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

Exercises 5: Model-based Control

(Thursday 26.11.2015 at 15:00 in Room SR 00 014)

Dr. Jörg Fischer, Prof. Dr. Moritz Diehl and Jochem De Schutter

1. Design a controller for an office heating system, using the model matching technique. The heating system is described by the transfer function (with units not in sec but in min)

$$G(s) = \frac{1.432}{(s+2.293)(s+0.876)} \quad . \tag{1}$$

   (a) Is this plant suitable for the model matching design method?

   (b) Find a model $M(s)$ for the command response, that has no overshoot (to avoid energy losses) and that has a static gain of 1 and a settling time $T_{5\%} = 1\mathrm{min}$.
   Hint: The choice of $M(s)$ is restricted by the relative degree of $G(s)$. The settling time $T_{5\%}$ of a second-order system with damping ζ and poles s_1 and s_2 can be approximated by

$\zeta < 0.8$	$T_{5\%} \approx \frac{3}{\zeta\omega_0} = \frac{3}{\lvert\mathrm{Re}\{s_{1,2}\}\rvert}$
$\zeta = 1$	$T_{5\%} \approx \frac{4.8}{\lvert s_{1,2}\rvert}$

   (c) Calculate the controller $K(s)$ for the chosen model $M(s)$ and transform it to Bode form. It is sufficient to state the DC-gain of the controller as a rational expression.

   (d) (`MATLAB`) Simulate the closed-loop step response and evaluate.

   (e) (`MATLAB`) Determine and simulate the disturbance response of the control loop for an input disturbance. Discuss the disturbance attenuation behaviour of the closed-loop.

2. Find an IMC controller for the following process model:

$$G(s) = \frac{(-s+1)e^{-s}}{s^2+s+1} \quad .$$

   The controller must satisfy the condition

$$\max_{\omega} \left| \frac{K_{\mathrm{IMC}}(j\omega)}{K_{\mathrm{IMC}}(0)} \right| \leq 20$$

   in order to limit noise amplification and to avoid actuator saturation.

   (a) Analyze, and if necessary factorize the process model $G(s)$ and determine the ideal IMC controller $K^*_{\mathrm{IMC}}(s)$ that minimizes the ISE (integral square error) for step reference inputs. The ideal IMC controller does not have to satisfy the above gain condition and does not have to be a proper transfer function.

   (b) Add a filter to obtain a realizable controller $K_{\mathrm{IMC}}(s)$. Choose the time constant T so that the noise amplification limit is respected.

   (c) (`MATLAB`) Simulate the step response of the closed-loop system and evaluate.

   (d) Check if the system is robust for a multiplicative uncertainty with an upper bound

$$\bar{\Delta}_{\mathrm{M}}(s) = \left| 0.01 \cdot \frac{\frac{1}{0.001}s+1}{\frac{1}{0.01}s+1} \right| \quad .$$

3. A mixing vessel of a process plant can be modelled as first-order system

$$G(s) = e^{-93.3s}\frac{5.6}{40.2s+1}. \tag{2}$$

   As is often the case for chemical processes, the dead time is more than twice as long as the time constant of the process. The open-loop response of the process has a long settling time ($250s$).

(a) In order to decrease the settling time and to compensate for disturbances, we could apply a PI-controller $K_\mathrm{p}(1 + \frac{1}{T_\mathrm{i} s})$ to the process. A good choice of control parameters would be $K_\mathrm{p} = 0.0501$ and $T_i = 47.35s$.

- (MATLAB) Evaluate the performance of the control loop with the PI-controller. Discuss the step response.
- (MATLAB) Can the performance be improved by increasing K_p?

(b) Design a Smith Predictor for the same process. Assume that the model $\hat{G}(s)$ is perfect. The closed-loop should have a steady state error of 0.01 for a step input.

Hint: For a perfect model, $K_\mathrm{R}(s)$ can be designed for $G_\mathrm{R}(s)$, as if there were no time delay. Try a proportional controller design for $K_\mathrm{R}(s)$.

(c) (MATLAB) Evaluate the closed-loop step response and compare with the PI-control loop.