Design of Active Seat Suspension Mechatronic System

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3rd Workshop on “Motion Comfort in Automated Driving”

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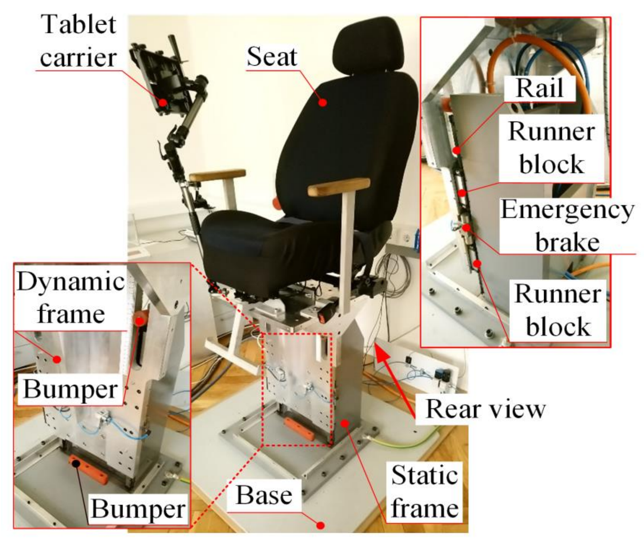
Introduction

The poster first outlines previous research results on LQR-based active suspension control system design and related ride comfort and task execution test outcomes. The results indicate that active seat suspension allows for using stiffer chassis suspension for better handling, while providing a favorable ride comfort. The poster then deals with overall active seat suspension mechatronic system design, including two variants of mechanical subsystem design, actuation system dynamics model, and model predictive control strategy together with low-level controls.

Previous research

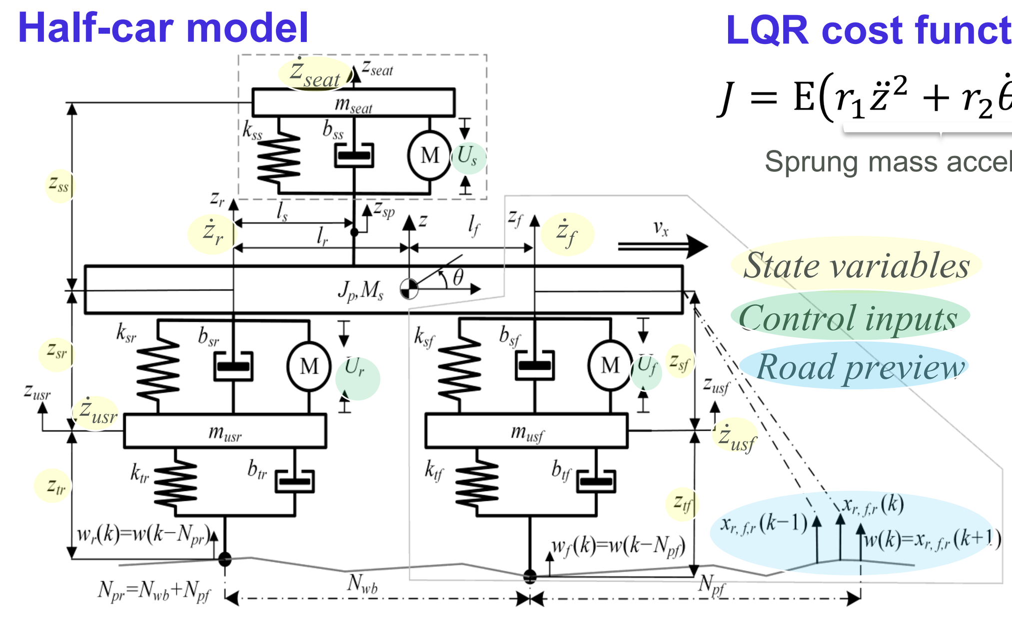
Shaker test rig

- based on the linear servo motor
- 2610 N @ 20 m/s, 6900 N @ 0.6 m/s maximum force @ speed
- 2.5 g @ 0.6 m/s, 1.8 g @ 1 m/s max. vertical net acceleration
- ±1 m/s max. vertical velocity
- ±100 mm max. vertical displacement



FAS - fully active; FASP - fully active w/ preview; SAS - semiactive; SASP - semi-active w/ preview

Half-car model

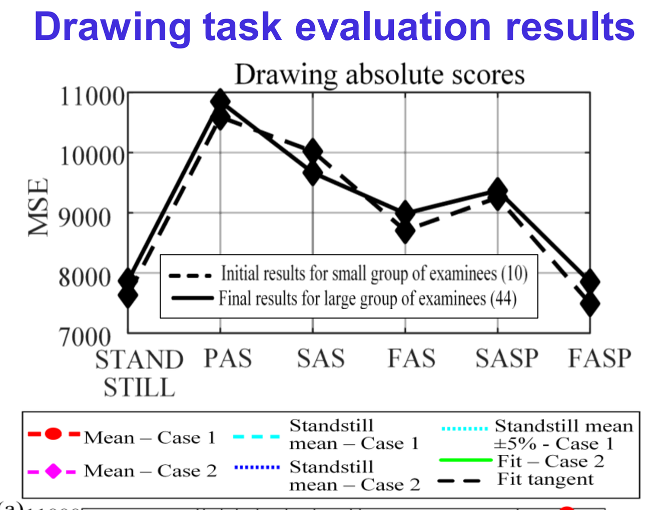


LQR cost function

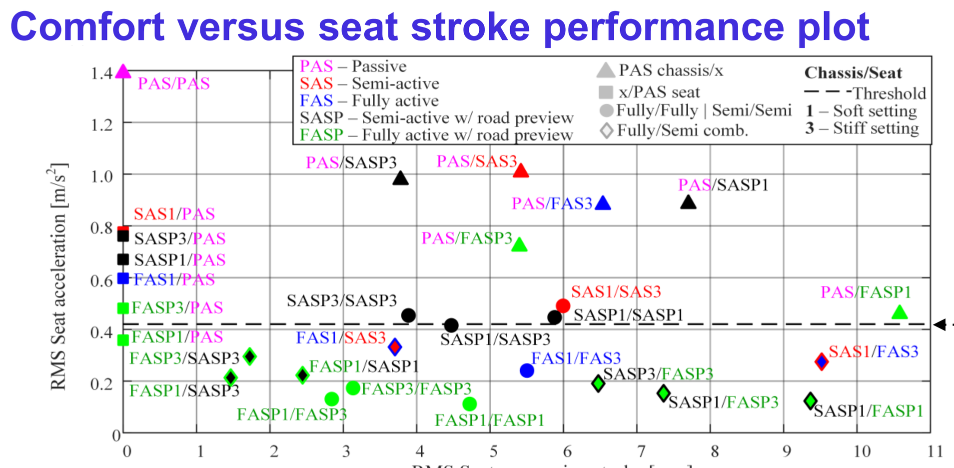
$$J = \mathrm{E}(r_1\ddot{z}^2 + r_2\ddot{\theta}^2 + r_{3f}z_{tf}^2 + r_{3r}z_{tr}^2 + r_{4f}z_{sf}^2 + r_{4r}z_{sr}^2)$$

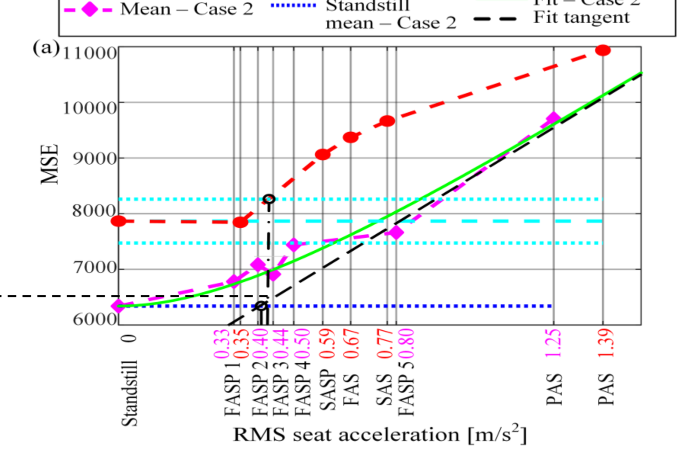
Sprung mass acceleration | Tire deflection | Suspension deflection

Drawing task evaluation results



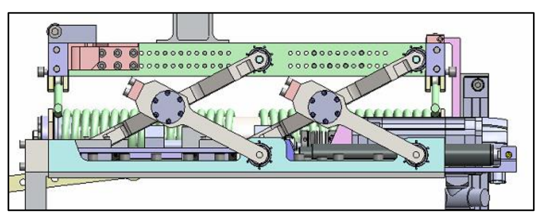
Comfort versus seat stroke performance plot

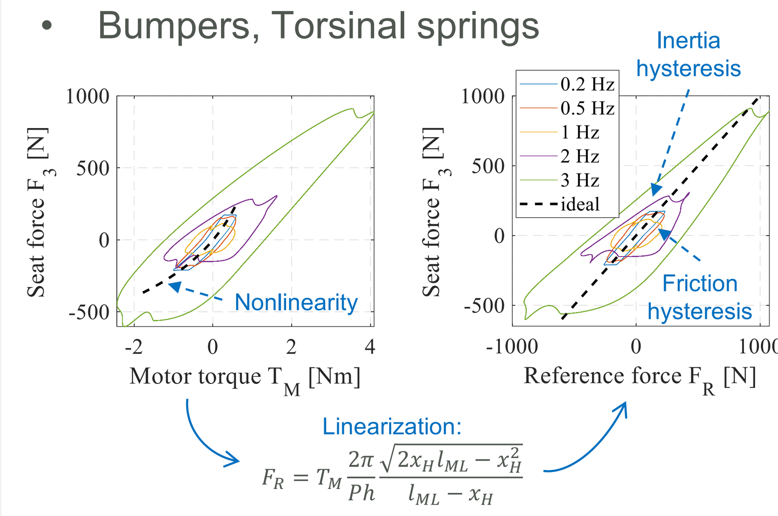




Modelling

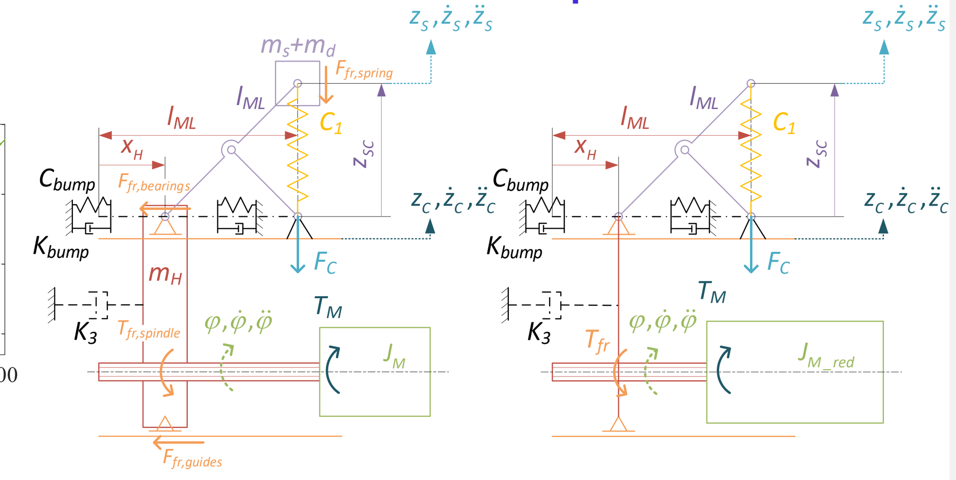
- Mathematical model for Design 1
- Inertia: Motor/spindle, H-frame, Seat, Driver
- Friction: Spindle, Seals, Guides, Bearings
- Nonlinear mechanism kinematics
- Bumpers, Torsinal springs



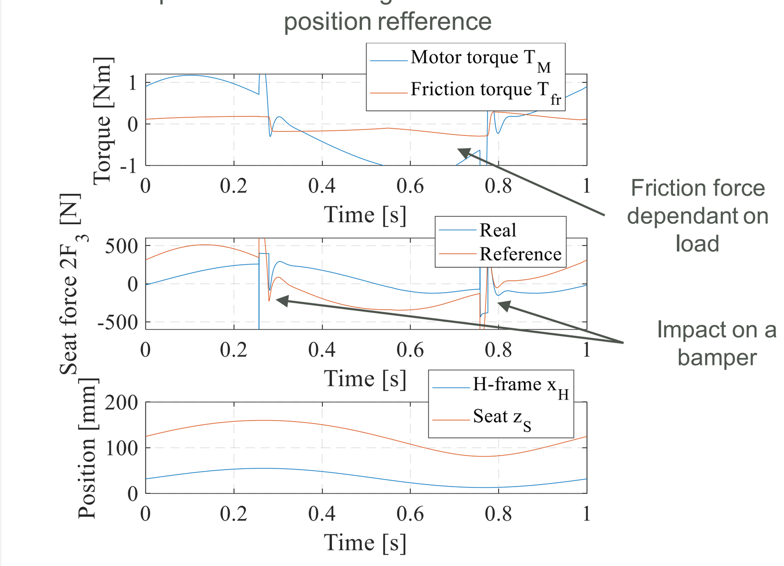


$$F_R = T_M \frac{2\pi}{Ph}\frac{\sqrt{2x_H l_{ML} - x_H^2}}{l_{ML} - x_H}$$

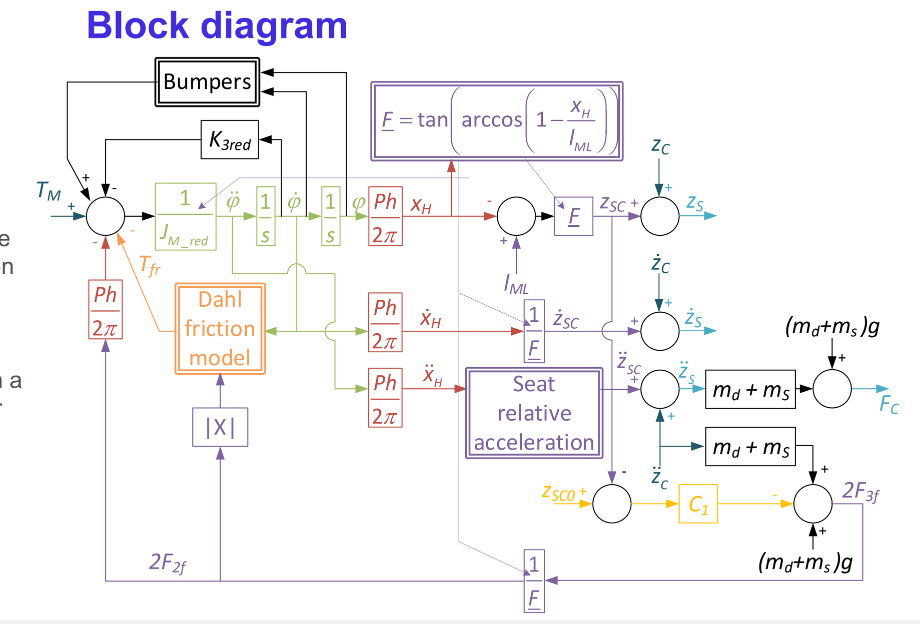
Full mechanical model | Lumped inertia model



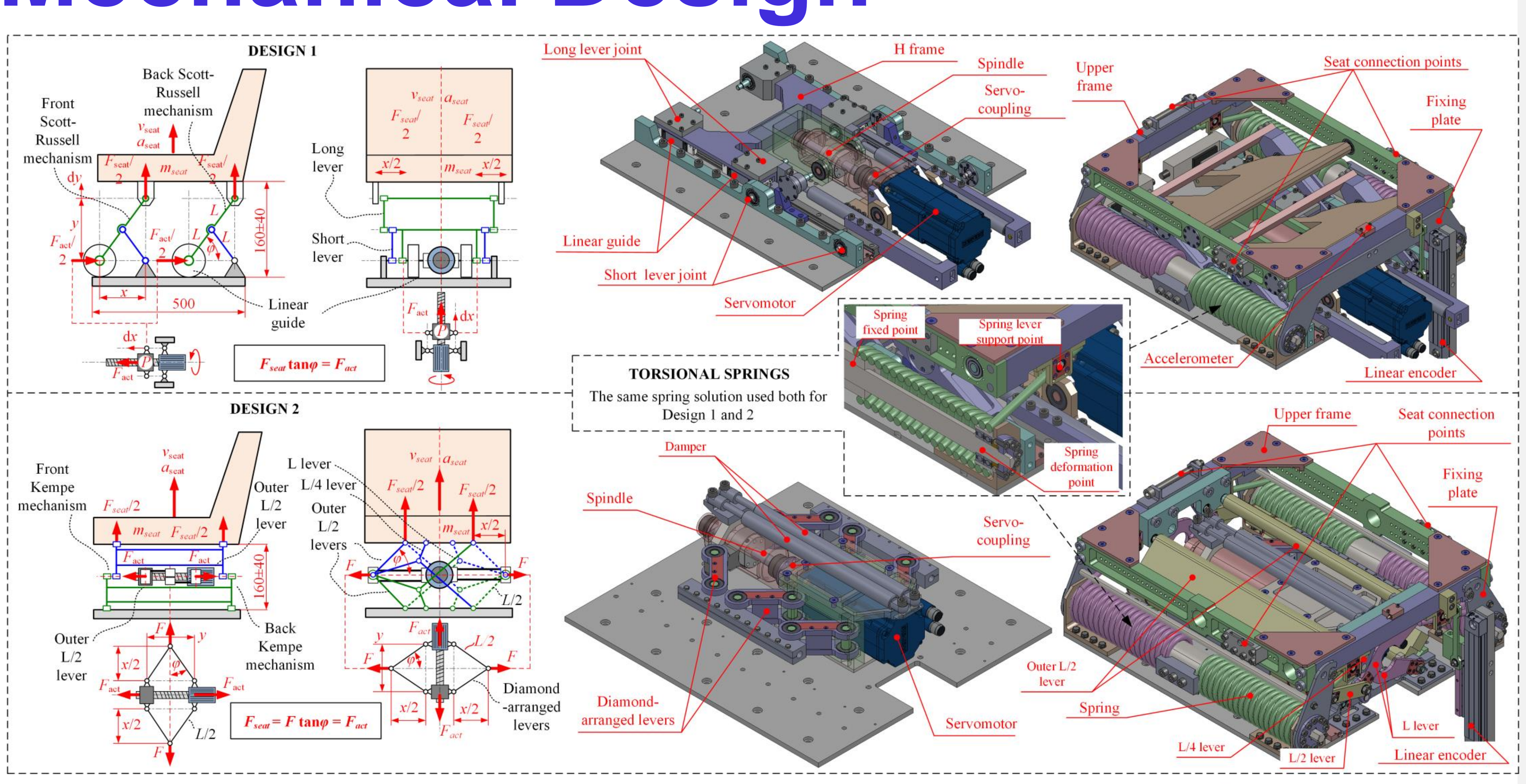
Time response for sine change of feedback controlled seat position refference



Block diagram



Mechanical Design



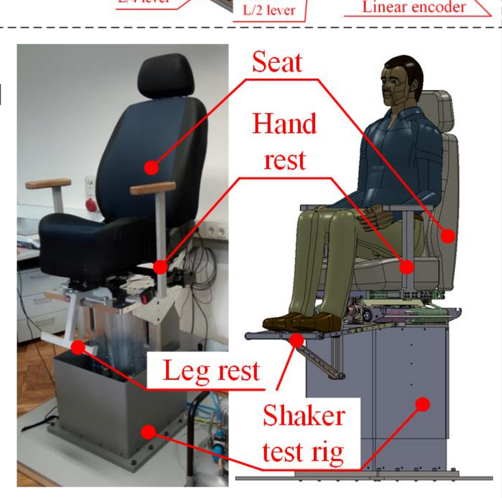
DESIGN 1 - Dual Scott-Russell mechanism

- Best mechanical properties
- High costs
- Suitable for experimental purposes

DESIGN 2 - Kempe mechanism + diamond-arranged levers

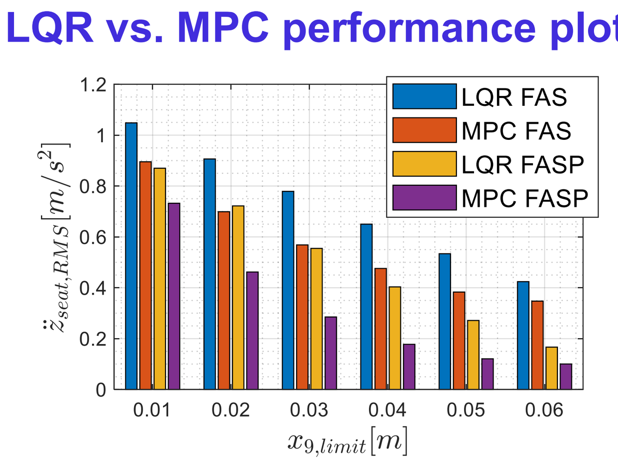
- Low cost (no linear guides, smaller motor due to constant transfer ratio)
- Lower stiffness
- Good candidate for mass production

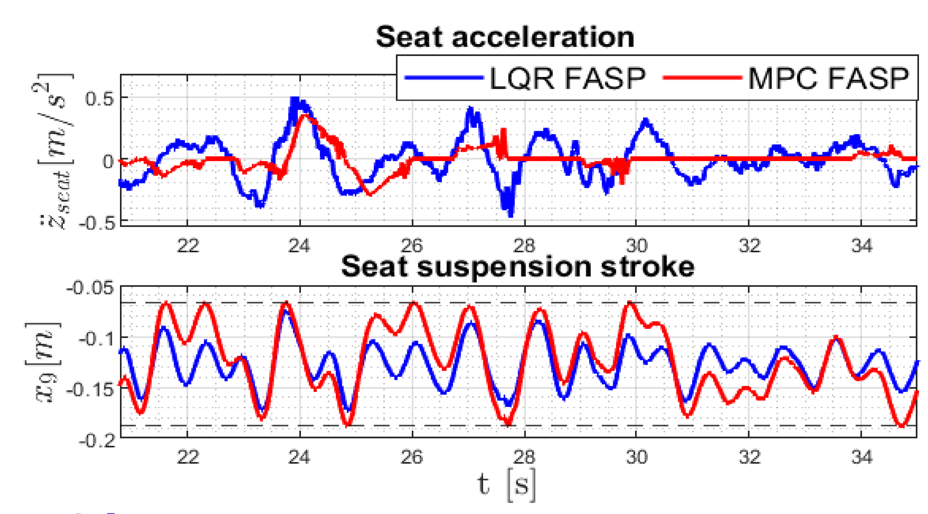
Both design solutions are to be manufactured and installed on the existing Shaker test rig



Control

LQR vs. MPC performance plot





LQR design

$$J_{LQR} = \mathrm{E}(\ddot{z}_{seat}^2 + q_1 x_9^2)$$

$T_s = 5$ ms

MPC design

$$J_{MPC} = \mathrm{E}(\ddot{z}_{seat}^2), \quad u_{min} \le u \le u_{max}$$

$$T_s = 5\ \mathrm{ms},\ N = 100, \quad -x_{9,limit} \le x_9 \le x_{9,limit}$$

- RMS seat acceleration minimized; seat suspension stroke penalized
- YALMIP implementation (*quadprog* solver)
- Full feedback case (both seat and chassis variables are fed back to controller)

Effect of low-level control active seat control perfromance

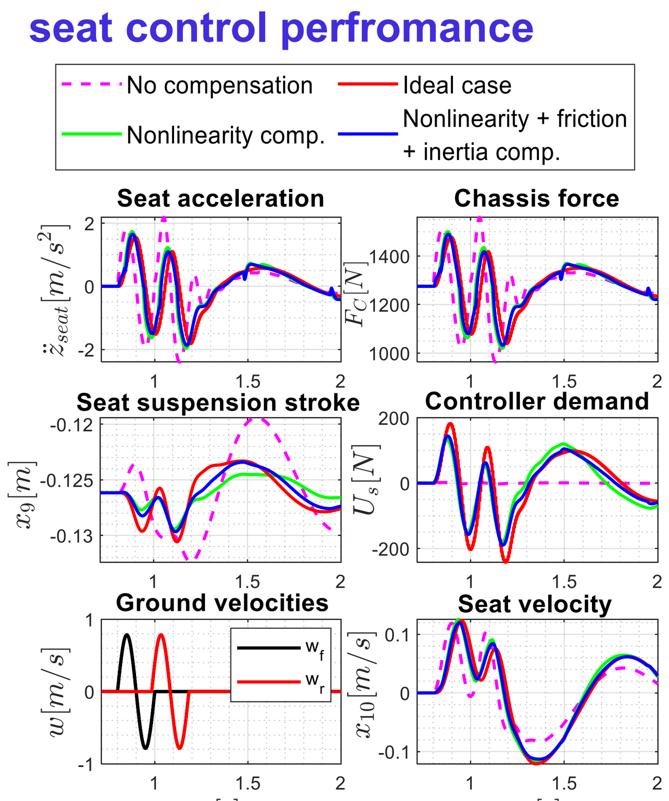
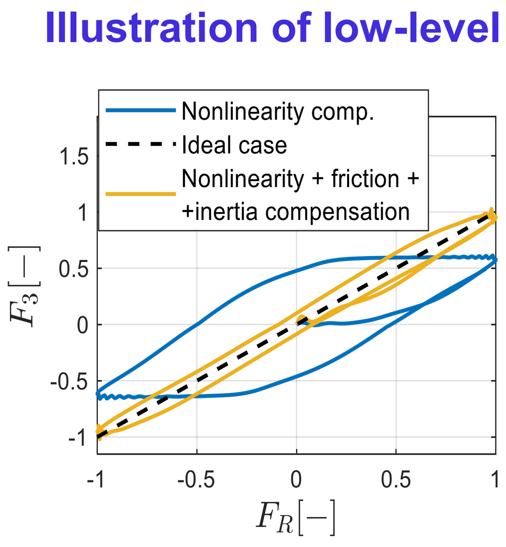


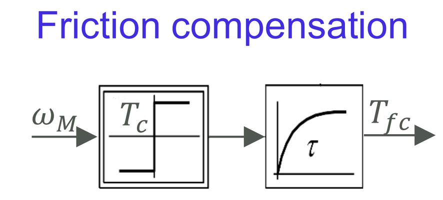
Illustration of low-level control actions



Nonlinearity compensation

$$T_M = F_R \frac{d_0 K_{spindle}}{2\tan(\cos^{-1}(1 - \frac{x_H}{l_{ML}}))}$$

Friction compensation



Acknowledgements

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