Systems and Control II (SC2)
Albert-Ludwigs-Universität Freiburg – Wintersemester 2015/2016

Exercises 7: Disturbance Feedforward and Cascaded Control

(Thursday 10.12.2015 at 15:00 in Room SR 00 014)

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1. Consider a DC-motor in the feedback control loop shown in Fig. 1. The plant $G(s)$ and the lead controller $K(s)$ are given by

$$G(s) = \frac{1}{s(s+1)} \quad \text{and} \quad K(s) = 10\frac{\frac{s}{2}+1}{\frac{s}{10}+1} \quad .$$

The DC-motor drives a load $\tau_1(t)$, that enters the feedback loop as an input disturbance $\frac{\tau_1(t)}{a_1}$, with $a_1 = 1\frac{\mathrm{V}}{\mathrm{Nm}}$.

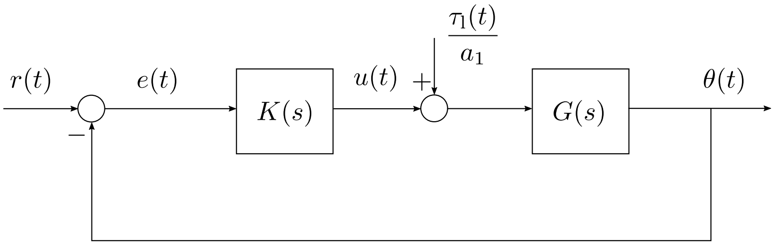

Figure 1: Set-up of the feedback control loop.

(a) Determine the steady state error of the closed-loop system for both a step reference input and a step input disturbance and evaluate.

(b) Draw the block diagram for the case that the closed-loop system is extended by a disturbance feedforward controller.

(c) Determine the ideal disturbance feedforward controller in order to achieve a zero steady state error for a step load torque, i.e. a step input disturbance.

2. A process can be divided into two partial processes $G_1(s)$ and $G_2(s)$ in series. The transfer functions of these processes are given by

$$G_1(s) = \frac{k_1}{(T_1 s+1)(T_2 s+1)} \quad \text{and} \quad G_2(s) = \frac{k_2}{T_3 s+1} \quad .$$

Design a cascaded controller for this process, so that the overall closed-loop system has an overshoot $M_\mathrm{p} < 5\%$ and a zero steady state error for a step reference input. The process parameters are $k_1 = 3$, $k_2 = 10$, $T_1 = \frac{1}{3}$ sec, $T_2 = \frac{1}{5}$ sec and $T_3 = 1$ sec.

(a) Draw the block diagram of a cascaded control-loop for the process $G(s) = G_1(s)G_2(s)$.

(b) Design a lead controller $K_1(s) = k_\mathrm{D}\frac{T_\mathrm{D}s+1}{T'_\mathrm{D}s+1}$ for $G_1(s)$, so that the inner closed-loop system has a settling time $T_\mathrm{s} \leq 0.5$ sec and an overshoot $M_\mathrm{p} < 5\%$.

Hint: Choose the lead zero so that it cancels out the slowest process pole. Analytically determine expressions for the desired T'_D and k_D, by analysing the expressions for the closed-loop poles.

(c) Approximate the obtained inner closed-loop system by a first order system $G_\mathrm{a}(s) = \frac{k_\mathrm{a}}{T_\mathrm{a}s+1}$.

(d) Design a PI-controller $K_2(s) = k_\mathrm{I}(1 + \frac{T_\mathrm{I}}{s})$ for the outer process, consisting of $G_\mathrm{a}(s)$ and $G_2(s)$, in order to meet the design requirements.

Hint: Apply the same design strategy as for the inner lead controller $K_1(s)$. Cancel out the slowest open-loop pole and analyse the expressions of the closed-loop poles.

(e) (`MATLAB`) The approximation of the inner closed-loop transfer function, $G_\mathrm{a}(s)$, is only valid for frequencies below $\frac{1}{T_\mathrm{a}}$. Check if the cross-over frequency of the outer open loop ($K_2(s)G_\mathrm{a}(s)G_2(s)$) remains below this limit.

(f) (`MATLAB`) Evaluate the step response of the overall closed-loop system. Compare it with the step response of a non-cascaded feedback system with the overall PI-controller $K(s) = 0.03(1 + \frac{1}{s})$.