

Quick overview of Johannes' QP framework + getting experiments to work

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$$M\ddot{\mathbf{q}} + C\dot{\mathbf{q}} + \boldsymbol{\tau}_{grav} = \underbrace{\begin{bmatrix} \mathbf{S}_{act}, & {}^{\tau}\mathbf{A}_{\rho} \end{bmatrix}}_{{}^{\tau}\mathbf{A}_u} \underbrace{\begin{bmatrix} \boldsymbol{\tau}_{act} \\ \boldsymbol{\rho} \end{bmatrix}}_u$$

$$\ddot{\mathbf{q}} = \underbrace{-M^{-1} (C\dot{\mathbf{q}} + \boldsymbol{\tau}_{grav})}_{\ddot{\mathbf{q}}_{MB}} + \underbrace{M^{-1} {}^{\tau}\mathbf{A}_u}_Q u$$

$$\mathbf{d}_{i,des} \stackrel{!}{=} \underbrace{D_i}_{d_i} u$$

task	task matrix D_i	desired task vector $d_{i,des}$
centr. mom.	$[\mathbf{0}_{6 \times n_{act}}, {}^{com}A_\rho]$	$F_{ext,des}$ $\tau_{com,des}$
foot tracking	$J_f Q$	$\ddot{x}_{f,des}$ $\dot{\omega}_{f,des}$ $-\dot{J}_f \dot{q} - J_f \ddot{q}_{MB}$
torso orient.	$J_{\omega,torso} Q$	$\dot{\omega}_{torso,des} - \dot{J}_{torso} \dot{q} - J_{torso} \ddot{q}_{MB}$
posture	$S_{post} Q u$	$\ddot{q}_{post,des} - S_{post} \ddot{q}_{MB}$
regulariz.	$I_{n_u \times n_u}$	$\mathbf{0}$

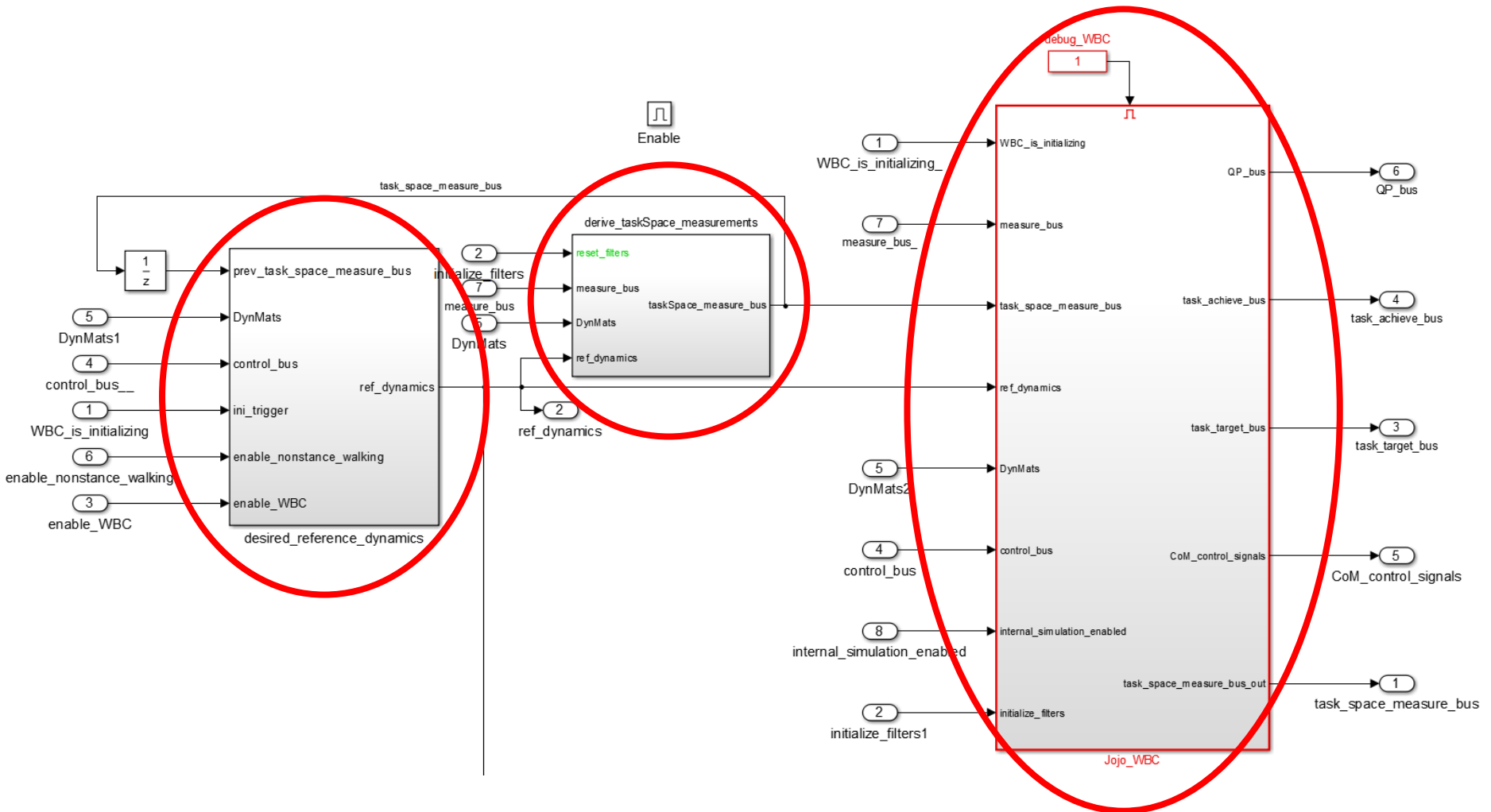
$$\Delta d_i = d_i - d_{i,des} = D_i u - d_{i,des}$$

$$\min_u \quad G = \frac{1}{2} \sum_i (\Delta d_i^T W_i \Delta d_i)$$

$$\text{s.t.} \quad \underline{\tau}_{act} \leq \tau_{act} \leq \overline{\tau}_{act}$$

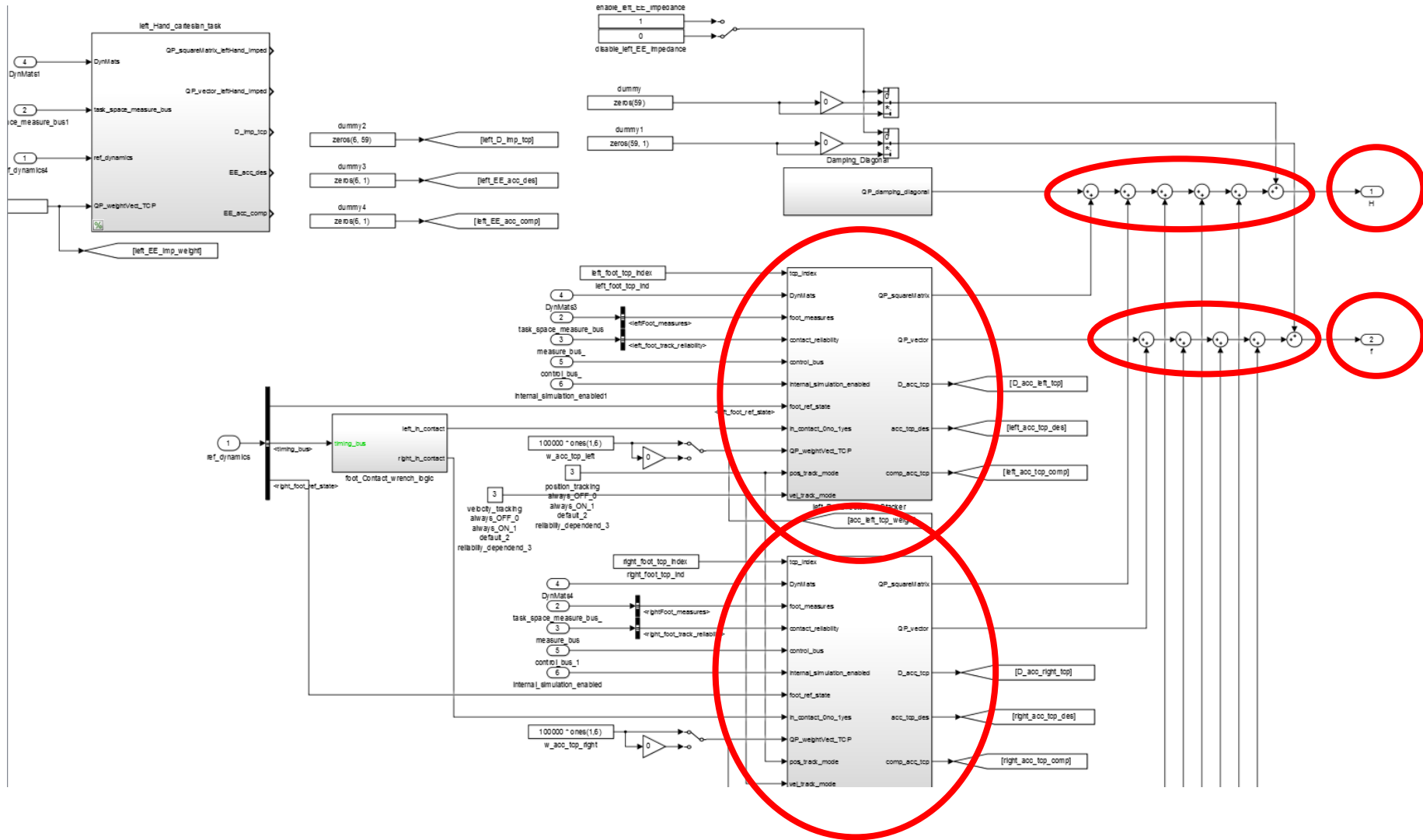
$$\mathbf{0} \leq \rho$$

main components



reference trajectories + taskspace measurements + taskspace controllers
(including filtering) + QP

task „assembly“

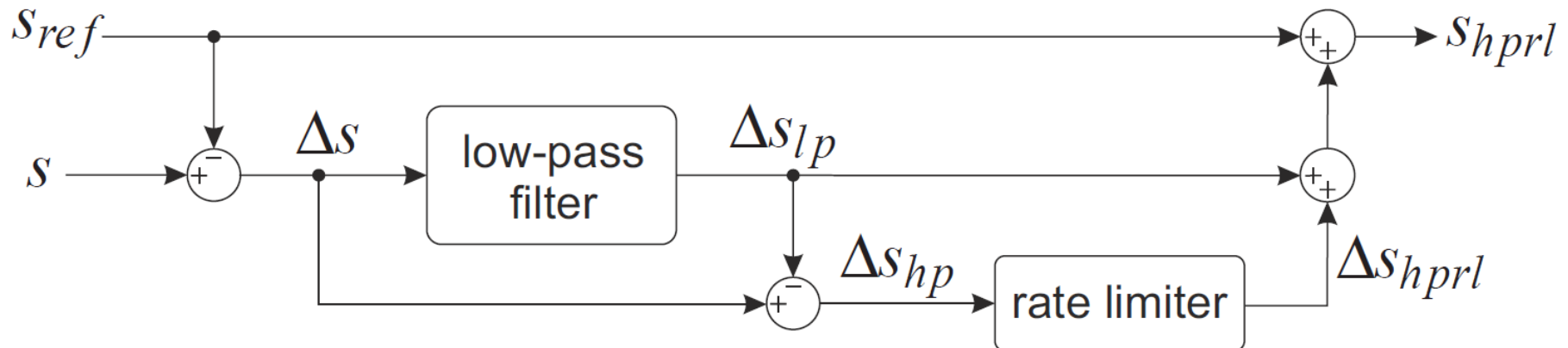


task 2 simulation

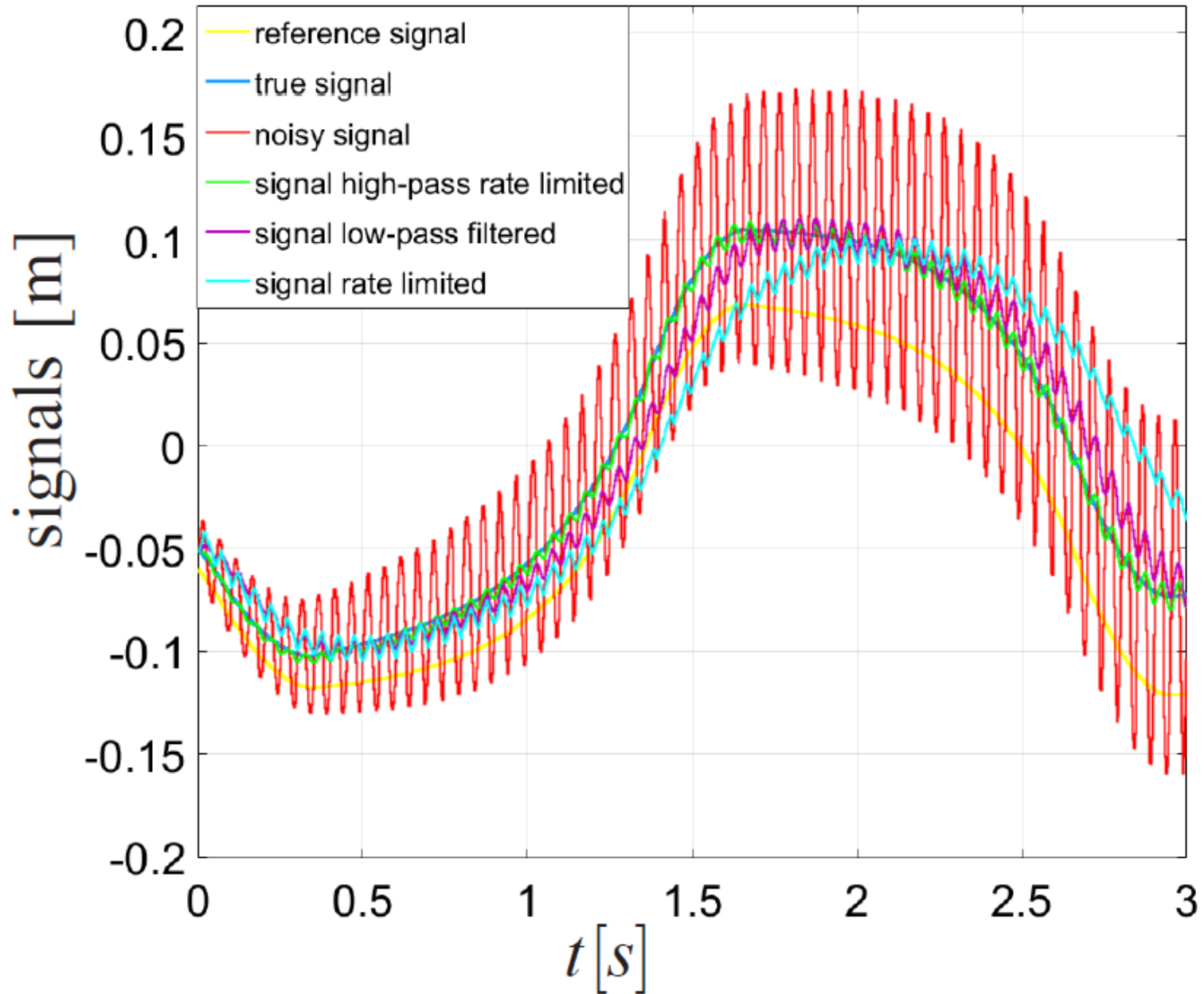
Problem:

- sensor noise, time delays & unmodelled dynamics (link elasticities) => vibrations (high frequency, amplified by controller (damping!!))
- first order filters / standard rate limiters: cause delays (phase shift)
- High-Pass Rate Limiter (HPRL) reduces vibrations while minimizing delays

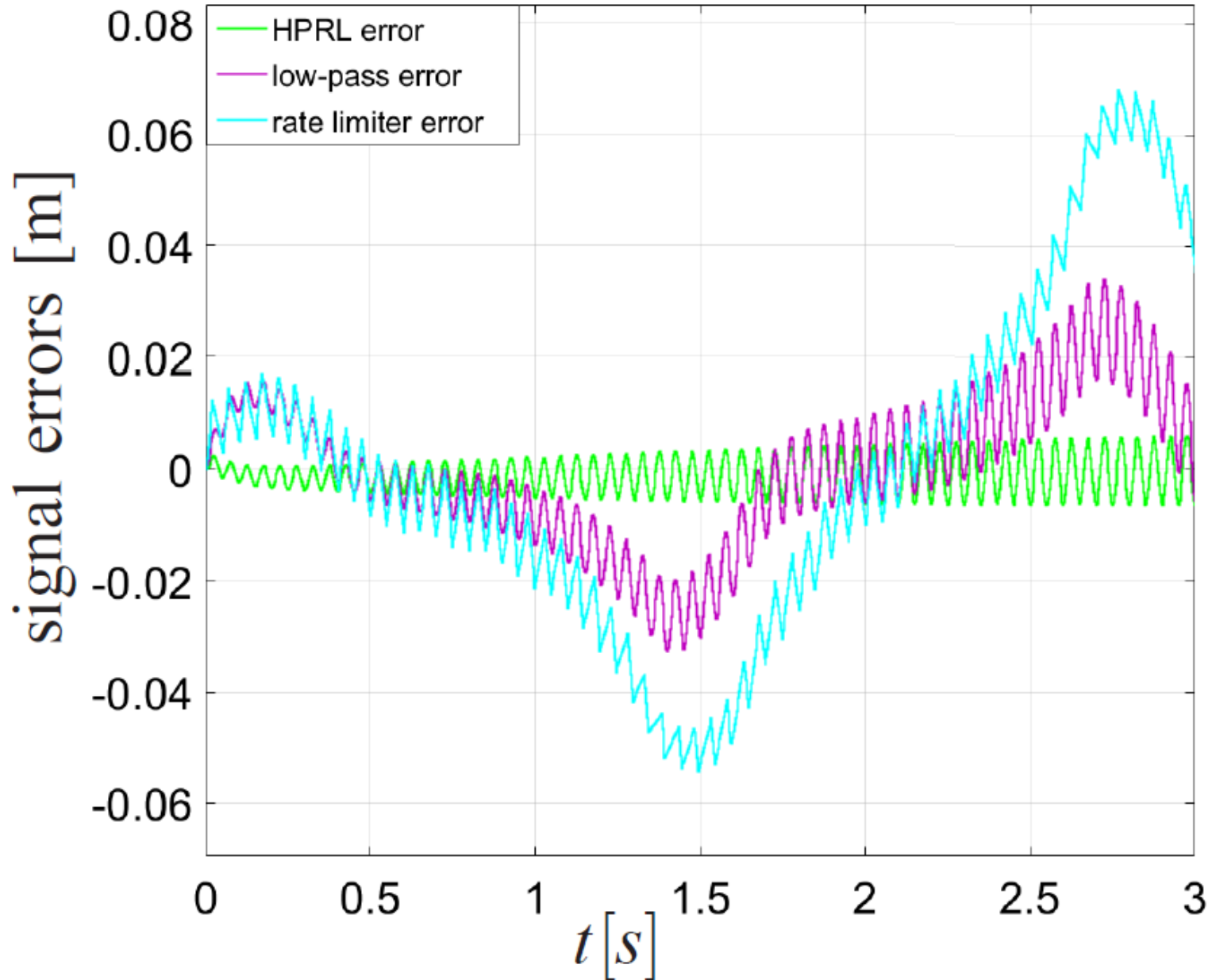
How it works ...



Filter comparison (absolute):



Filter comparison (errors):



- **state estimation:**
information $dx_{\text{foot}} = 0$ now depends
on measured GRF (from FTS)
- **PD foot tracking gains:**
remain active as long as foot is not yet
firmly on the ground (from FTS)

I.e., both no longer purely time-based
but additionally based on GRF feedback.

**torque-based walking
(inverse dynamics)**



**Merci pour
votre attention!! 😊**

Questions?