UNIVERSITY OF PADOVA

Control Engineering Laboratory

Second Laboratory Challenge

SECOND SHIFT (Friday 10:30) GROUP NAME: F.1

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1 Challenge Description

The challenge requires the design of a control system for the QUANSER SRV-02 MOTOR (real or black-box model) capable of asymptotic tracking of step references with an overshoot $M_p \leq 10\%$ for a $r = 60°$ reference signal and settling time of $t_{s,5\%} \leq 0.2$ s. The goal is to employ the longest sampling time T_s possible. For the sake of comparability with other groups, the design was carried out solely in the form of Simulink simulations using the black-box model.

2 Control Strategy

To match all the performance specifications mentioned above, a robust state-space controller was used. Since the controller makes use of the whole state (the angular position ϑ and the angular velocity ω) rather than only the system output ϑ, a reduced state observer was employed to estimate the missing state, while leaving the output untouched. The controller and observer were designed in the continuous-time regime and discretized using the backward Euler emulation method. Both follow the same structure described in the handout accompanying the laboratory activity. Figure 1 shows the implementation of the controller. The used feedforward gains are trivial; thus, the control input u can be calculated as follows:

$$u(k) = k_1 \cdot e(k) - k_2 \cdot \omega(k) + k_I \sum_{i=0}^{k-1} e(i) \tag{1}$$

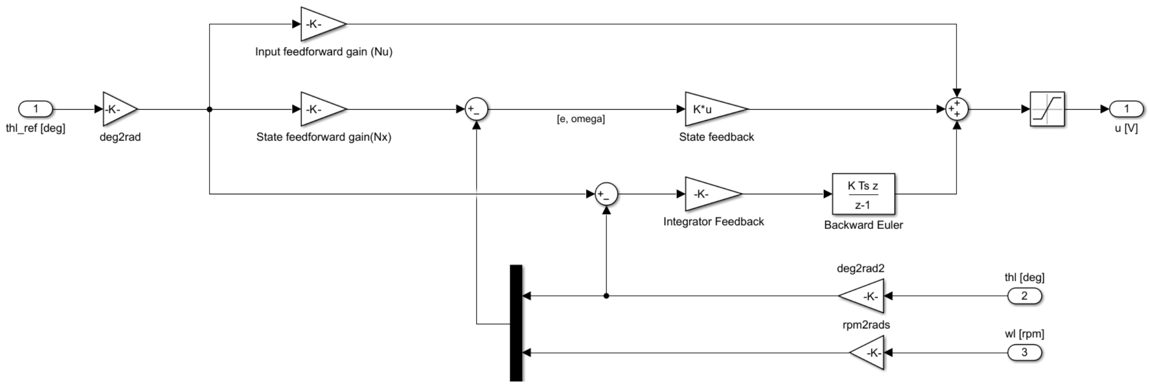

Figure 1: Discrete time robust state-space controller.

Besides the feedforward gains, the state-space controller can be characterized by three real-valued parameters. The typical procedure to choose these values is to choose the desired closed-loop eigenvalues and compute the feedback gains that realize these. The employed strategy, however, followed a different approach, modifying the feedback gains directly. Noticing that the plant can be approximated as an IT_2-system, it becomes clear that an impulse is the simplest input to lead the output trajectory to follow a step reference. The first step is thus to design an auxiliary discrete impulse input signal with a chosen step size T_s and amplitude A_{impulse} such that a satisfactory output trajectory is reached (Note: this impulse is only used in the design phase and does not constitute the solution to the challenge). For the design, a sampling time of $T_s = 0.2\ s$ was used. The second step is to modify the gains of the controller in such a way that the control input mimics the impulse as closely as possible. As the system is assumed to start from zero initial conditions, it is easy to see that the control input in the first sampling period is just the first state feedback gain applied to the reference value. From this, the first feedback value can be computed as the desired impulse amplitude divided by the reference:

$$u(0) = k_1 \cdot r \overset{!}{=} A_{\text{impulse}} \tag{2}$$

$$\Rightarrow k_1 = \frac{A_{\text{impulse}}}{r} \tag{3}$$

As every following control input should be close to zero, the second feedback gain can be computed from the error and velocity measured at the second sampling instance using the auxiliary input response:

$$u(1) = k_1 \cdot e(1) - k_2 \cdot \omega(1) + k_I \cdot e(0) \overset{!}{=} 0 \tag{4}$$

$$\Rightarrow k_2 = \frac{k_1 \cdot e(1) + k_I \cdot r}{\omega(1)} \tag{5}$$

Choosing the integrator gain k_I sufficiently small prevents any possible problems due to windup, while still ensuring perfect asymptotic tracking. The observer design was carried out based on eigenvalue allocation, so that the dynamics are stable and considerably faster than the (reduced) plant. All final parameters can be found in Table 1.

Table 1: Control gains and measured quantities.

Quantity	Value
State feedback gain	[1.2939, 0.0170]
Integral gain	0.30
Observer Φ_0	0.0062
Observer Γ_0	[0.3758, -740,8861]
Observer H_0	[0; 0.0062]
Observer J_0	[0, 1; 0.3758, 4.5858]
T_s	0.2 s
A_{impulse}	1.355 V
$e(1)$	0.09844 rad
$\omega(1)$	26.04 rad/s

2.1 Results

Figure 2 shows the resulting response of the controlled system to a 60° step reference signal using a sampling time of $\boldsymbol{T_s} = \mathbf{0.2}$ **s** $= \mathbf{200}$ **ms**. The response has an overshoot of $\boldsymbol{M_p} = \mathbf{2.6}$ % and a settling time of $\boldsymbol{t_{s,5\%}} = \mathbf{0.1989}$ **seconds**.

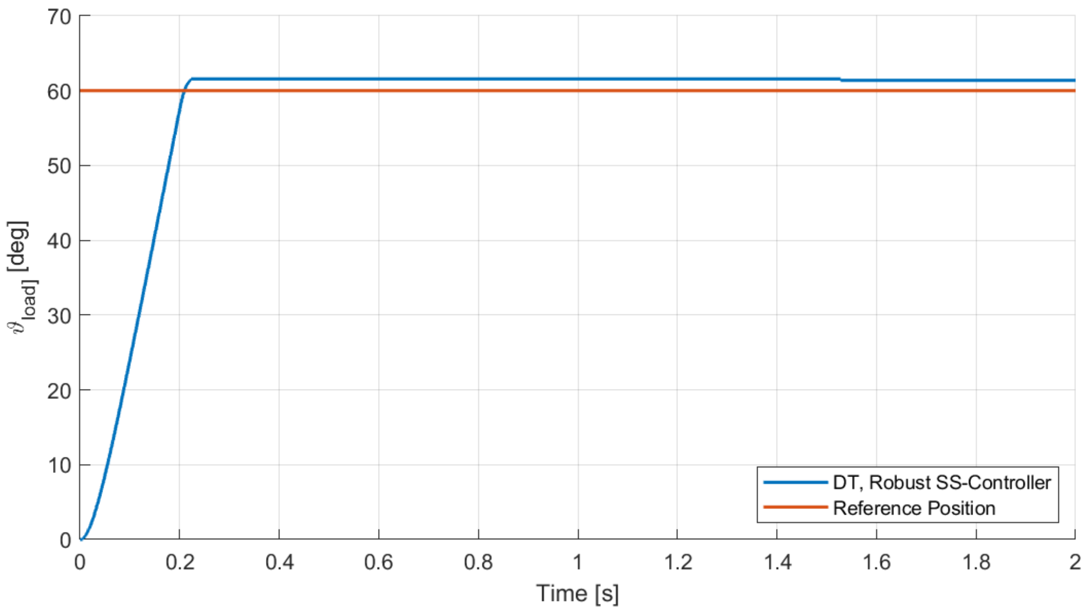

Figure 2: Transient of the step response to a reference value of 60°.