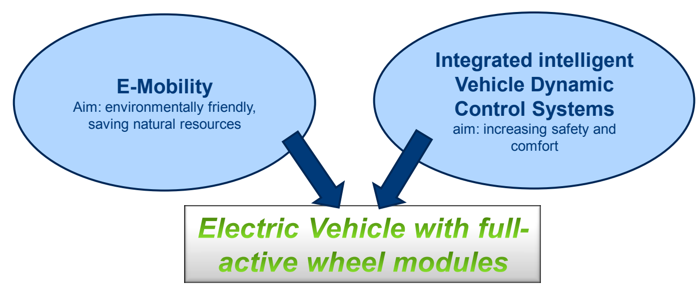
M(echatronic)-Mobile – Motivation and aims



Fusion of two key technologies

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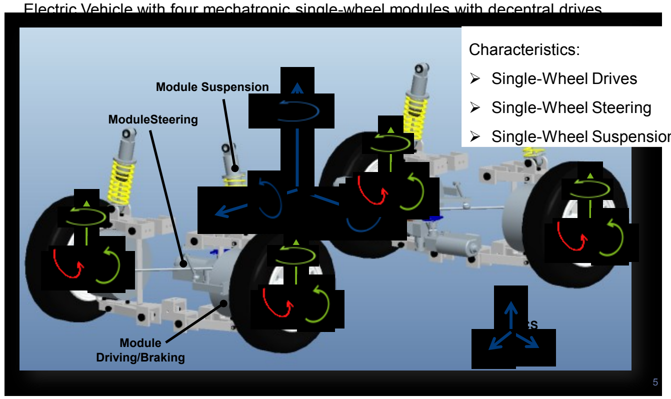
M-Mobile – Configuration

Electric Vehicle with four mechatronic single-wheel modules with decentral drives



Characteristics:

- ➢ Single-Wheel Drives
- ➢ Single-Wheel Steering
- ➢ Single-Wheel Suspension

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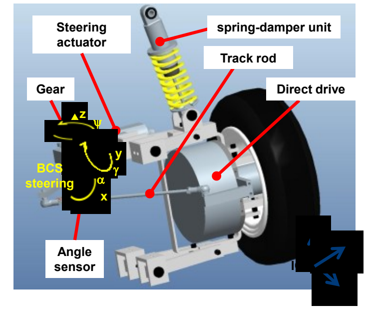
M-Mobile – Active single-wheel module



- Direct drive
- Steer-by-wire system
- Spring-damper unit

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M-Mobile – Concept

three fundamental, decoupled mechatronic function modules

- ➢ **Driving-/Braking module:** With the gearless hub motors as decentralised drives this modules' actuators accelerate and decelerate the vehicle.
- ➢ **Steering module:** The lateral vehicle dynamics and the damping of the yaw movement are achieved by a wheel individual by-wire steering.
- ➢ **Suspension/tilt module:** An active system realises a comfortable suspension and a compensation of the tilt movement

further modules:

- ➢ **Accumulator:** Li-Ion-battery for the storage of electrical energy
- ➢ **Drive- and Energy-Management**: Control of the energy flow, decelerating for recuperation, driving strategy
- ➢ **Chassis management**: Intelligent vehicle dynamics systems like active steer-by-wire, torque vectoring, ESP-functionality and active body control

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M-Mobile - Prototype

- ➢ Scale 1:3
- ➢ Longitudinal max speed: 0-60 km/h
- ➢ acceleration: 3 m/s²
- ➢ RCP-Hardware by dSPACE
- ➢ Human Machine Interface per remote connection via WLAN

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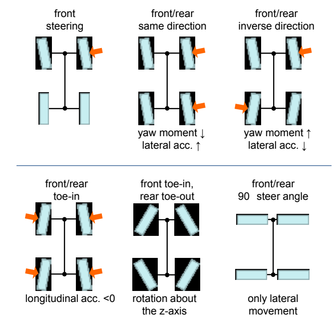
Wheel-individual Steering – Possibilities



- Only front steering
- Front and rear steering same direction
- Front and rear steering inverse direction
- Front and rear steering toe-in
- Front steering toe-in, rear steering toe-out
- Front and rear steering, 90 deg

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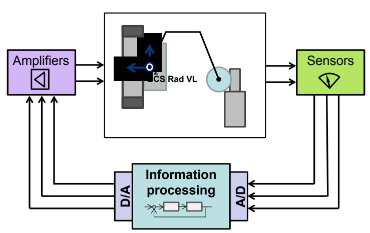
Mechatronic Steer-by-wire module



- Mechanical structure
- Electric actuator with gear
- Angle and current sensors
- Information processing

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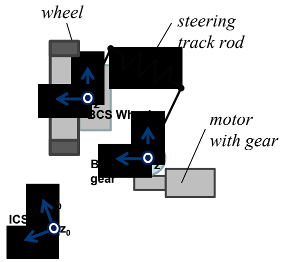
Modeling the steer-by-wire module

Physical model of the steer-by-wire module

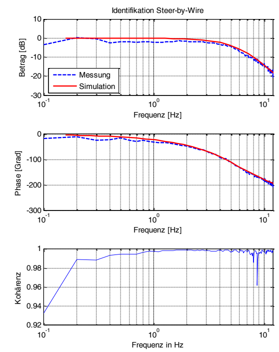


- Dynamic of mechanical system
- Dynamic of electric actuator
- Influence of tyre-ground contact as disturbance

$$\dot{\underline{x}} = \underline{\underline{A}} \cdot \underline{x} + \underline{B} \cdot \underline{u} + \underline{B}_z \cdot \underline{z}$$
$$\underline{y} = \underline{C} \cdot \underline{x} + \underline{D} \cdot \underline{u}$$
$$\text{with } \underline{x} = \begin{bmatrix} i \\ \dot{\varphi}_g \\ \varphi_g \end{bmatrix},$$
$$\underline{u} = [u_{mot}], \underline{z} = [M_{tyre}], \underline{y} = [\varphi_g]$$

Parameter identification

Bodeplot measurement/ simulation



- Identification in frequency domain
- Model fits up to 12 Hz
- Model structure and depth are sufficient for control design

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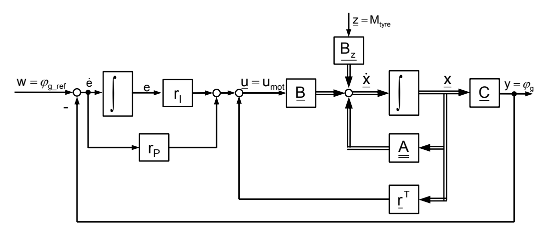
Model-Based Control Design - Control Structure

Control structure: PI control with state feedback



- State control with proportional and integral gain instead of prefilter
- Accuracy under disturbant influence
- Less complex compared to cascade control

Model-Based Control Design

System input with the reference value w:

$$\underline{u} = \underline{r}^T \cdot \underline{x} + r_P \cdot (w - \underline{C} \cdot \underline{x}) + r_I \cdot e$$

$$\underline{r}^T = [r_1 \quad r_2 \quad r_3]$$

State space with the control algorithm:

$$\underline{\dot{x}_{PI}} = \underline{\underline{A_{PI}}} \cdot \underline{x_{PI}} + \underline{B_{PI}} \cdot w + \underline{B_{z,PI}} \cdot \underline{z}$$

$$y = \underline{C_{PI}} \cdot \underline{x_{PI}} + \underline{D} \cdot \underline{u}$$

$$with\ \underline{x_{PI}} = \begin{bmatrix} i \\ \dot{\varphi}_g \\ \varphi_g \\ e \end{bmatrix},$$

$$w = \varphi_{g\_ref},\ \underline{z} = [M_{tyre}],\ y = \varphi_g$$

Integral gain increases order by one.

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Model-Based Control Design

Reference transfer function:

$$G_w(s) = \frac{\varphi_g(s)}{\varphi_{g\_ref}(s)} = \underline{C_{PI}} \cdot \left(s \cdot \underline{\underline{E}} - \underline{\underline{A_{PI}}}\right)^{-1} \cdot \underline{B_{PI}}$$

Control Parameters are determined by pole placement.
The eigenvalues for the reference behavior were chosen for a sufficient dynamic with good damping.

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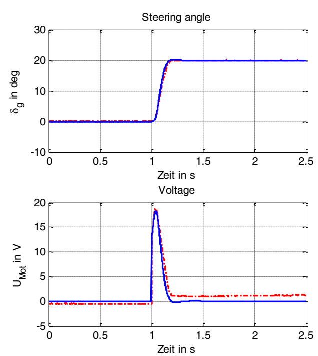
Verification

- A verification was realised with the prototype of the M-Mobile.
- Reference step response without disturbance is shown in the right figure.
- The steering is stimulated with a step of 20 deg at the reference input at a time of 1 s.
- The signal follows the step quite well and has a good steady state accuracy.
- The simulation matches the measurement (dotted line) quite well.



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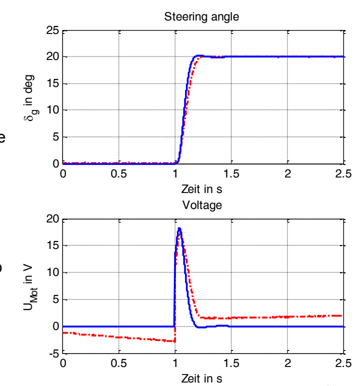
Verification

- Reference step response with tyre ground contact as disturbance
- The stimulus is the same as in the last figure.
- To emphasize the disturbing influence the simulation was done without the tyre-ground contact
- In the result the measured signal (dotted line) follows a little delayed in comparison to the simulation but also without a steady state control error



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Conclusion

- Concept of the M-Mobile was introduced (symbiosis of e-mobility and integrated vehicle dynamic systems)
- Possibilities with a wheel-individual steering
- Modeling the steer-by-wire module
- Parameter identification in frequency domain
- Model-Based Control Design of a PI control with state feedback
- Verification of control algorithm with prototype of M-Mobile

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Thank You.

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