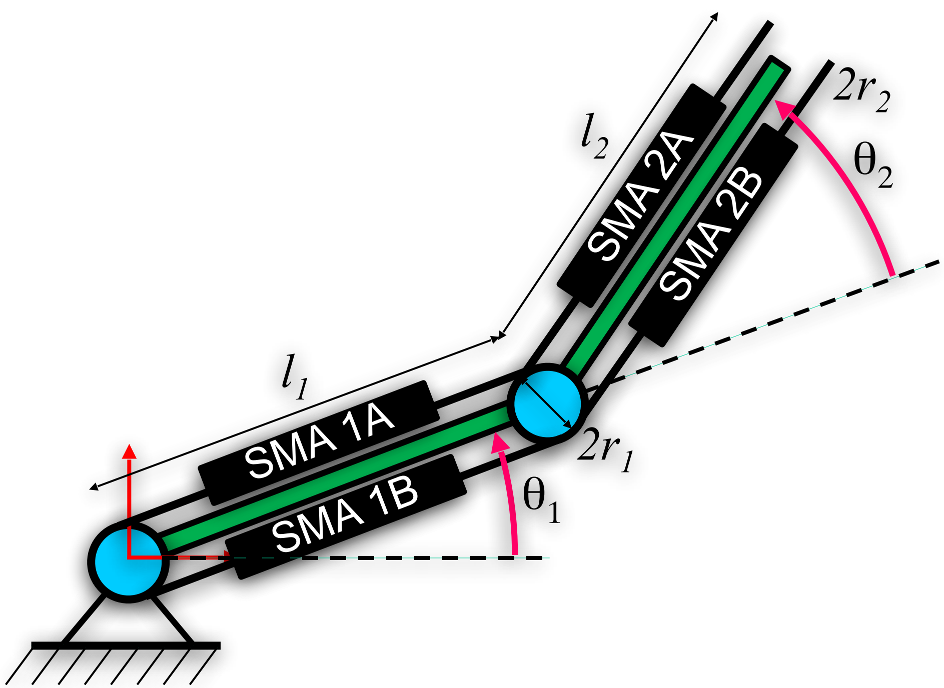
Aktorik und Sensorik mit intelligenten Materialsystemen 4

ASIM 4 Final Exam Assignment: SMA Actuated Wing

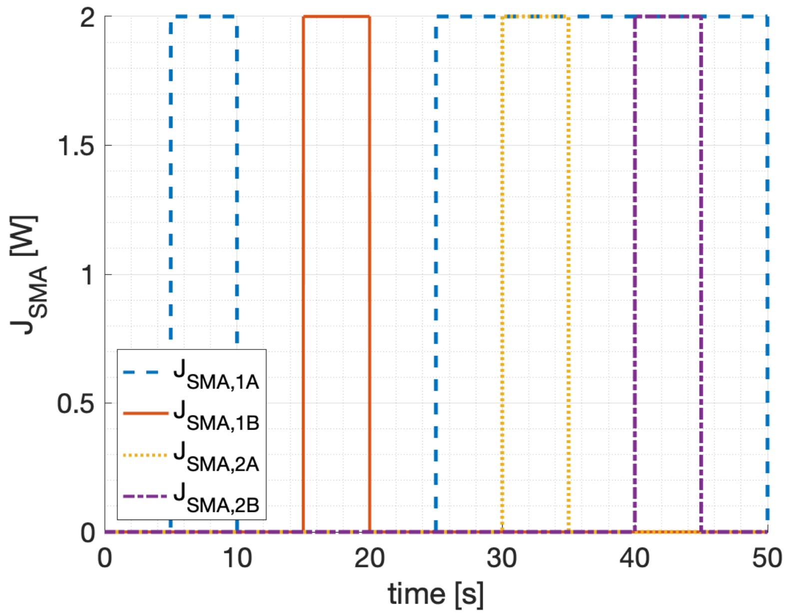


Tim Goll
Matthias Baltes
tim@timgoll.de
baltesmatthias@aol.com

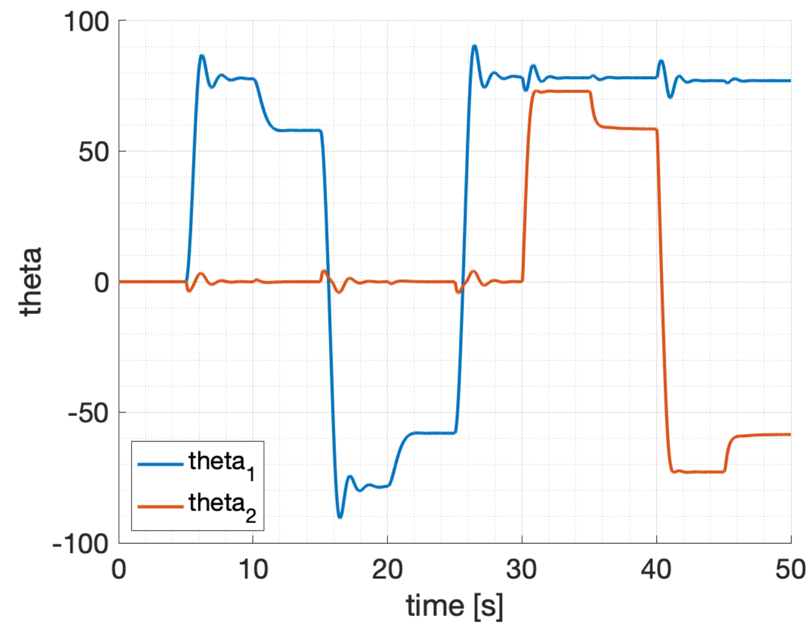
ASIM 4 Final Exam: SMA Wing

Effect of control inputs $J_{SMA,1A}$, $J_{SMA,1B}$, $J_{SMA,2A}$ and $J_{SMA,2B}$ on the actuator

Joule heating signals ($0W - 2W$)

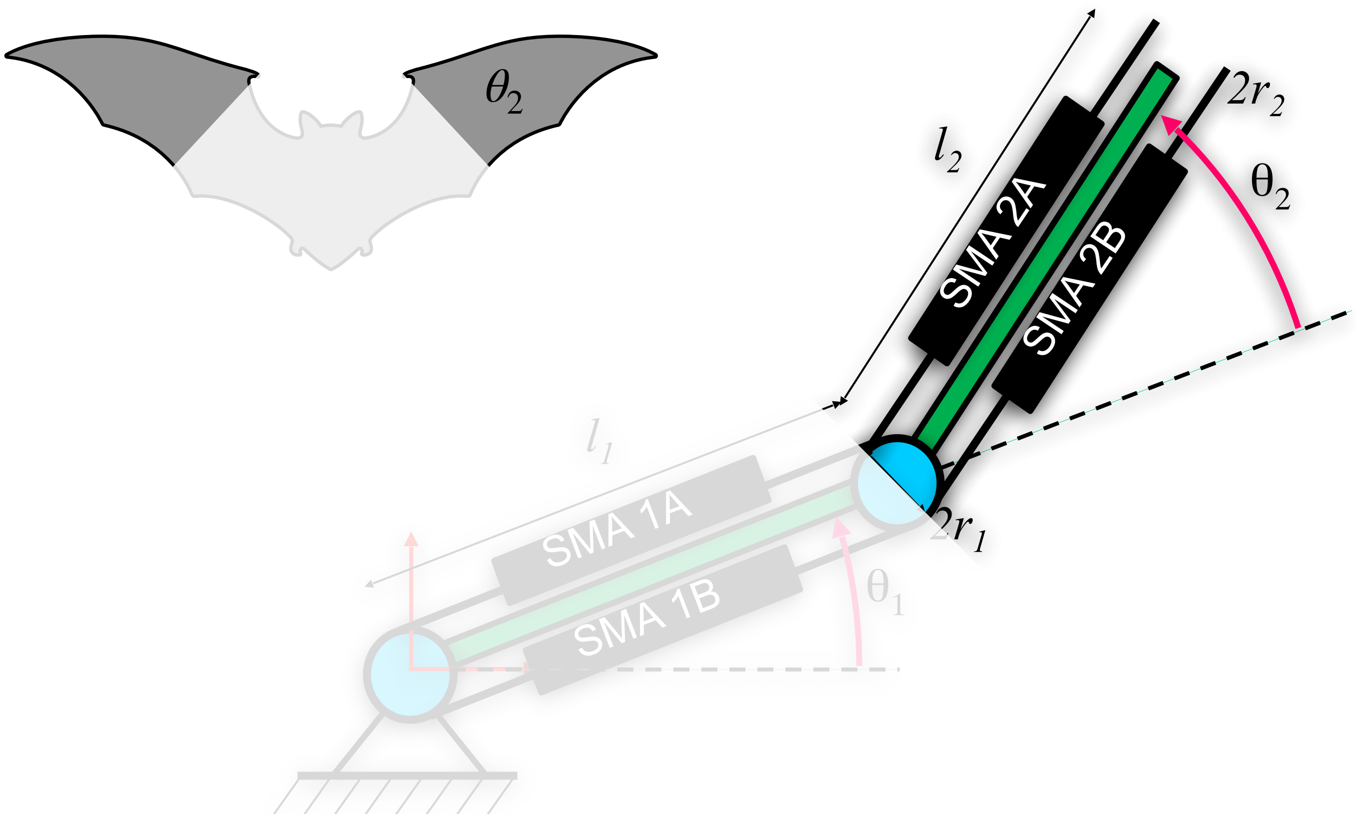


Output θ_1 and θ_2



Output θ_1 limited between -80° and 80°
Output θ_2 limited between -72° and 72°

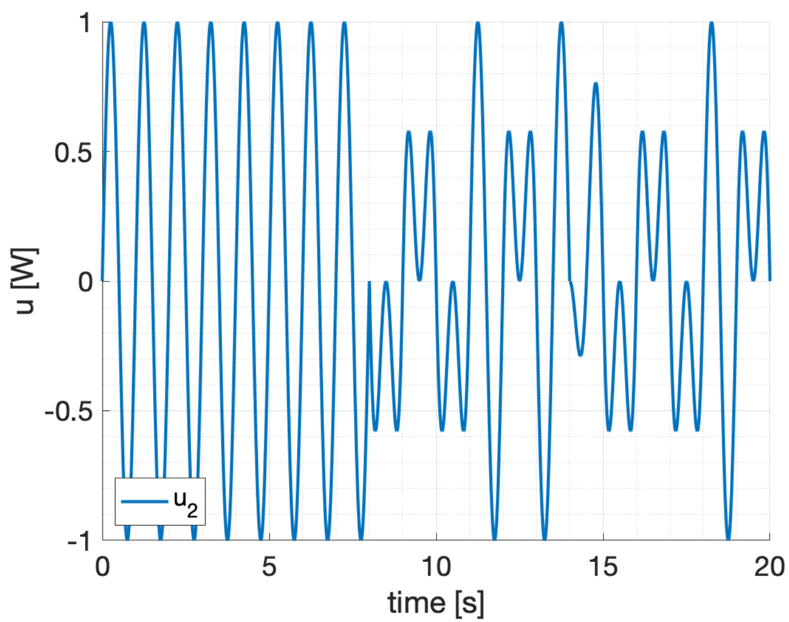
Linear control of θ_2



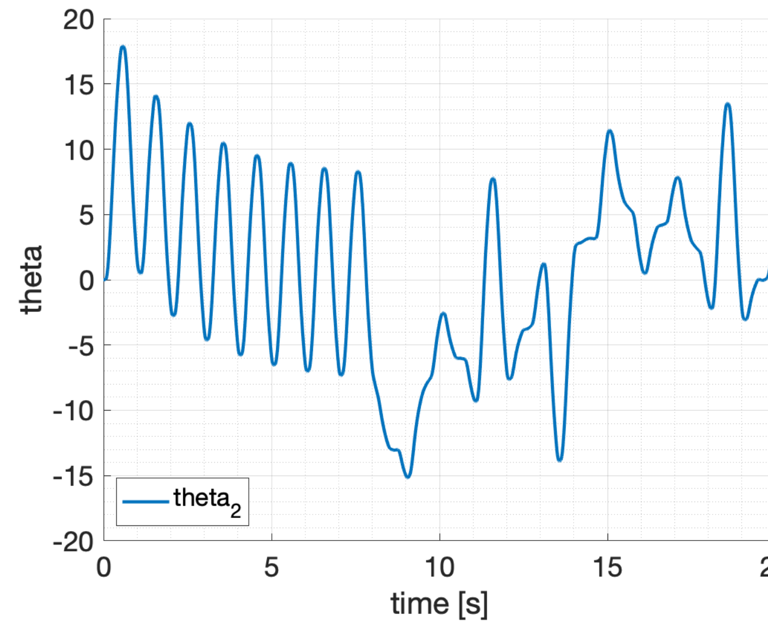
Response between u_2 and θ_2

Numerical linearization with the system identification toolbox:

Input u_2 (noisy signal after 8s)



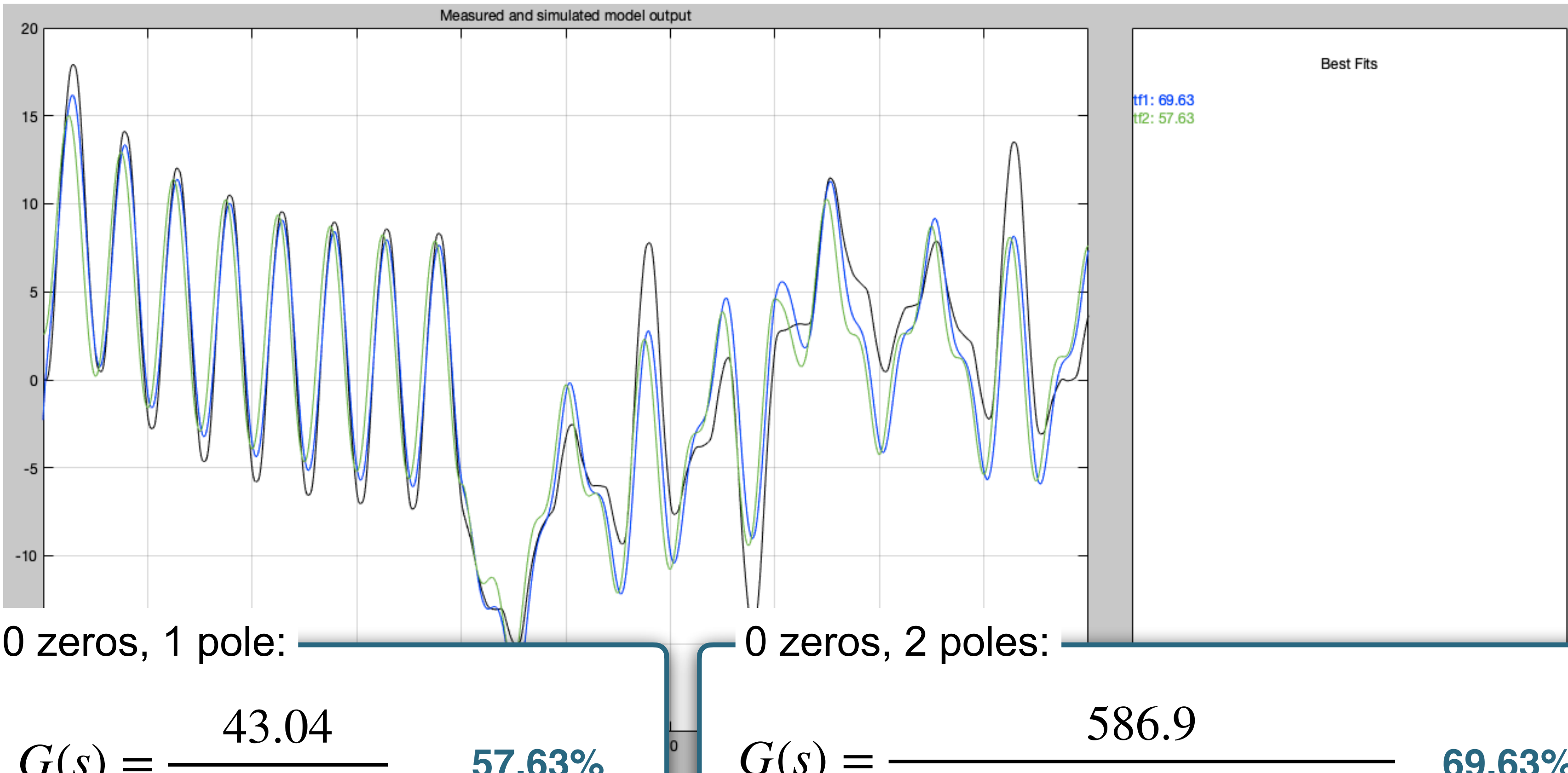
Output θ_2



Response between u_2 and θ_2

Numerical linearization with the system identification toolbox:

Systems Identification Toolbox



0 zeros, 1 pole:

$$G(s) = \frac{43.04}{s + 0.2933}$$

57.63%

0 zeros, 2 poles:

$$G(s) = \frac{586.9}{(s + 11.89) \cdot (s + 0.3653)}$$

69.63%

Linear Controller for set Point regulation of θ_2

Model based PI-Controller for a system with 2 real poles:

$$G(s) = \frac{586.9}{(s + 11.89) \cdot (s + 0.3653)}$$

We propose a PI:

$$C(s) = k_p + \frac{k_i}{s}$$

Open loop transfer function:

$$L(s) = k_p \frac{s + \frac{k_i}{k_p}}{s} \frac{k}{(s + p_1)(s + p_2)}$$

Linear Controller for set Point regulation of θ_2

Assume $p_1 > p_2$ and cancel the slowest system pole with PI zero:

Choose: $\dfrac{k_i}{k_p} = p_2 \rightarrow$ open loop transfer function:

$$L(s) = \frac{k_p k}{s(s + p_1)}$$

$\rightarrow$ closed loop transfer function:

$$T(s) = \frac{k_p k}{s^2 + p_1 s + k_p k}$$

Closed loop dampening and natural frequency:

$$\delta = \frac{p_1}{2\sqrt{k_p k}} \qquad \omega_n = \sqrt{k_p k}$$

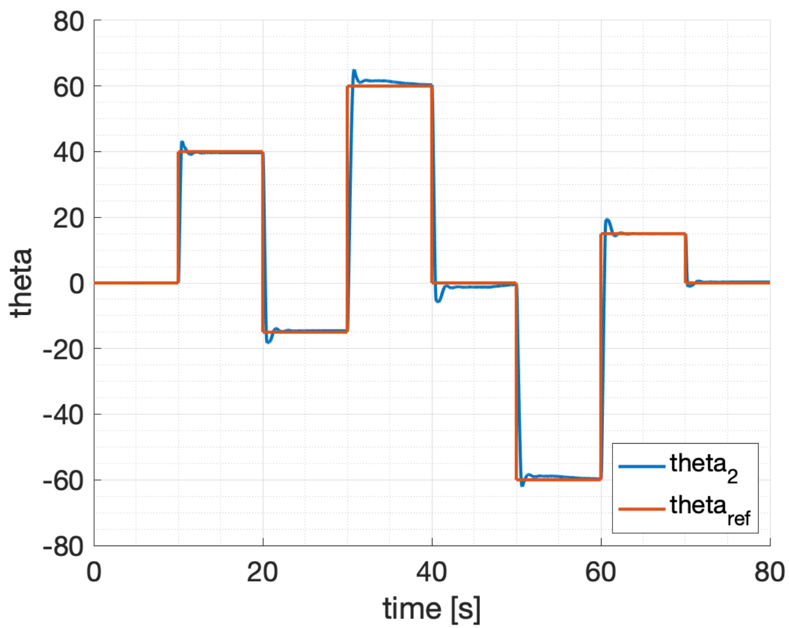
Now choose $\delta = 0.707$:

$$k_p = \frac{p_1^2}{4k\delta^2} \qquad k_i = \frac{p_2 p_1^2}{4k\delta^2}$$

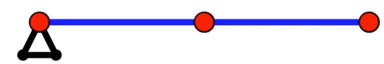
Linear Controller for set Point regulation of θ_2

Set Point regulation for θ_2 with model based PI

θ_2 reference and θ_2 simulated



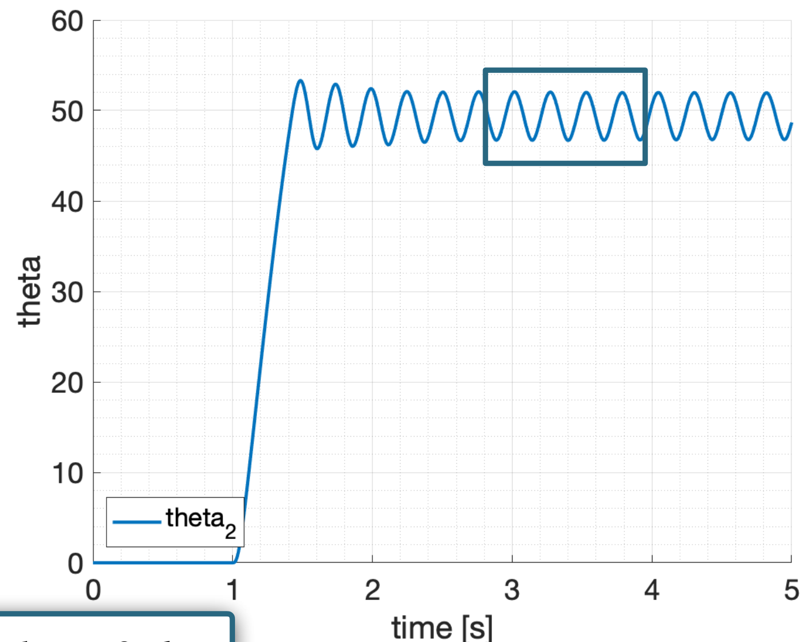
Animation



Linear Controller for set Point regulation of θ_2

PID design for θ_2 with Ziegler-Nichols method

θ_2 with self-sustained oscillation

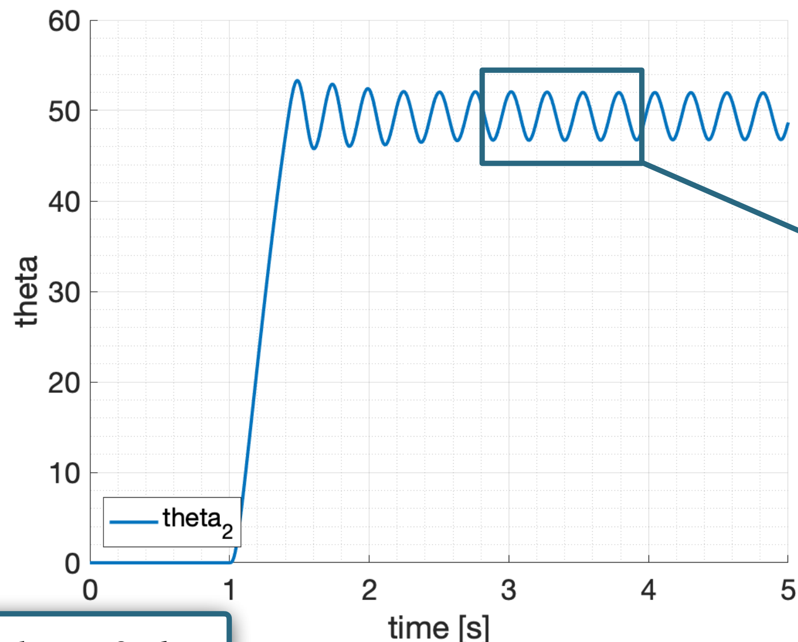


$k_p = 0.6$

Linear Controller for set Point regulation of θ_2

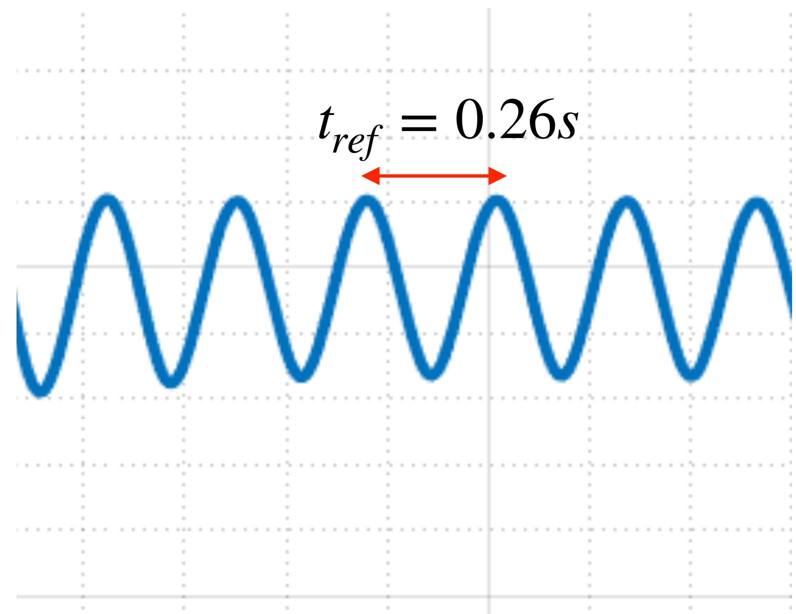
PID design for θ_2 with Ziegler-Nichols method

θ_2 with self-sustained oscillation



$k_p = 0.6$

Detail

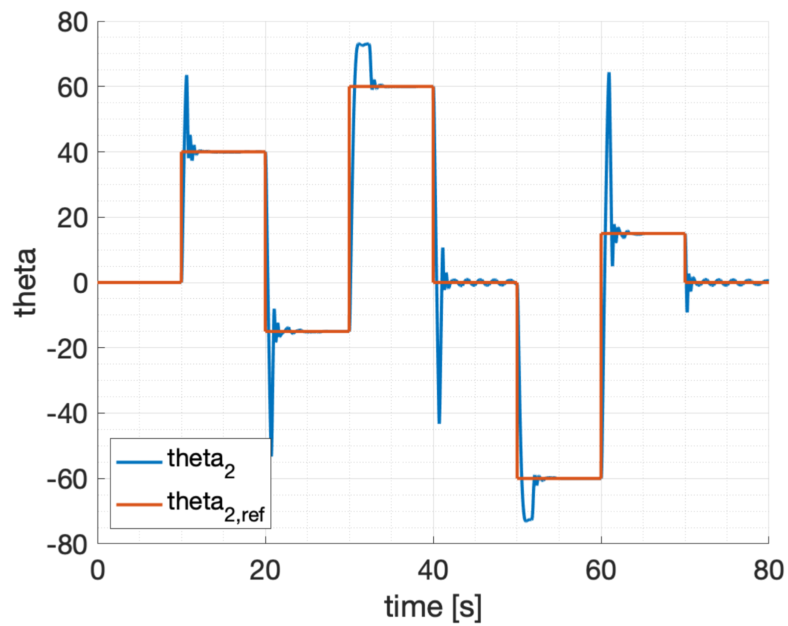


→ this results in:

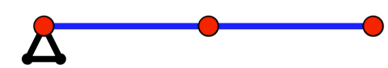
$$k_p = 0.36,\ k_i = 2.769,\ k_d = 0.012$$

Set Point regulation for θ_2 with Ziegler-Nichols method

θ_2 reference and θ_2 simulated

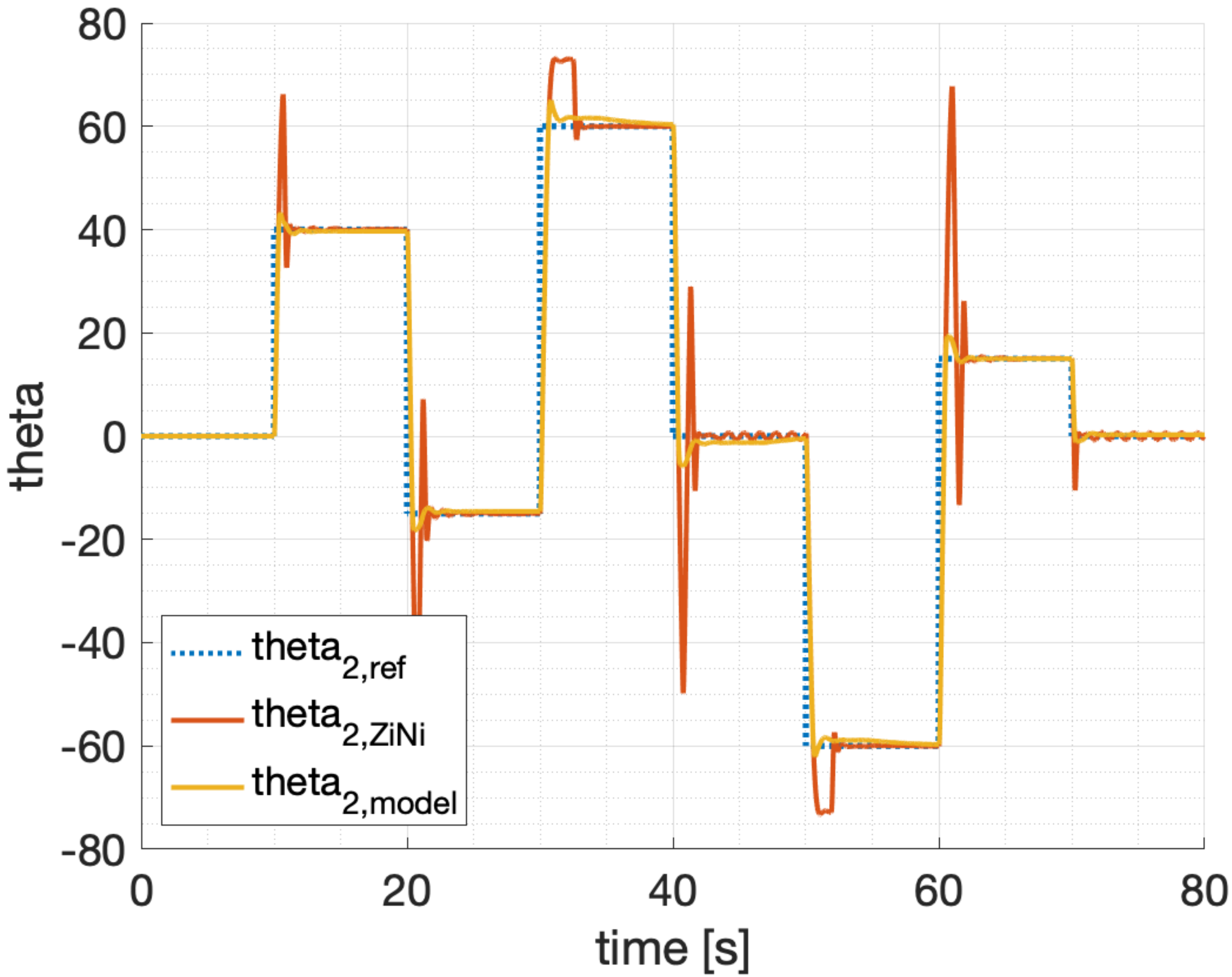


Animation



Linear Controller for set Point regulation of θ_2

Comparison of both linear PID controllers



Linear Controller for Trajectory Tracking of θ_2

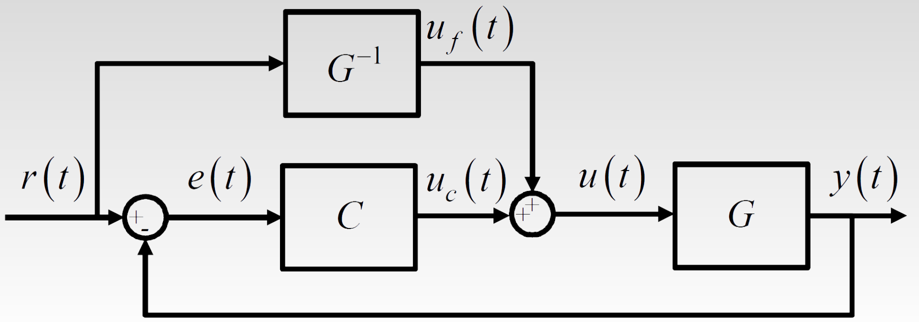
UNIVERSITÄT DES SAARLANDES

Lehrstuhl für intelligente Materialsysteme

intelligent Material Systems Lab

Feedforward and feedback method:

$$G(s) = \frac{b_0}{s^2 + a_1 s + a_0}$$



Our system:

$$G(s) = \frac{586.9}{(s+11.89)\cdot(s+0.3653)} = \frac{586.9}{(s^2+12.2553s+4.3434)}$$

Feedforward input in time domain:

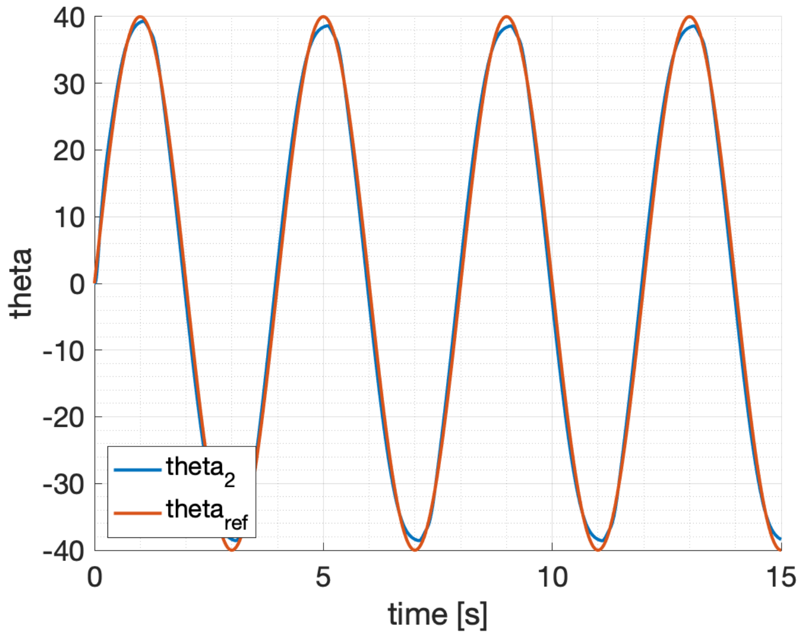
$$u_f(t) = \frac{1}{b_o}\ddot{r}(t) + \frac{a_1}{b_0}\dot{r}(t) + \frac{a_0}{b_0}r(t) = \frac{1}{586.9}\ddot{r}(t) + \frac{12.2553}{586.9}\dot{r}(t) + \frac{4.3434}{586.9}r(t)$$

→reference signal $r(t)$ must be a two-time differentiable trajectory

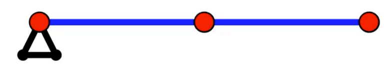
Linear Controller for Trajectory Tracking of θ_2

Trajectory tracking for θ_2 combination of feedforward and feedback method (model based method)

θ_2 reference and θ_2 simulated



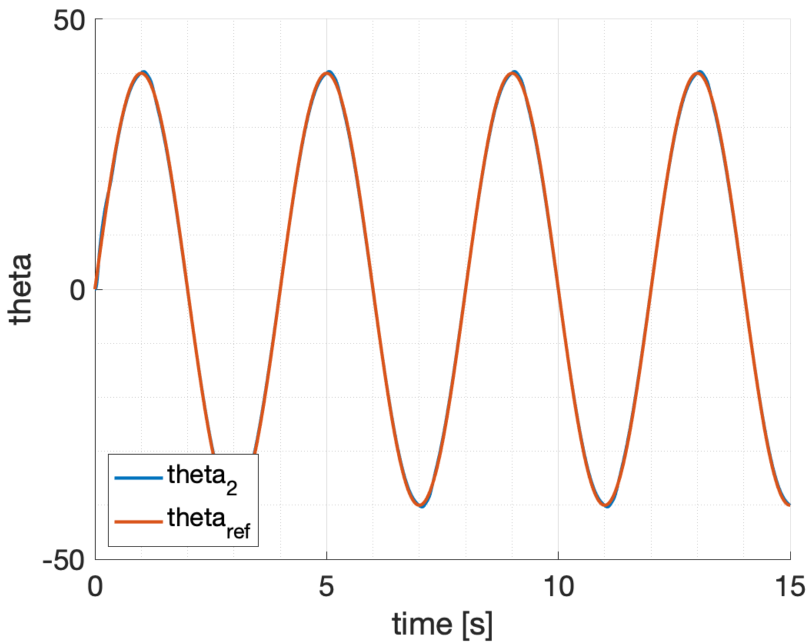
Animation



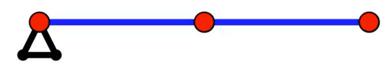
Linear Controller for Trajectory Tracking of θ_2

Trajectory tracking for θ_2 combination of feedforward and feedback method (Ziegler-Nichols method tuned)

θ_2 reference and θ_2 simulated

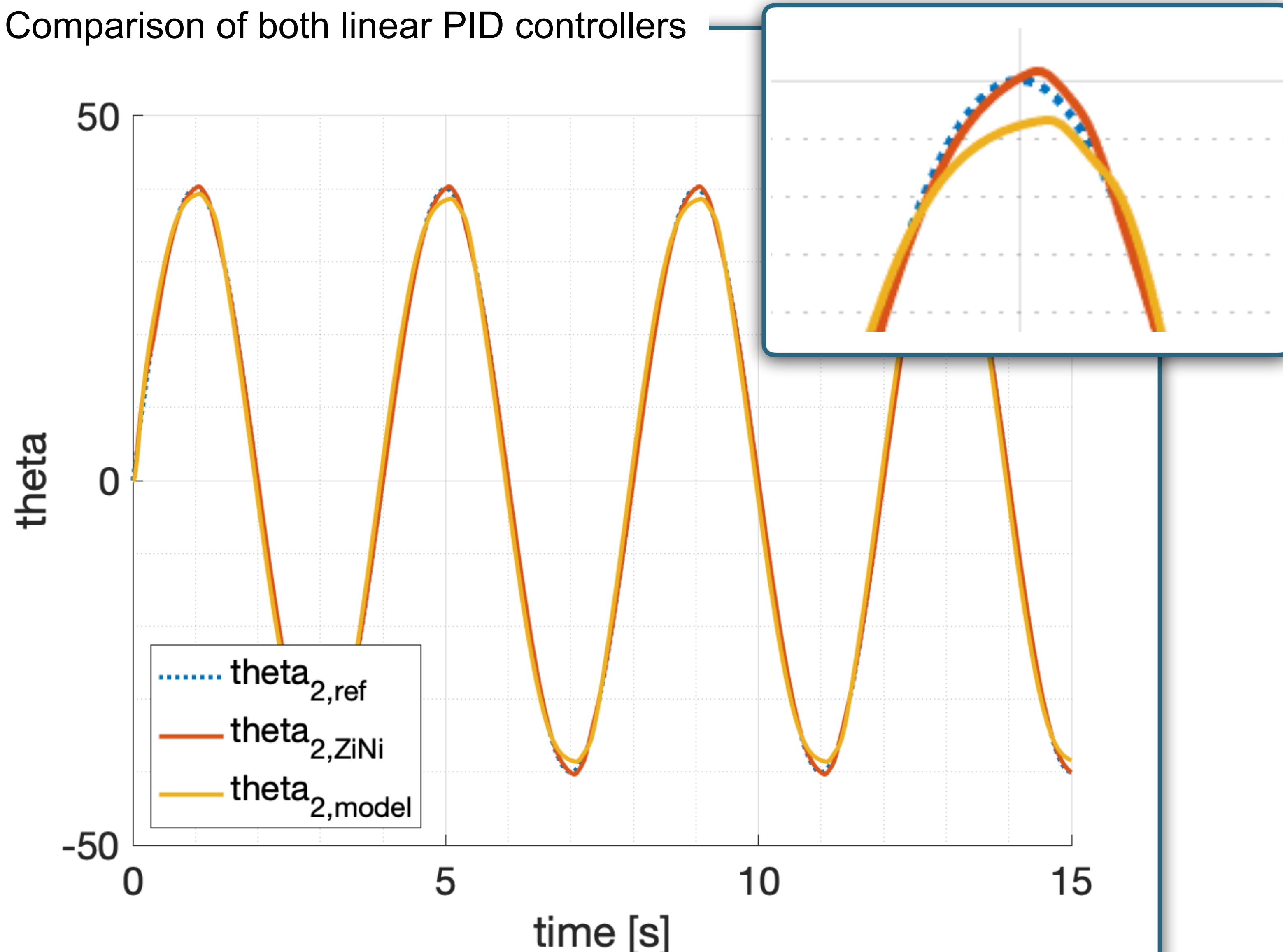


Animation

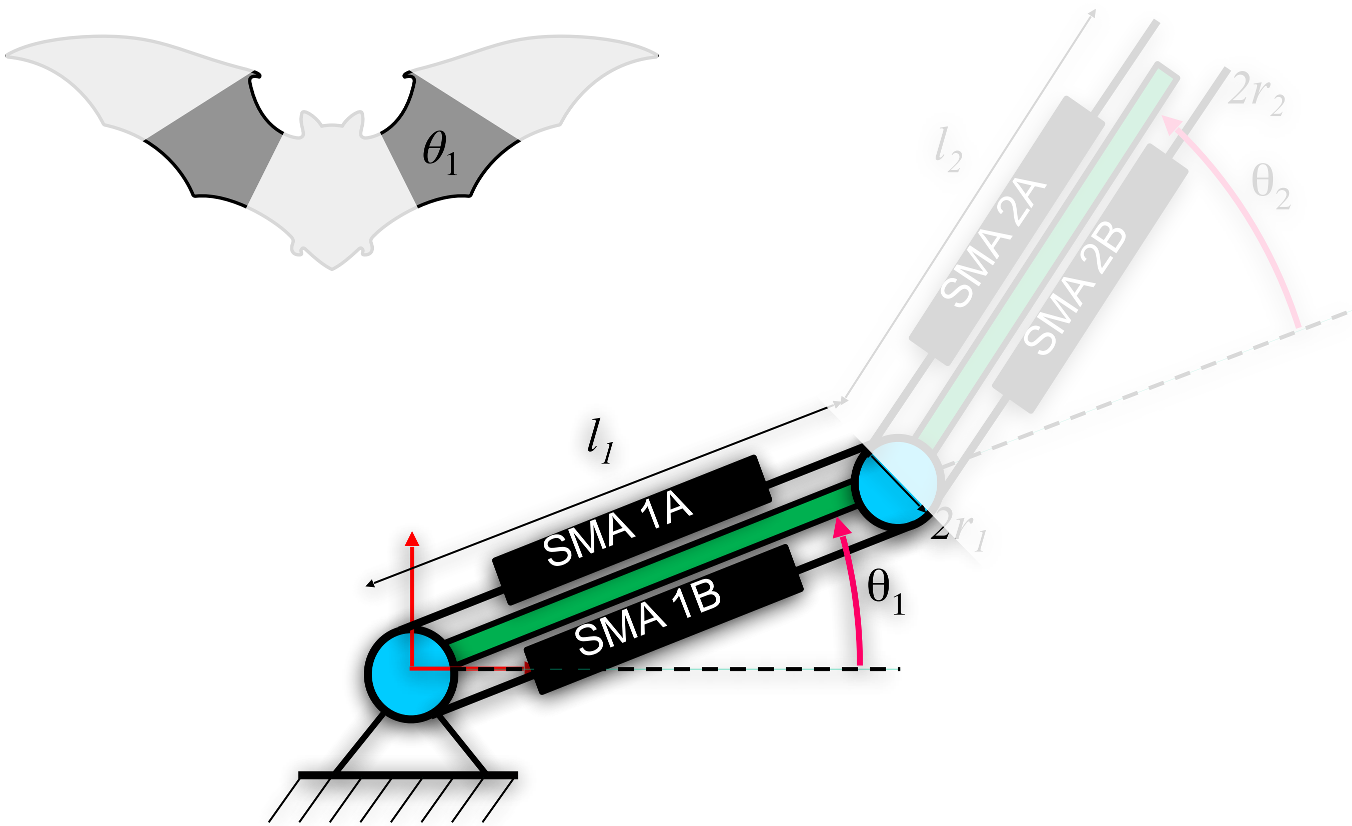


Linear Controller for Trajectory Tracking of θ_2

Comparison of both linear PID controllers



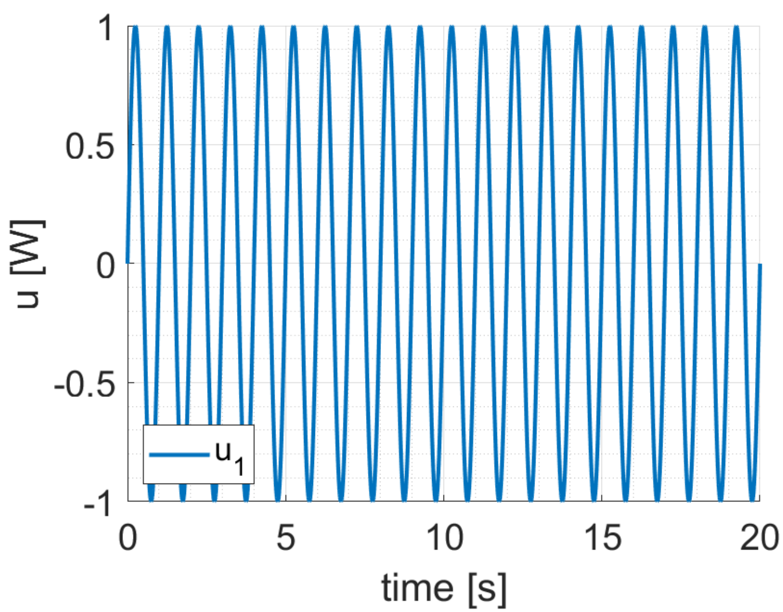
Linear control of θ_1



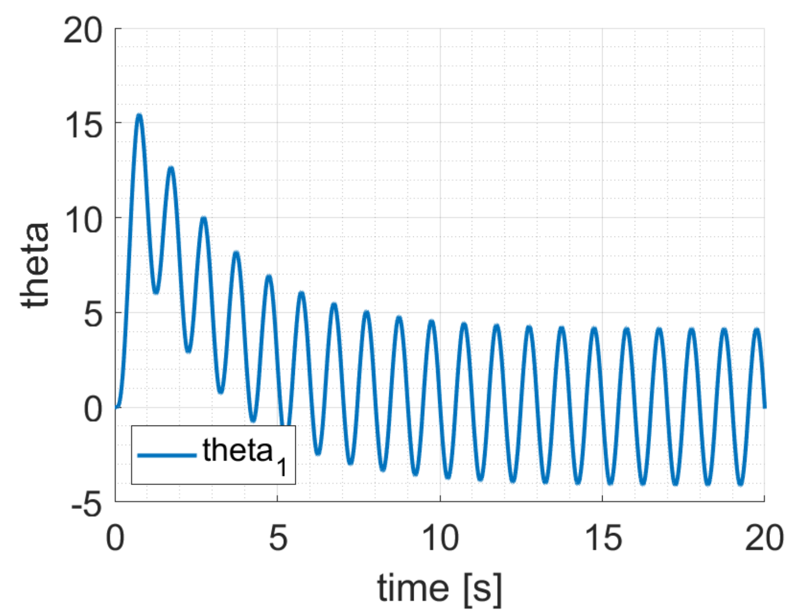
Response between u_1 and θ_1

Numerical linearization with the system identification toolbox:

Input u_1 (sine wave)



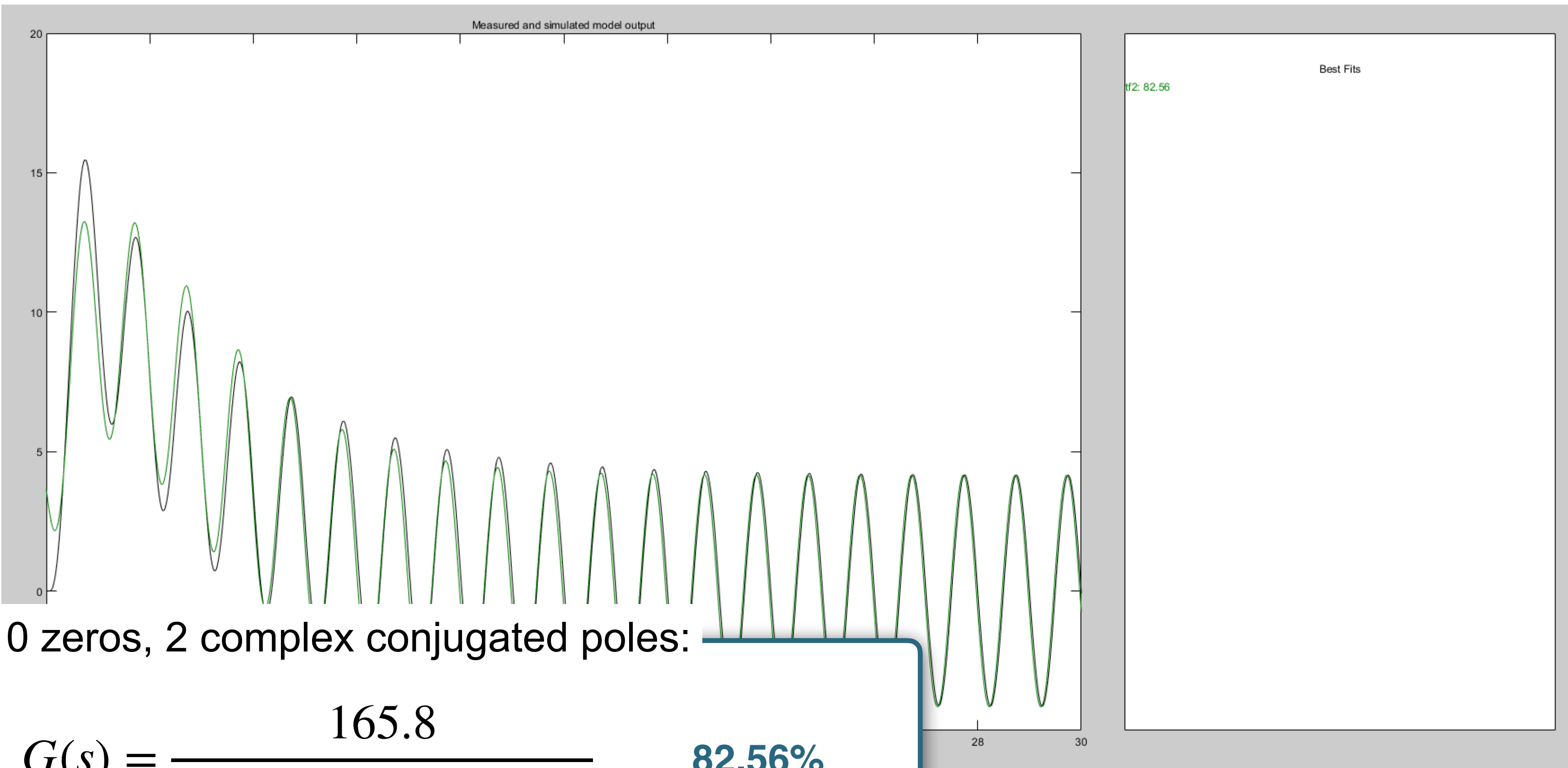
Output θ_1 (initial effects over after 8s)



Response between u_1 and θ_1

Numerical linearization with the system identification toolbox:

Systems Identification Toolbox



0 zeros, 2 complex conjugated poles:

$$G(s) = \frac{165.8}{s^2 + 1.351s + 0.4741}$$

82.56%

Linear Controller for set Point regulation of θ_1

Model based PI-Controller for a system with 2 complex conjugated poles:

$$G(s) = \frac{165.8}{s^2 + 1.351s + 0.4741}$$

We propose a PID:

$$C(s) = k_p + \frac{k_i}{s} + k_d s$$

Open loop transfer function:

$$L(s) = k_d \frac{s^2 + \frac{k_p}{k_d}s + \frac{k_i}{k_d}}{s} \frac{b_0}{s^2 + a_1 s + a_0}$$

Linear Controller for set Point regulation of θ_1

Cancel both poles with PID zeros:

Choose: $\frac{k_p}{k_d} = a_1$, $\frac{k_i}{k_d} = a_0$ → open loop transfer function:

$$L(s) = \frac{k_d b_o}{s}$$

→ closed loop transfer function:

$$T(s) = \frac{k_d b_0}{s + k_d b_o}$$

k_d as a function of the closed loop time constant $\tau *$:

Choose: $k_d = \frac{1}{\tau * b_o}$ → closed loop transfer function:

$$T(s) = \frac{1}{\tau * s + 1}$$

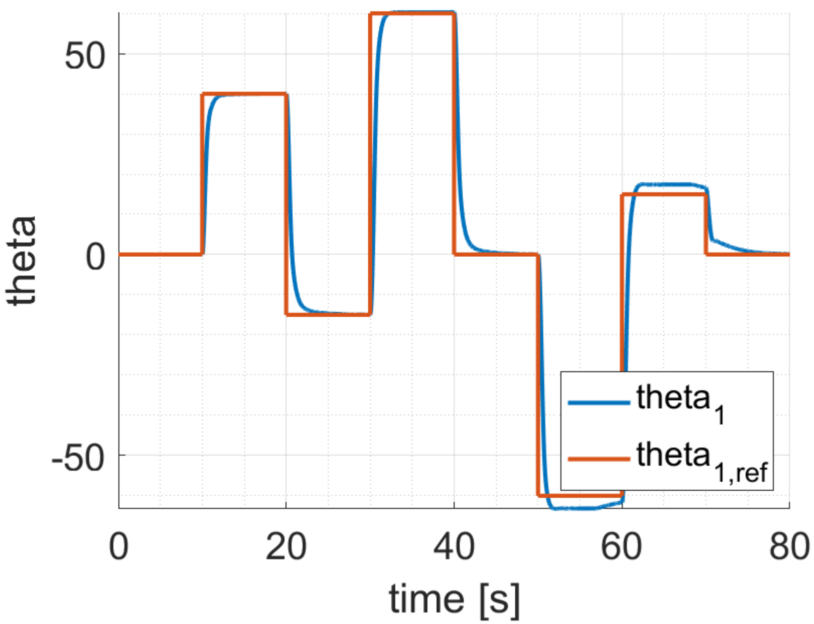
Now choose $\delta = 0.707$:

$$k_p = \frac{a_1}{b_0 \tau *} \qquad k_i = \frac{a_0}{b_0 \tau *} \qquad k_d = \frac{1}{b_0 \tau *}$$

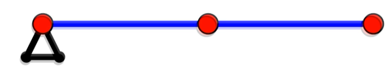
Linear Controller for set Point regulation of θ_1

Set Point regulation for θ_1 with model based PI

θ_1 reference and θ_1 simulated



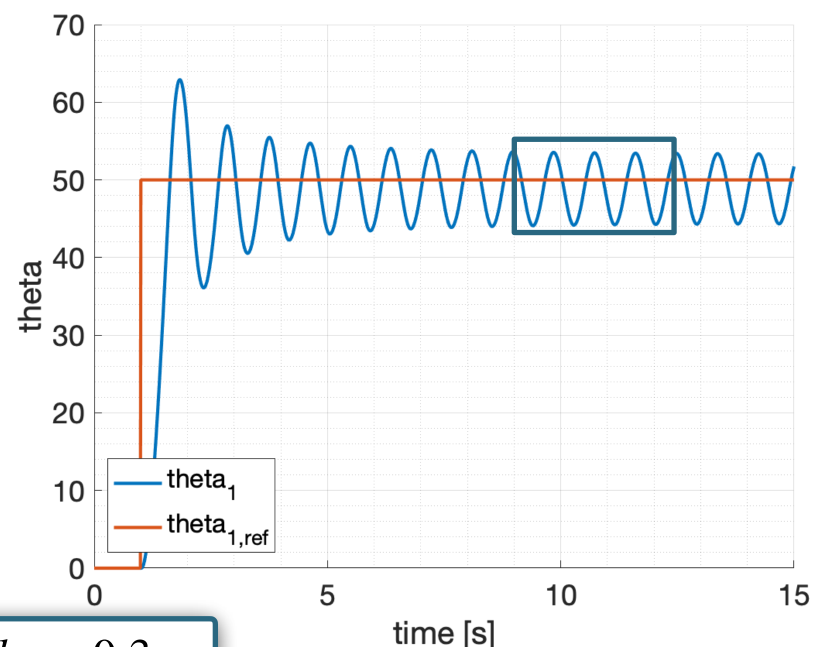
Animation



Linear Controller for set Point regulation of θ_1

PID design for θ_1 with Ziegler-Nichols method

θ_1 with self-sustained oscillation

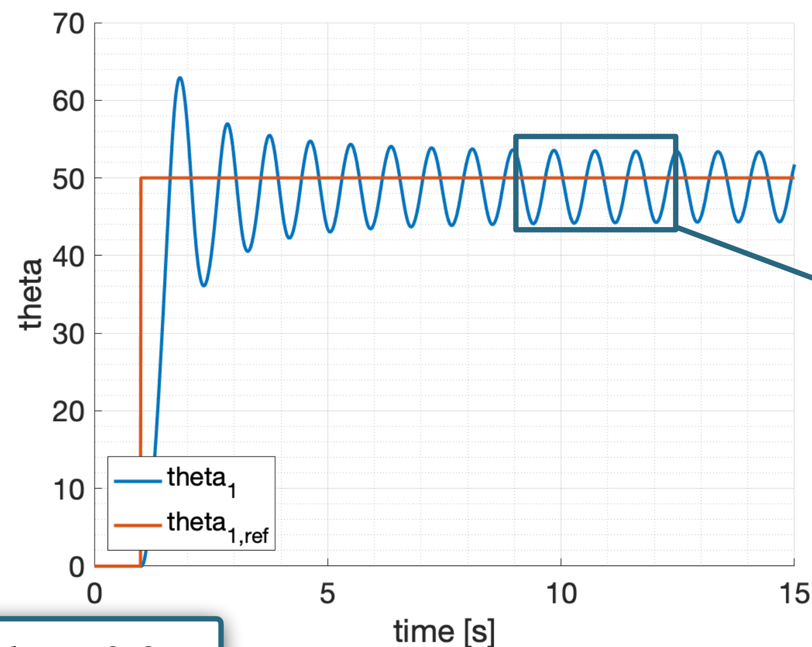


$k_p = 0.3$

Linear Controller for set Point regulation of θ_1

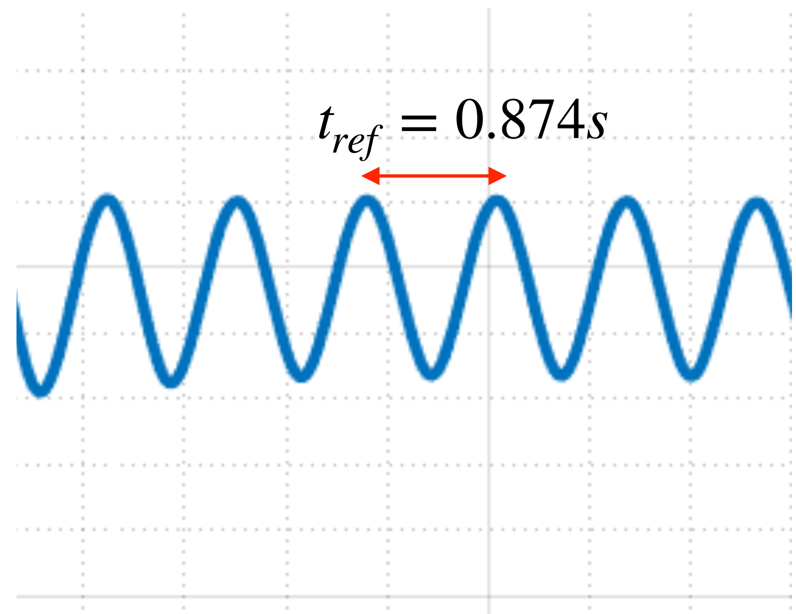
PID design for θ_1 with Ziegler-Nichols method

θ_2 with self-sustained oscillation



$k_p = 0.3$

Detail



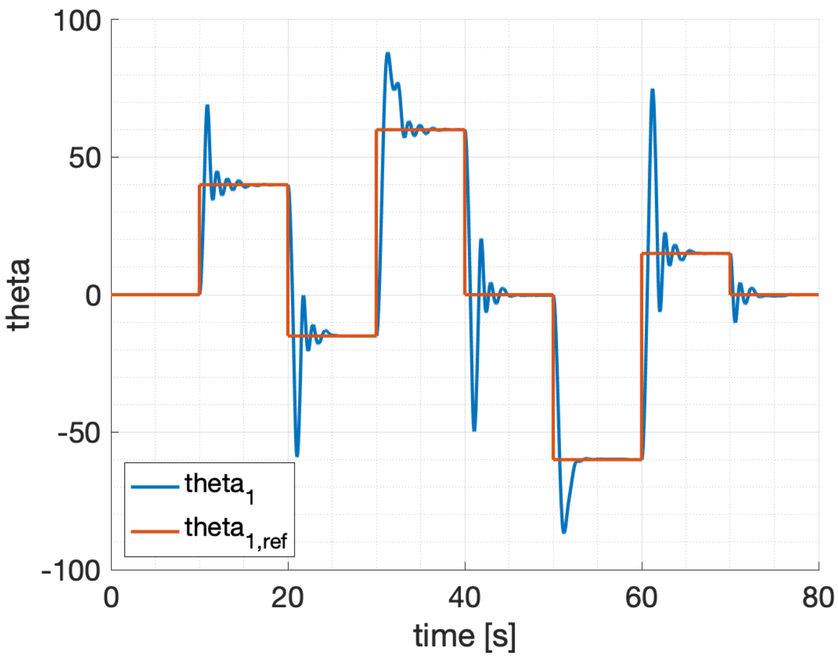
→ this results in:

$$k_p = 0.18,\ k_i = 0.1373,\ k_d = 0.2622$$

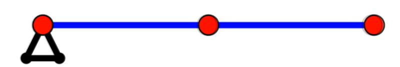
Linear Controller for set Point regulation of θ_1

Set Point regulation for θ_1 with Ziegler-Nichols method

θ_1 reference and θ_1 simulated

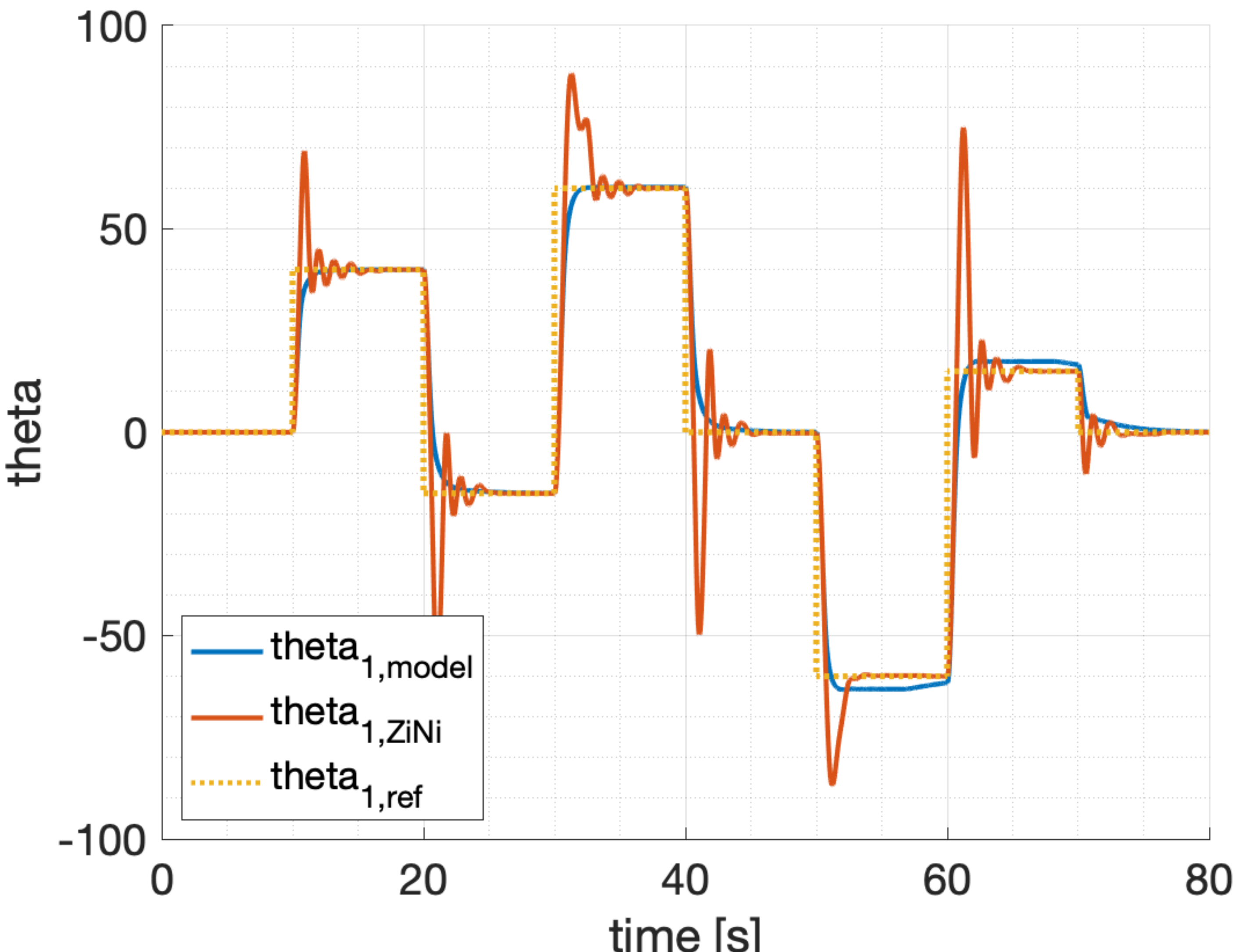


Animation



Linear Controller for set Point regulation of θ_1

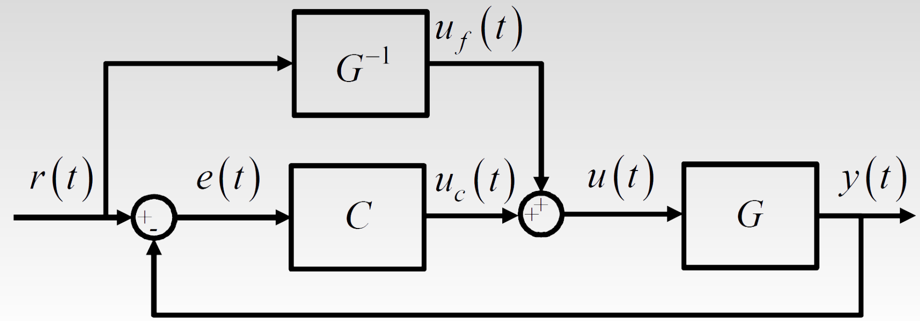
Comparison of both linear PID controllers



Linear Controller for Trajectory Tracking of θ_1

Feedforward and feedback method:

$$G(s) = \frac{b_0}{s^2 + a_1 s + a_0}$$



Our system:

$$G(s) = \frac{165.8}{s^2 + 1.351s + 0.4741}$$

Feedforward input in time domain:

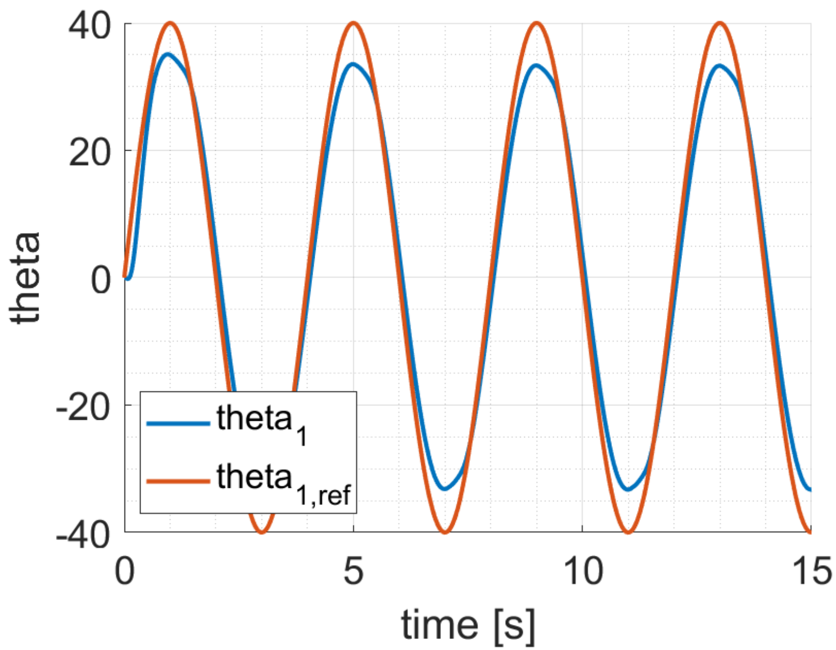
$$u_f(t) = \frac{1}{b_o}\ddot{r}(t) + \frac{a_1}{b_0}\dot{r}(t) + \frac{a_0}{b_0}r(t) = \frac{1}{165.8}\ddot{r}(t) + \frac{1.351}{165.8}\dot{r}(t) + \frac{0.4741}{165.8}r(t)$$

→reference signal $r(t)$ must be a two-time differentiable trajectory

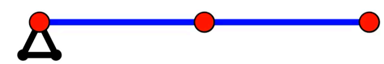
Linear Controller for Trajectory Tracking of θ_1

Trajectory tracking for θ_1 with combination of feedforward and feedback method (model based method)

θ_1 reference and θ_1 simulated



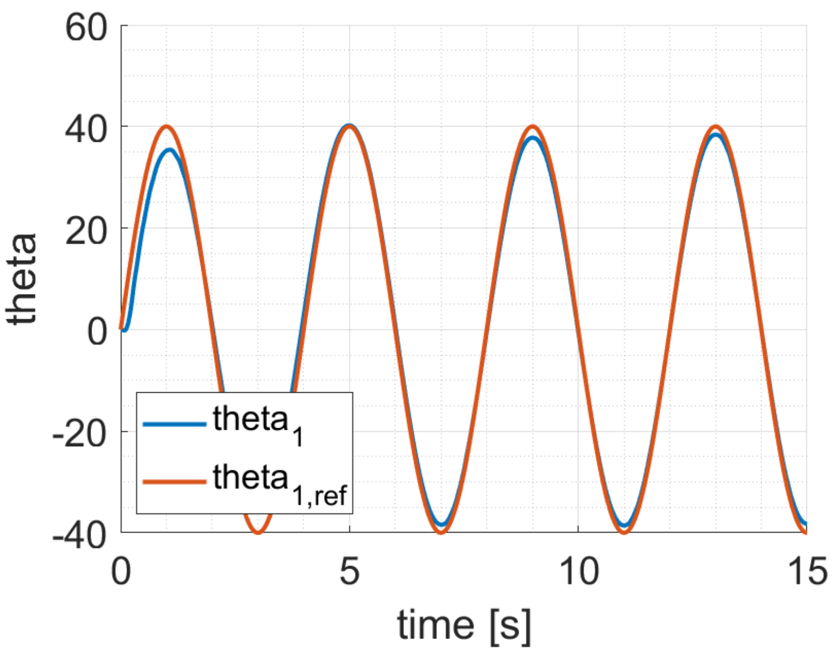
Animation



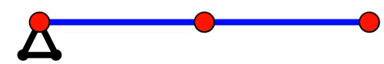
Linear Controller for Trajectory Tracking of θ_1

Trajectory tracking for θ_1 with combination of feedforward and feedback method (Ziegler-Nichols method tuned)

θ_1 reference and θ_1 simulated

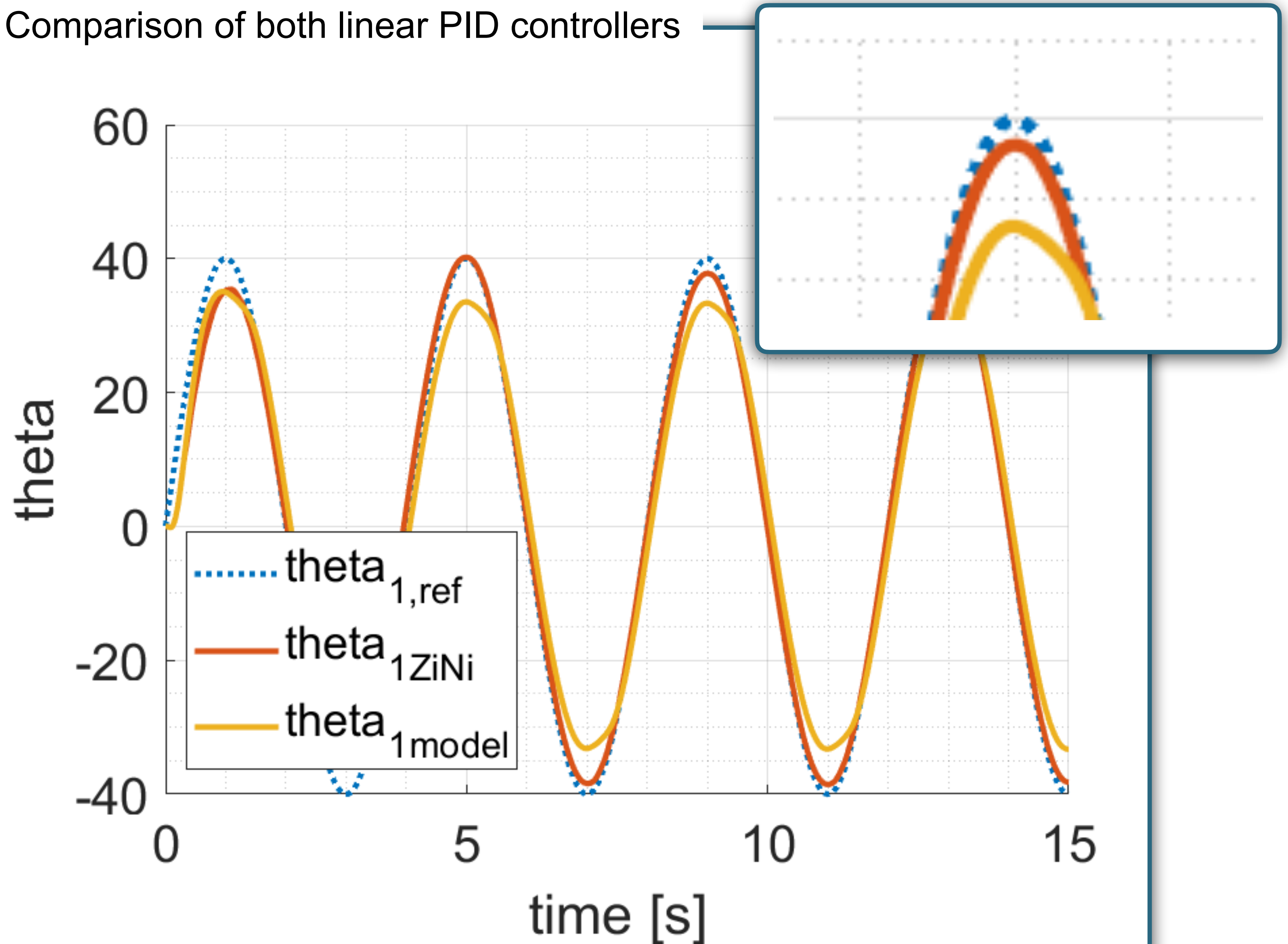


Animation

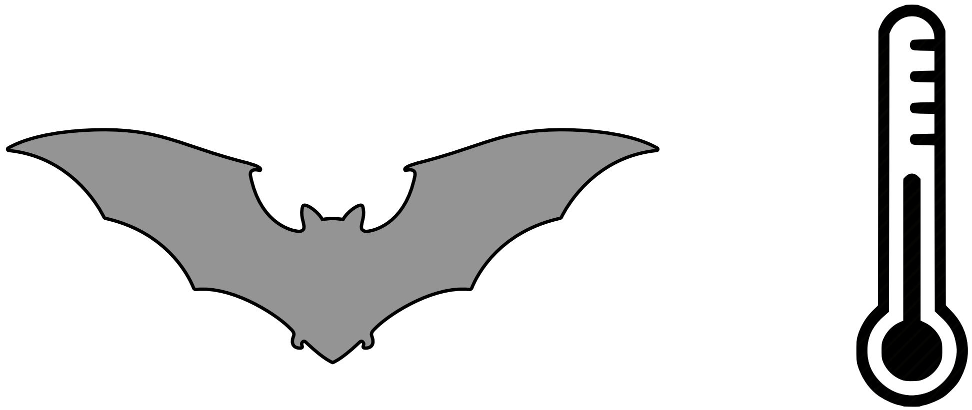


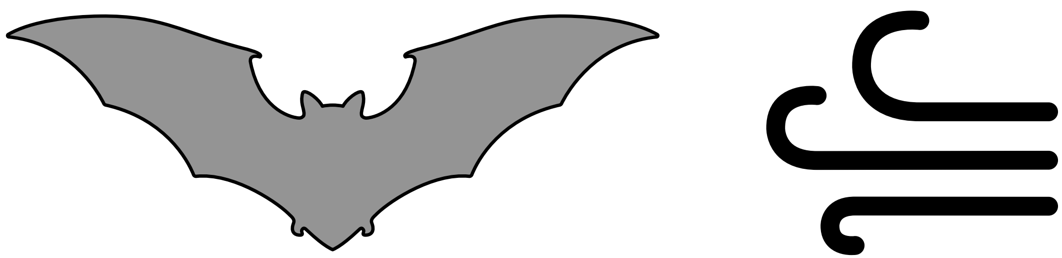
Linear Controller for Trajectory Tracking of θ_1

Comparison of both linear PID controllers



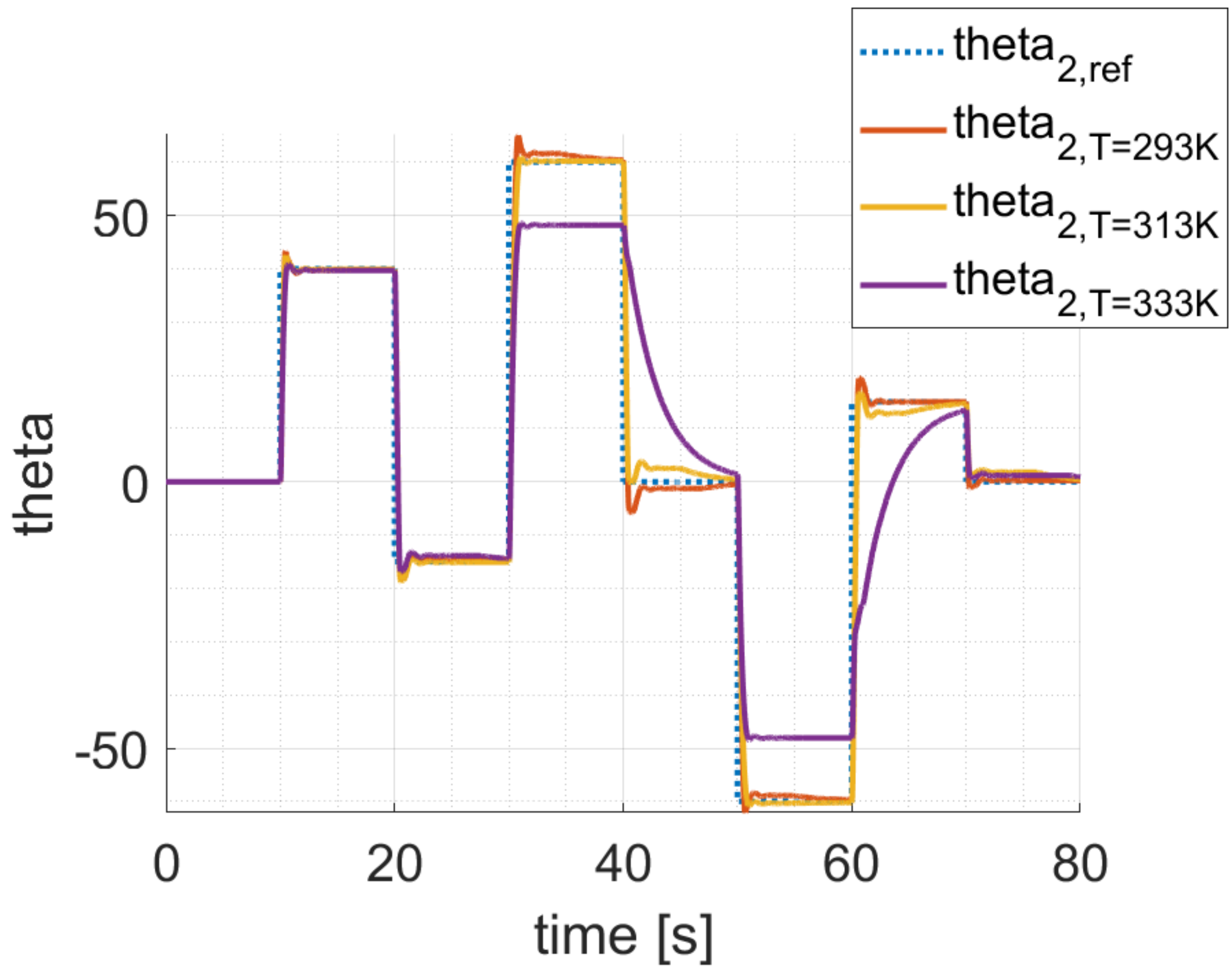
Linear control with disturbance





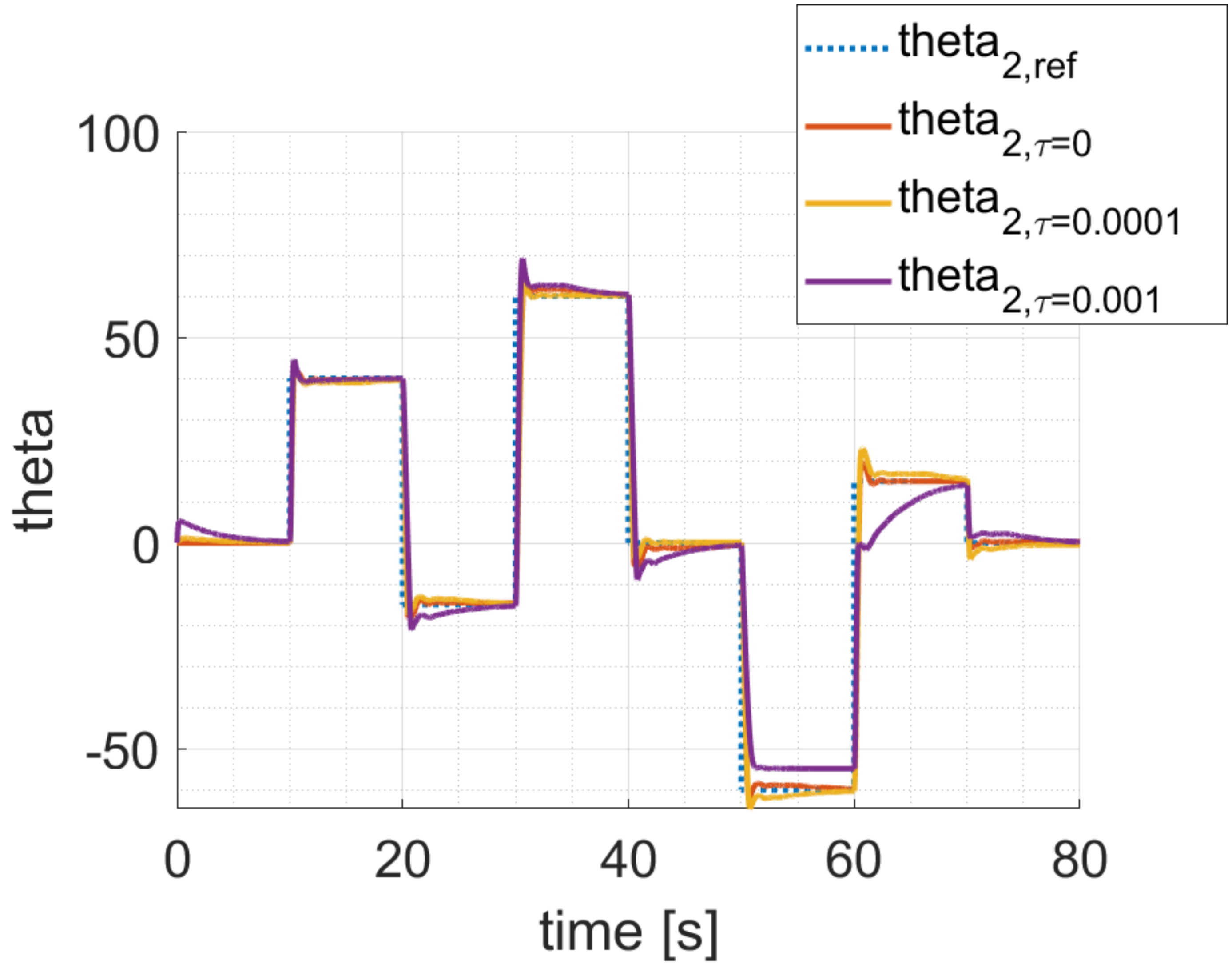
Temperature dependency (control of θ_2)

Control of θ_2 with different temperatures



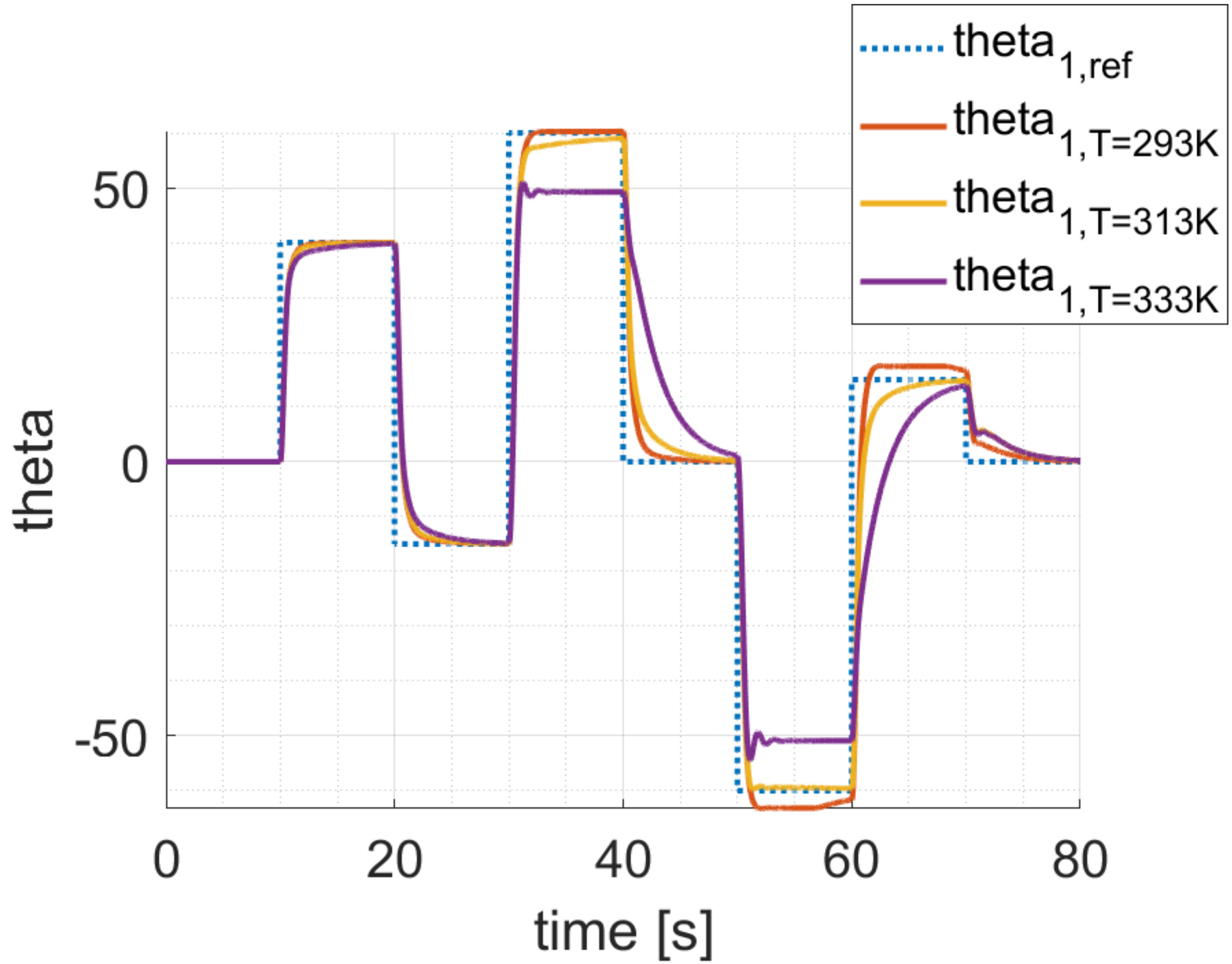
Control of θ_2 with disturbance τ

Control of θ_2 with different disturbances



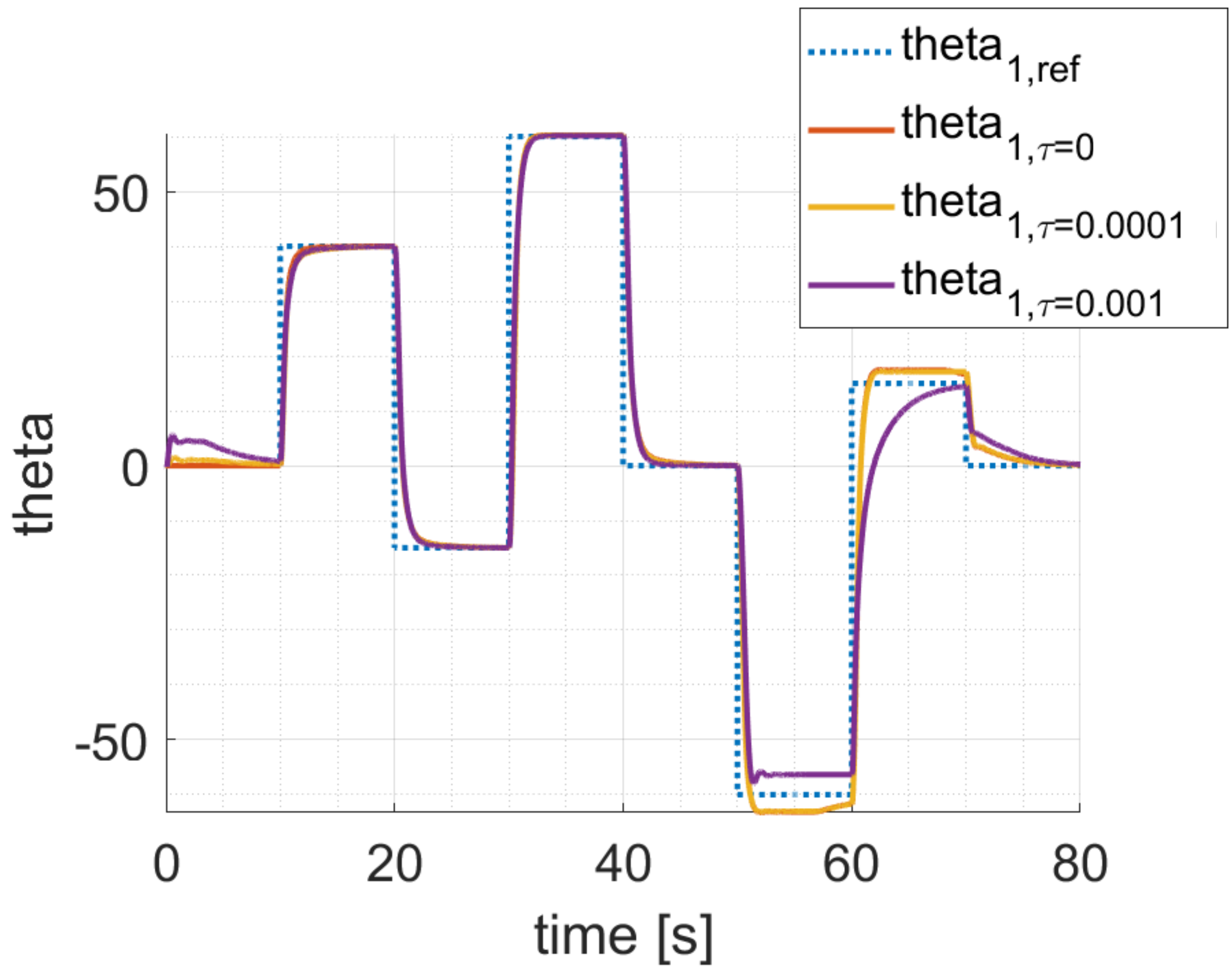
Temperature dependency (control of θ_1)

Control of θ_1 with different temperatures

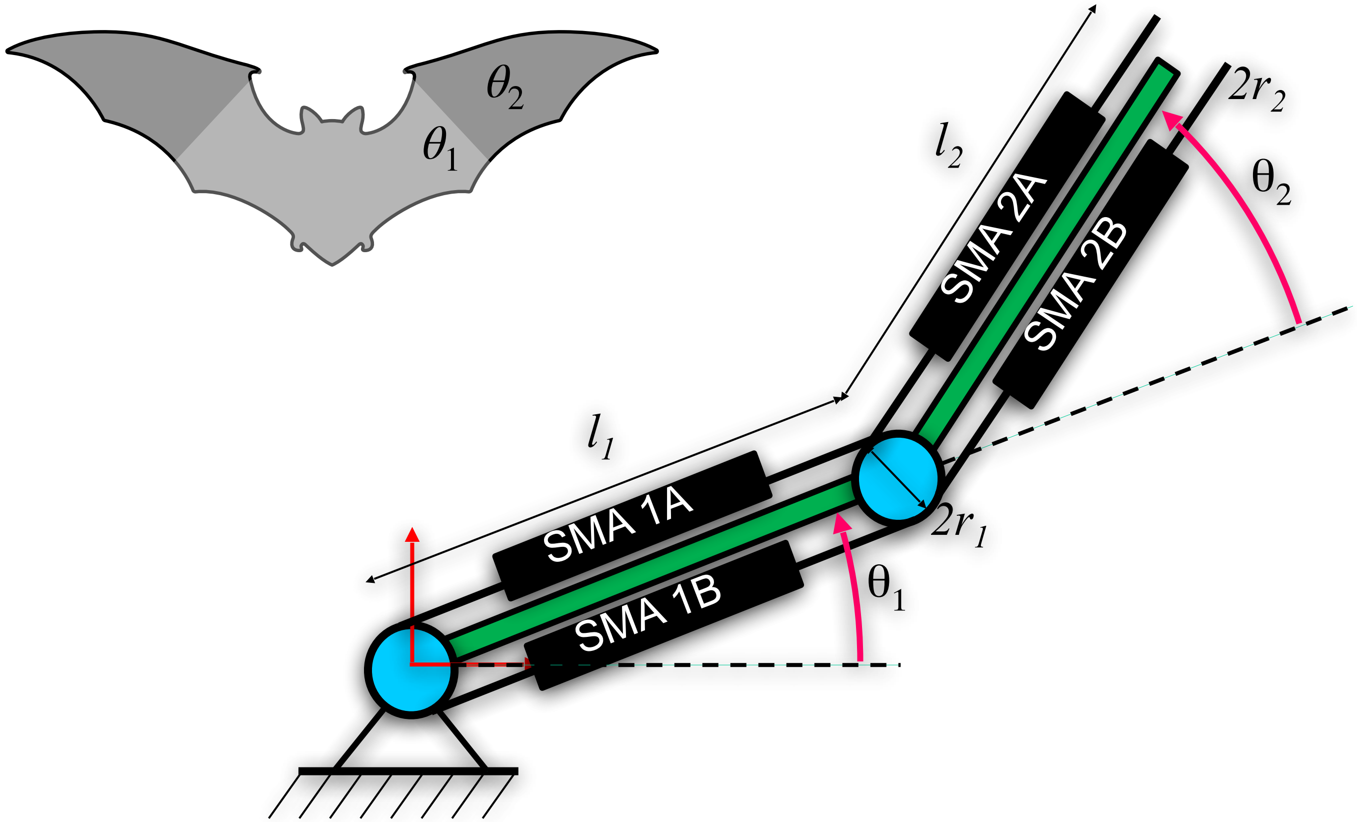


Control of θ_1 with disturbance τ

Control of θ_1 with different disturbances

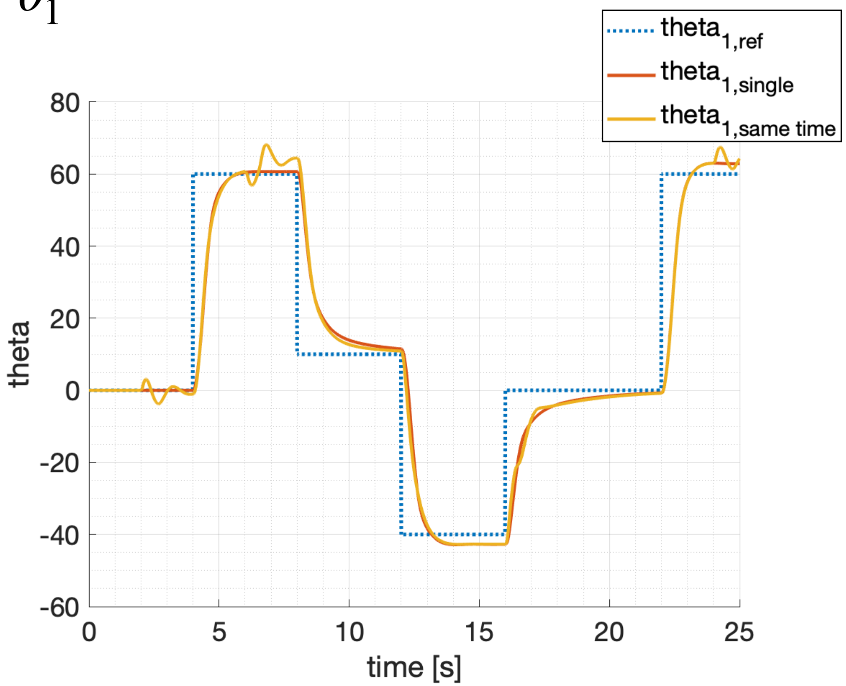


Same time control of θ_1 and θ_2

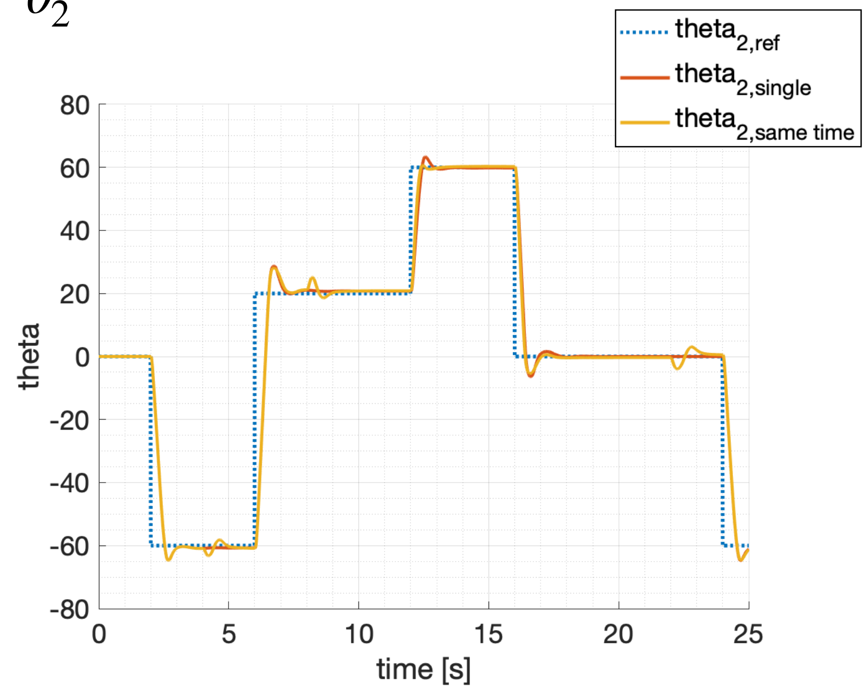


Same time control of θ_1 and θ_2

θ_1



θ_2

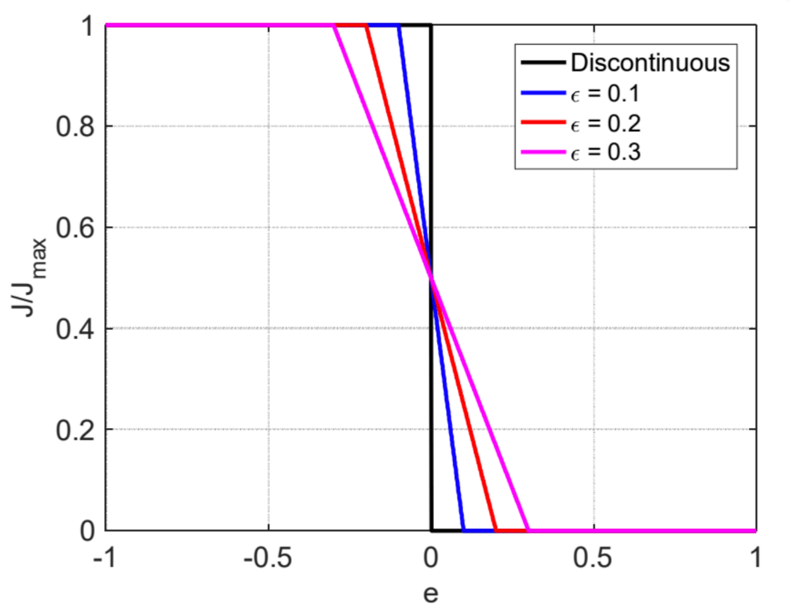


Conclusion linear controller

- Control of a bat wing beat possible with PID controllers
- Model based PID worked well without tuning
- Ziegler-Nichols needs tuning to reach the same performance

Nonlinear control

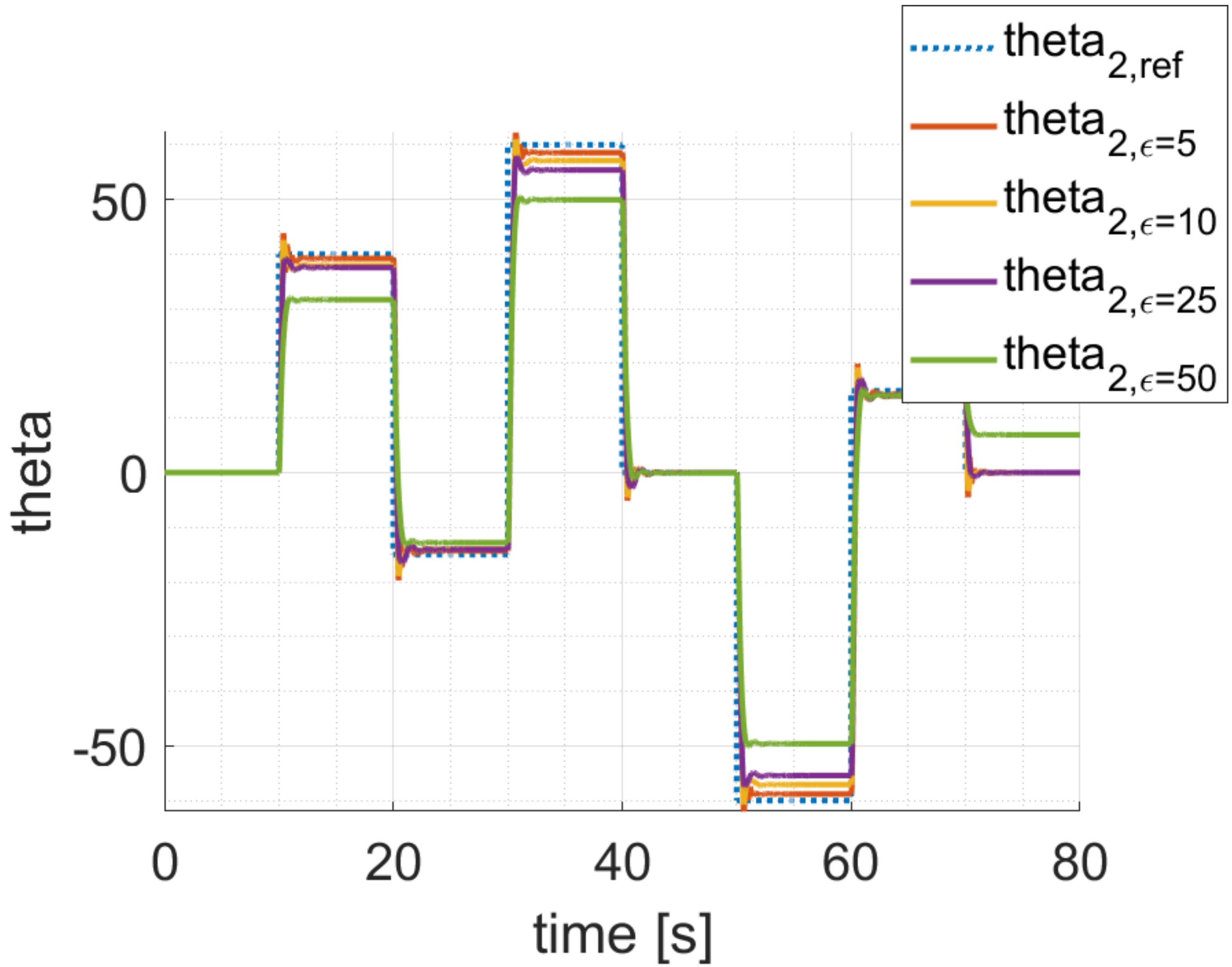
Sliding mode controller



$$J = \begin{cases} 0 & if \quad e > \varepsilon \\ \dfrac{J_{\max}}{2}\left(1 - \dfrac{e}{\varepsilon}\right) & if \quad -\varepsilon \le e \le \varepsilon \\ J_{\max} & if \quad e < -\varepsilon \end{cases}$$

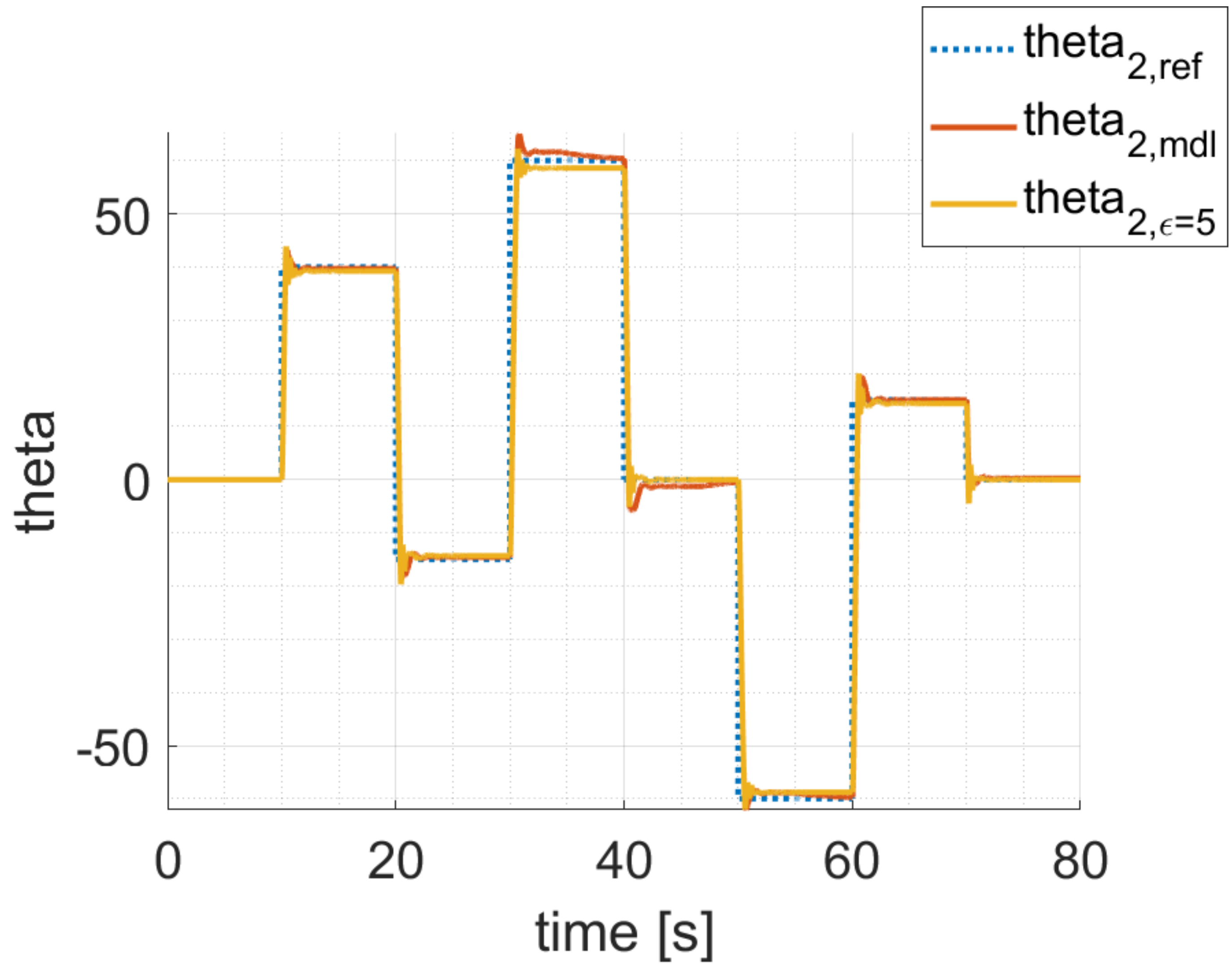
Nonlinear Controller for set Point regulation of θ_2

Set Point regulation for θ_2 with sliding mode Controller



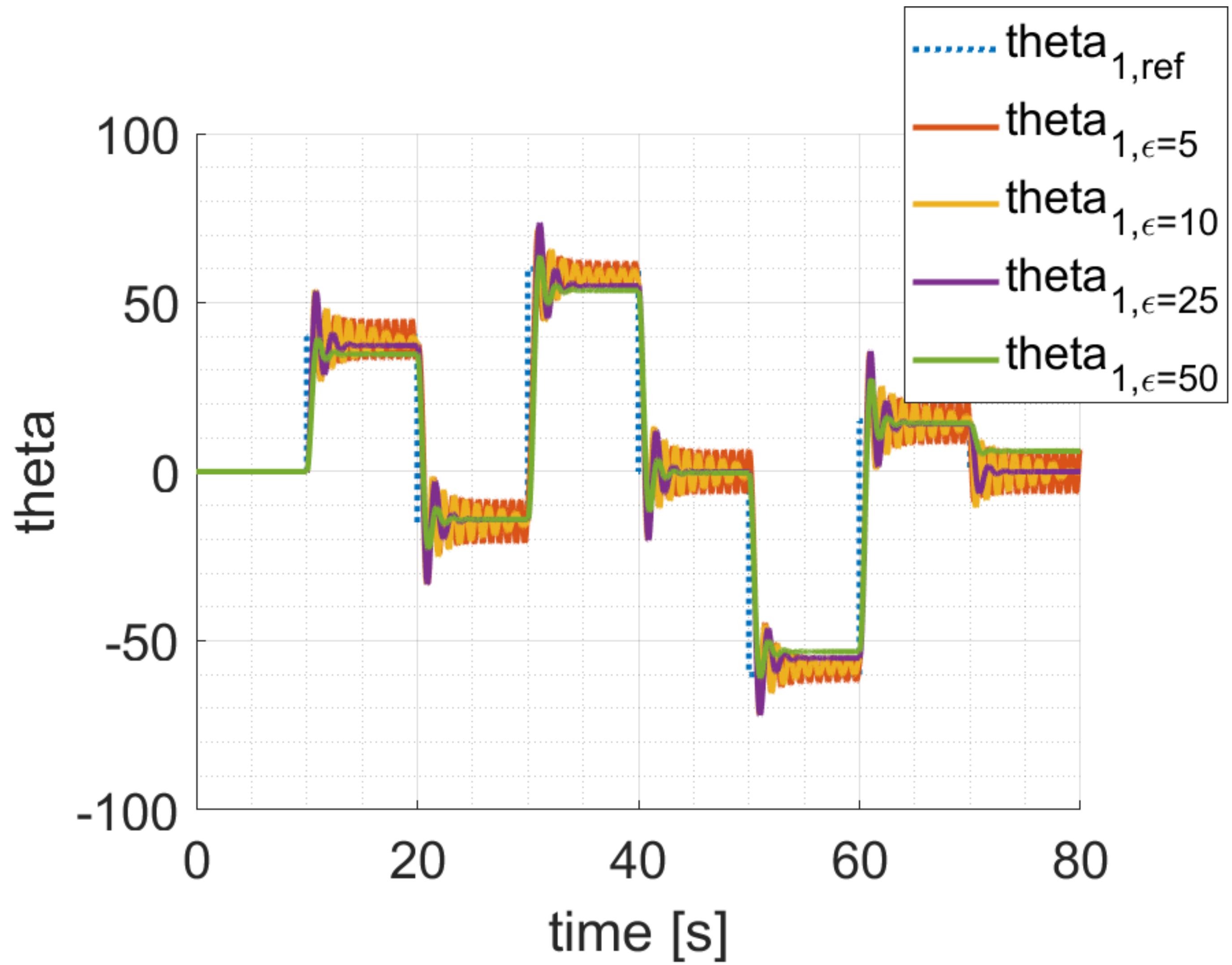
Nonlinear Controller for set Point regulation of θ_2

Sliding mode controller compared with linear controller



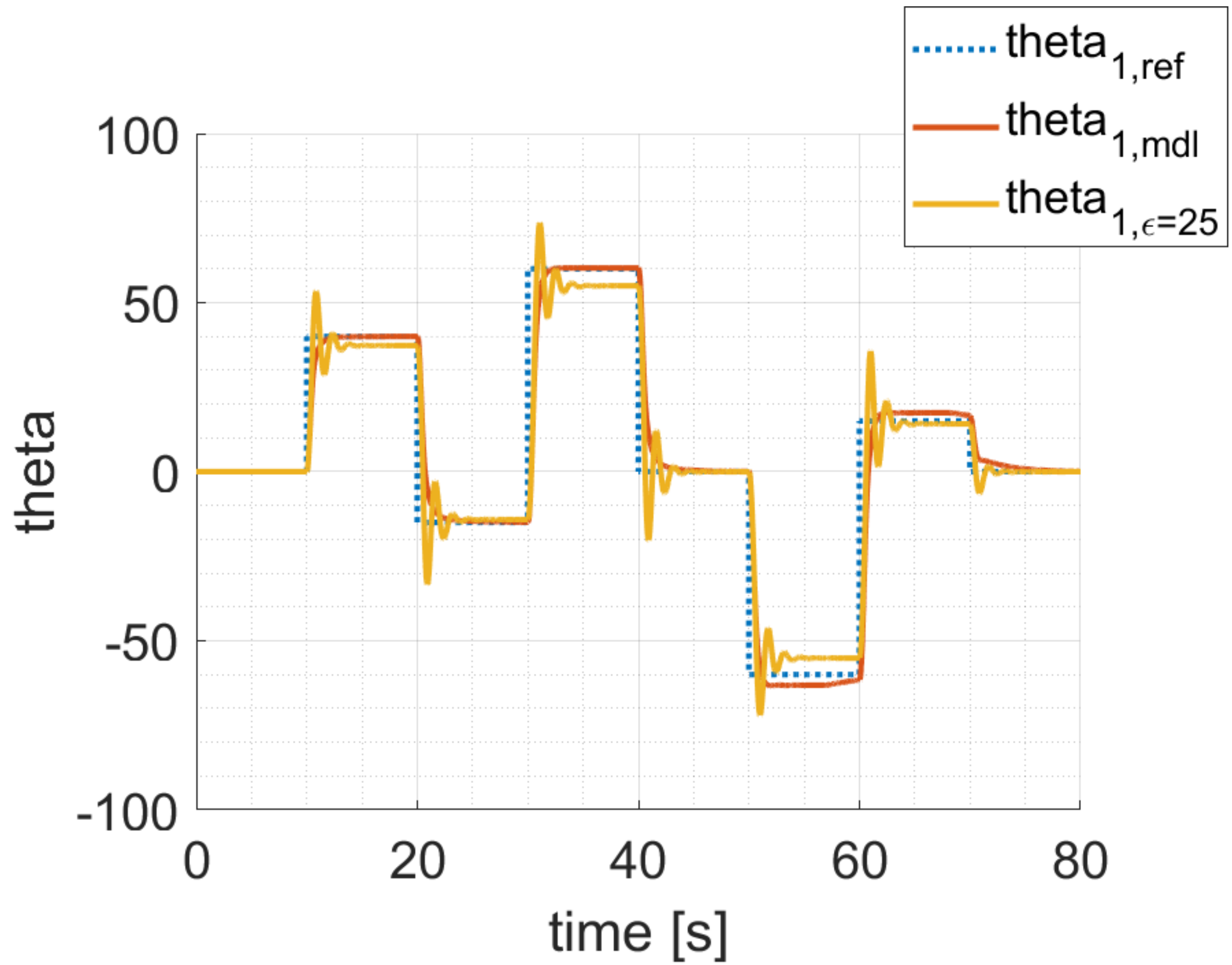
Nonlinear Controller for set Point regulation of θ_1

Set Point regulation for θ_1 with sliding mode Controller



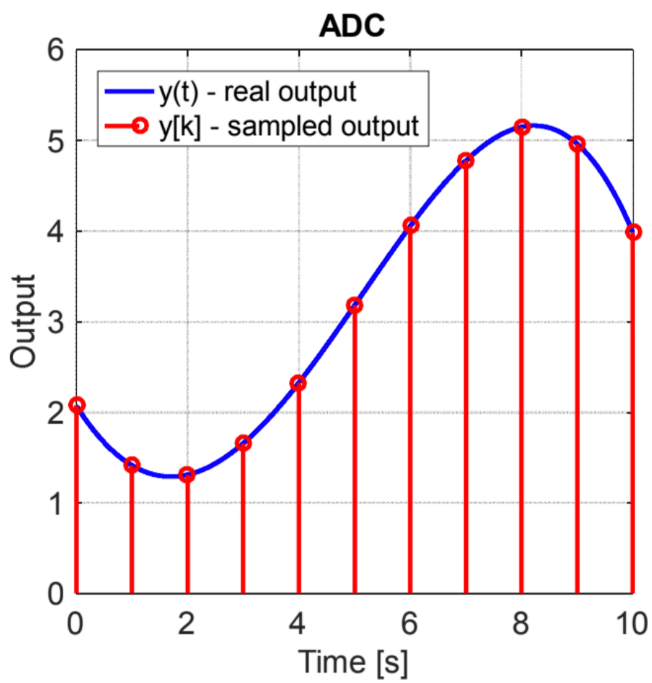
Nonlinear Controller for set Point regulation of θ_1

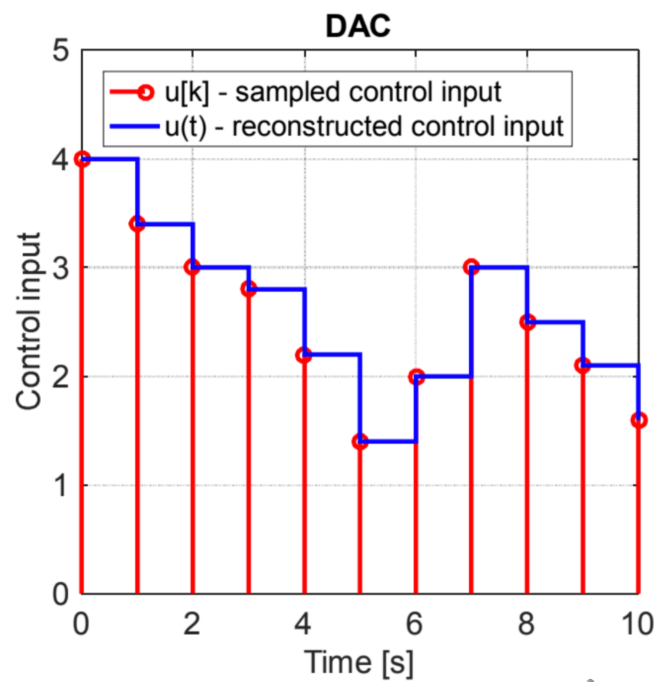
Sliding mode controller compared with linear controller

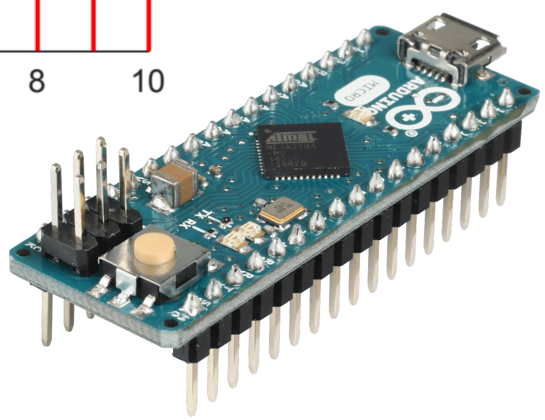


Discrete control

Time discrete control to implement on a digital controller

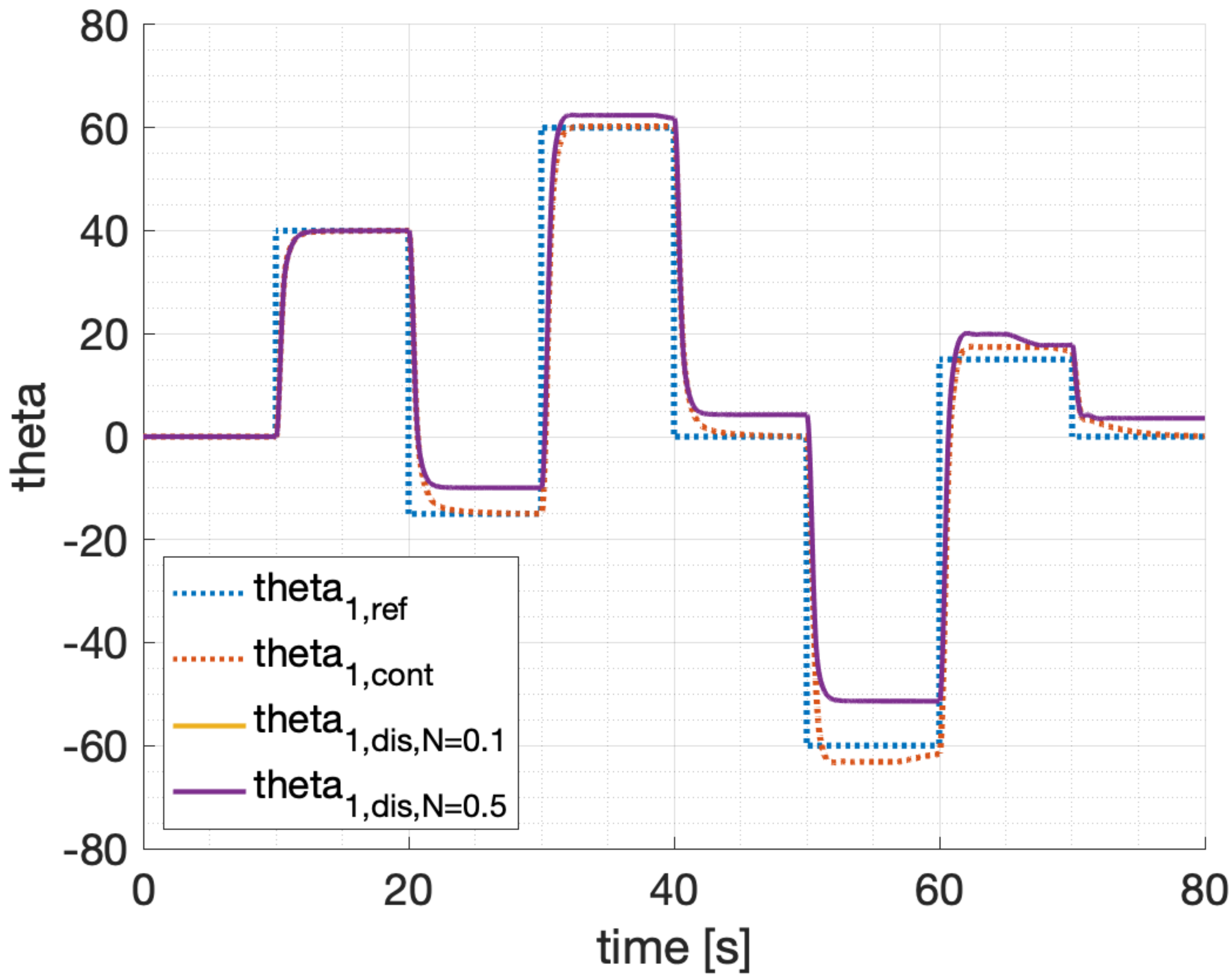






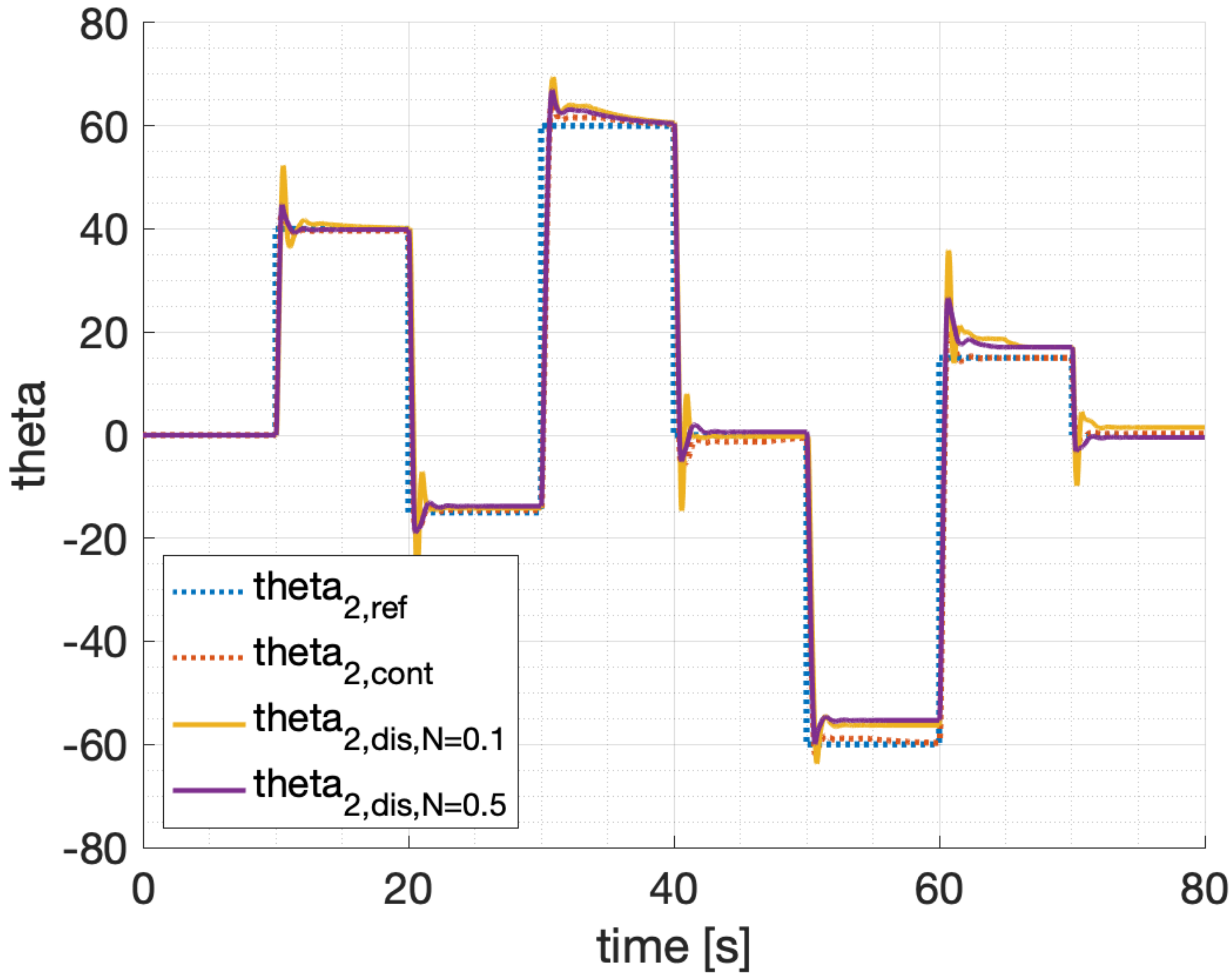
Discrete control of θ_1

Control of θ_1 with different discrete time steps



Discrete control of θ_2

Control of θ_2 with different discrete time steps



Thanks for your attention