Laboratory Challenge 3:

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Group: 7, Thursday shift

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# 1 Design

For this Laboratory Challenge, we started by considering LQR design for nominal perfect steady-state tracking using the cost function of equation (12) in the assignment. Instead of deciding on the input cost parameter $r$ with the help of the symmetric root locus, we push it to a low value to make the resulting controller faster. Finally, we add intermediate set points to the step reference to reduce the overshoot, which is a commonly used technique in robotics [1]. This way, we tuned the controller such that the overshoot does not leave the 5%-error band to minimize the settling time.

Because we are working with a nominal design, we switch deterministically to a PI-Controller after the system has settled close to the required reference, in order to guarantee perfect tracking.

# 2 Implementation

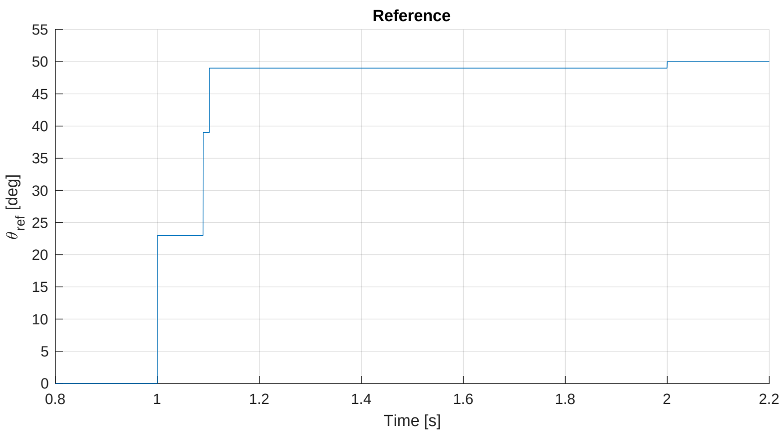


Figure 1: Effective reference after introduction of intermediate set points.

For the final design, we chose three intermediate set points. The resulting stair-shaped reference is shown in fig. 1. The exact parameters, namely the final choice of the input cost parameter $r$, reference amplitudes $A_i$ and their respective starting times $t_i$ are reported in table 1. The parameters of the PI-Controller, $K_p$ and $K_i$, and the switching time $t_s$ are reported in table 2.

To tune the controller, we followed an iterative approach. First, we reduce the input cost parameter $r$. Then we tune the timing and height of the intermediate set points until the overshoot is inside the 5%-error band. Then we reduce $r$ again and start over. As an initial value for $r$, we

[1] B. Siciliano, L. Sciavicco, L. Villani, G. Oriolo, Robotics. Modelling, Planning and Control. Springer London, 2010, p.169

chose the one we designed for exercise 2.4.1 of the assignment.

The PI-Controller was tuned to give satisfactory steady-state behaviour.

| $r$ | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|---|---|---|---|
| 8.6e-6 | 1s | 1.09s | 1.102s | 2s | 23° | 39° | 49° | 50° |

Table 1: Input cost parameter $r$ used for the LQR design and exact stair amplitudes $A_i$ and starting times $t_i$.

| $t_s$ | $K_p$ | $K_i$ |
|---|---|---|
| 2s | 100 | 10 |

Table 2: Chosen proportional $K_p$ and integral $K_i$ gains for the PI-Controller and switching time $t_s$.

# 3 Results

Simulation results on the black box model for a target reference of 50° at 1s are shown in fig. 2. The achieved performances are summarised in table 3.

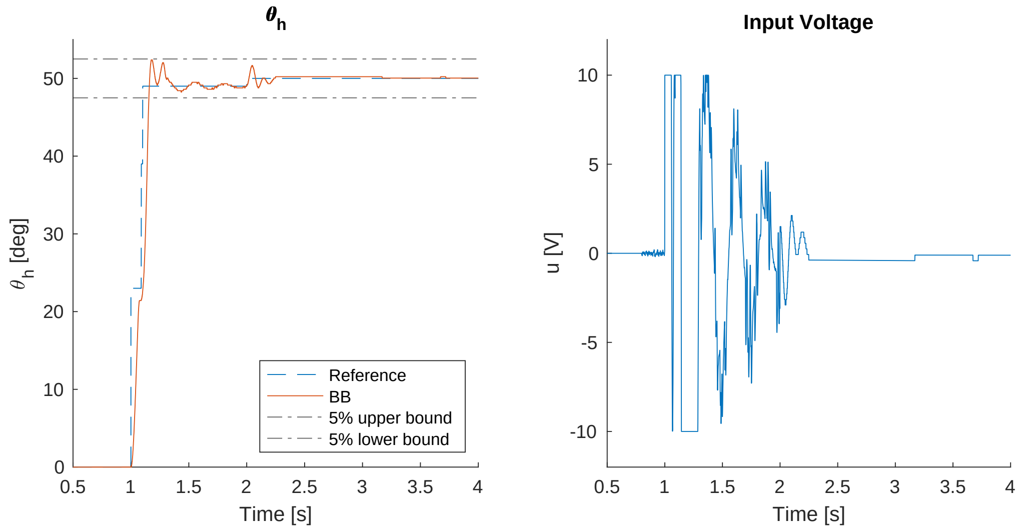


Figure 2: Final Reference Shape

| Settling time | Overshoot |
|---|---|
| 0.155s | 4.76% |

Table 3: Achieved settling time and overshoot.

# 4 Comments

This design was tuned for a 50° step reference. However, the same controller is able to track any step amplitude by scaling the stair reference with the target reference. The operation we perform on the original step reference to get the required stair reference can be realized by simple delay and scaling blocks. In any case, the final PI-Controller, to which we switch deterministically, ensures robust steady-state tracking for any step reference.